FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV Offshore Codes consist of a three level hierarchy of documents:

— **Offshore Service Specifications.** Provide principles and procedures of DNV classification, certification, verification and consultancy services.

— **Offshore Standards.** Provide technical provisions and acceptance criteria for general use by the offshore industry as well as the technical basis for DNV offshore services.

— **Recommended Practices.** Provide proven technology and sound engineering practice as well as guidance for the higher level Offshore Service Specifications and Offshore Standards.

DNV Offshore Codes are offered within the following areas:

A) Qualification, Quality and Safety Methodology
B) Materials Technology
C) Structures
D) Systems
E) Special Facilities
F) Pipelines and Risers
G) Asset Operation

Amendments April 2002

This Code has been amended, but not reprinted in April 2002. The changes are incorporated in the Web, CD and printable (pdf) versions. The amendments are shown in red colour in the Web and CD versions.

All changes affecting DNV Offshore Codes that have not been reprinted, are published separately in the current *Amendments and Corrections*, issued as a printable (pdf) file.

Acknowledgement

This Offshore Standard has been developed in close co-operation with the industry. In order to ensure constructive and effective feedback at an early stage of the development, working groups for design, material, installation and operation were established. The following companies were members of working groups:

— Statoil
— Norsk Hydro
— Saga Petroleum
— Phillips Petroleum
— J.P.Kenny A/S
— Reinertsen Engineering

The Standard has been circulated on extensive internal and external hearing. The following organisations have made major contributions to the hearing process:

| Allseas Engineering | Exxon Prod. Research Company | Røntgen Technische Dienst bv |
| Andrew Palmer & Associates | ITOCHU | Reinertsen Engineering |

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DNV is grateful for the valuable co-operations and discussions with the individual personnel of these companies.
### Sec. 7 Components and Assemblies

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>General</td>
<td>64</td>
</tr>
<tr>
<td>A 100</td>
<td>Scope</td>
<td>64</td>
</tr>
<tr>
<td>A 200</td>
<td>Quality assurance</td>
<td>64</td>
</tr>
<tr>
<td>B</td>
<td>General requirements for Design of Pipeline Components</td>
<td>64</td>
</tr>
<tr>
<td>B 100</td>
<td>General</td>
<td>64</td>
</tr>
<tr>
<td>B 200</td>
<td>Material selection</td>
<td>64</td>
</tr>
<tr>
<td>B 300</td>
<td>Flanged and mechanical connections</td>
<td>65</td>
</tr>
<tr>
<td>B 400</td>
<td>Bolting</td>
<td>65</td>
</tr>
<tr>
<td>B 500</td>
<td>Valves</td>
<td>66</td>
</tr>
<tr>
<td>B 600</td>
<td>Pressure vessels</td>
<td>65</td>
</tr>
<tr>
<td>B 700</td>
<td>Components fabricated by welding</td>
<td>65</td>
</tr>
<tr>
<td>B 800</td>
<td>Insulating joints</td>
<td>65</td>
</tr>
<tr>
<td>B 900</td>
<td>Pipeline fitting</td>
<td>66</td>
</tr>
<tr>
<td>B 1000</td>
<td>Anchor flanges</td>
<td>66</td>
</tr>
<tr>
<td>B 1100</td>
<td>Other components</td>
<td>66</td>
</tr>
<tr>
<td>B 1200</td>
<td>Structural items</td>
<td>66</td>
</tr>
<tr>
<td>C</td>
<td>Material and Manufacturing Specifications for Components</td>
<td>68</td>
</tr>
<tr>
<td>C 100</td>
<td>Material and manufacturing specifications</td>
<td>66</td>
</tr>
<tr>
<td>D</td>
<td>Material for Hot Formed, Forged and Cast Components</td>
<td>67</td>
</tr>
<tr>
<td>D 100</td>
<td>General</td>
<td>67</td>
</tr>
<tr>
<td>D 200</td>
<td>Components made of low alloy C-Mn steel</td>
<td>67</td>
</tr>
<tr>
<td>D 300</td>
<td>Components made of ferritic-austenitic (duplex) steel, other stainless steel and nickel-based corrosion resistant alloy (CRA)</td>
<td>66</td>
</tr>
<tr>
<td>D 400</td>
<td>Delivery condition</td>
<td>68</td>
</tr>
<tr>
<td>E</td>
<td>Hot Forming, Forging, Casting and Heat Treatment</td>
<td>68</td>
</tr>
<tr>
<td>E 100</td>
<td>Hot forming</td>
<td>68</td>
</tr>
<tr>
<td>E 200</td>
<td>Forging</td>
<td>68</td>
</tr>
<tr>
<td>E 300</td>
<td>Casting</td>
<td>68</td>
</tr>
<tr>
<td>E 400</td>
<td>Heat treatment</td>
<td>68</td>
</tr>
<tr>
<td>F</td>
<td>Manufacturing of Components, Equipment and Structural Items</td>
<td>70</td>
</tr>
<tr>
<td>F 100</td>
<td>General</td>
<td>69</td>
</tr>
<tr>
<td>F 200</td>
<td>Manufacture of flanges</td>
<td>69</td>
</tr>
<tr>
<td>F 300</td>
<td>Manufacture of valves</td>
<td>69</td>
</tr>
<tr>
<td>F 400</td>
<td>Manufacture of pressure-containing equipment and components fabricated by welding</td>
<td>70</td>
</tr>
<tr>
<td>F 500</td>
<td>Manufacture of other equipment and components</td>
<td>70</td>
</tr>
<tr>
<td>F 600</td>
<td>Fabrication of structural items</td>
<td>70</td>
</tr>
<tr>
<td>F 700</td>
<td>Mechanical testing of hot formed, cast and forged components</td>
<td>70</td>
</tr>
<tr>
<td>G</td>
<td>Manufacture of Bends</td>
<td>71</td>
</tr>
<tr>
<td>G 100</td>
<td>General</td>
<td>71</td>
</tr>
<tr>
<td>G 200</td>
<td>Mother pipe for seawater service</td>
<td>72</td>
</tr>
<tr>
<td>G 300</td>
<td>Supplementary requirements to mother pipe</td>
<td>72</td>
</tr>
<tr>
<td>G 400</td>
<td>Requirements to pipe other than dedicated mother pipe</td>
<td>72</td>
</tr>
<tr>
<td>G 500</td>
<td>Required post bending heat treatment</td>
<td>72</td>
</tr>
<tr>
<td>G 600</td>
<td>Bending procedure qualification</td>
<td>72</td>
</tr>
<tr>
<td>G 700</td>
<td>Bending and post bend heat treatment</td>
<td>73</td>
</tr>
<tr>
<td>G 800</td>
<td>Non-destructive testing and visual inspection</td>
<td>74</td>
</tr>
<tr>
<td>G 900</td>
<td>Production testing of bends</td>
<td>74</td>
</tr>
<tr>
<td>G 1000</td>
<td>Dimensions, tolerances and marking</td>
<td>75</td>
</tr>
<tr>
<td>G 1100</td>
<td>Repair</td>
<td>75</td>
</tr>
<tr>
<td>H</td>
<td>Fabrication of Risers, Expansion Loops, Pipe Strings for Reeling and Towing</td>
<td>75</td>
</tr>
<tr>
<td>H 100</td>
<td>General</td>
<td>75</td>
</tr>
<tr>
<td>H 200</td>
<td>Quality Assurance</td>
<td>75</td>
</tr>
<tr>
<td>H 300</td>
<td>Materials for risers, expansion loops, pipe strings for reeling and towing</td>
<td>75</td>
</tr>
<tr>
<td>H 400</td>
<td>Fabrication procedures and planning</td>
<td>76</td>
</tr>
<tr>
<td>H 500</td>
<td>Material receipt, identification and tracking</td>
<td>76</td>
</tr>
<tr>
<td>H 600</td>
<td>Cutting, forming, assembly, welding and heat treatment</td>
<td>76</td>
</tr>
<tr>
<td>H 700</td>
<td>Hydrostatic testing</td>
<td>76</td>
</tr>
<tr>
<td>H 800</td>
<td>Non-destructive testing and visual examination</td>
<td>77</td>
</tr>
<tr>
<td>H 900</td>
<td>Dimensional verification</td>
<td>77</td>
</tr>
<tr>
<td>H 1000</td>
<td>Corrosion protection</td>
<td>77</td>
</tr>
<tr>
<td>I</td>
<td>Documentation, Records, Certification and Marking</td>
<td>77</td>
</tr>
<tr>
<td>I 100</td>
<td>Documentation, records, certification and marking</td>
<td>77</td>
</tr>
</tbody>
</table>
Sec. 8 Corrosion Protection and Weight coating ...... 78

A. General ................................................................. 78
A 100 Objective ......................................................... 78
A 200 Application ....................................................... 78
A 300 Definitions ....................................................... 78

B. General Principles for Corrosion Control During Design ... 78
B 100 General ............................................................. 78
B 200 Evaluation of options for corrosion control ................. 78

C. Pipeline External Coatings ........................................... 79
C 100 General ............................................................. 79
C 200 Coating materials, surface preparation and application .. 79

D. Special Riser Coatings ................................................ 79
D 100 General ............................................................. 79
D 200 Coating materials, surface preparation and application .. 80

E. Field Joint Coatings ................................................... 80
E 100 General ............................................................. 80
E 200 Coating materials, surface preparation and application .. 80

F. Concrete Weight Coating ............................................. 80
F 100 General ............................................................. 80
F 200 Concrete materials and coating manufacturing ............. 80
F 300 Inspection and testing ........................................... 81

G. Cathodic Protection Design .......................................... 81
G 100 General ............................................................. 81
G 200 Design parameters and calculations .......................... 81

H. Manufacturing and Installation of Sacrificial Anodes ........... 82
H 100 General ............................................................. 82
H 200 Anode installation ................................................ 82

I. Design and Manufacturing/Fabrication of Internal Corrosion Protection .................................................. 82
I 100 General ............................................................. 82
I 200 Internal corrosion protection by fluid processing .......... 82
I 300 Internal corrosion protection by use of linepipe in Corrosion Resistant Alloys (CRAs). ................. 83
I 400 Internal corrosion protection by organic coatings or linings ................................................. 83
I 500 Internal corrosion protection by chemical treatment .... 83

Sec. 9 Installation ........................................................ 84

A. General ................................................................. 84
A 100 Objective ......................................................... 84
A 200 Application ....................................................... 84
A 300 Failure Mode Effect Analysis (FMEA) and Hazard and Operability (HAZOP) studies ..................... 84
A 400 Installation and testing specifications and drawings ........ 84
A 500 Installation Manuals ............................................. 84
A 600 Quality Assurance ............................................... 84
A 700 Welding ............................................................. 85
A 800 Non-destructive testing and visual examination ............ 85
A 900 Production tests .................................................. 85

B. Pipeline Route, Survey and Preparation ................................ 85
B 100 Pre-installation route survey .................................... 85
B 200 Seabed preparation .............................................. 86
B 300 Pipeline and cable crossings .................................... 86
B 400 Preparations for shore approach ............................... 86

C. Marine Operations .................................................... 86
C 100 General ............................................................. 86
C 200 Vessels ............................................................. 86
C 300 Anchoring systems, anchor patterns and anchor positioning ......................................................... 86
C 400 Positioning systems .............................................. 87
C 500 Dynamic positioning ............................................ 87
C 600 Cranes and lifting equipment .................................. 87
C 700 Anchor handling and tug management ....................... 87
C 800 Contingency procedures ...................................... 87

D. Pipeline Installation ................................................... 87
D 100 General ............................................................. 87
D 200 Installation Manual .............................................. 88
D 300 Review and qualification of the installation manual, essential variables and validity .................................. 88

D 400 Operating limit conditions ...................................... 89
D 500 Installation procedures .......................................... 89
D 600 Contingency procedures ....................................... 89
D 700 Layvessel arrangement, laying equipment and instrumentation ................................................. 89
D 800 Requirements for installation .................................. 90

E. Additional Requirements for Pipeline Installation Methods ................................. 91
E 100 General ............................................................. 91
E 200 Installation Manual .............................................. 91
E 300 Qualification of the Installation Manual ................. 91
E 400 Installation procedures .......................................... 91
E 500 Requirements for installation .................................. 91

F. Pipeline Installation by Towing ...................................... 92
F 100 General ............................................................. 92
F 200 Installation Manual .............................................. 92
F 300 Qualification of Installation Manual ......................... 92
F 400 Operating limit conditions ...................................... 92
F 500 Installation procedures .......................................... 92
F 600 Contingency procedures ....................................... 92
F 700 Arrangement, equipment and instrumentation ........... 92
F 800 Pipestring tow and installation ................................. 92

G. Other Installation Methods ........................................... 93
G 100 General ............................................................. 93

H. Shore Pull ............................................................... 93
H 100 General ............................................................. 93
H 200 Installation Manual .............................................. 93
H 300 Qualification of Installation Manual ......................... 93
H 400 Operating limit conditions ...................................... 93
H 500 Installation procedures .......................................... 93
H 600 Contingency procedures ....................................... 93
H 700 Arrangement, equipment and instrumentation ........... 93
H 800 Requirements for Installation .................................. 93

I. Tie-in Operations ....................................................... 93
I 100 General ............................................................. 93
I 200 Installation Manual .............................................. 93
I 300 Qualification of Installation Manual ......................... 93
I 400 Operating limit conditions ...................................... 94
I 500 Tie-in procedures ................................................ 94
I 600 Contingency procedures ....................................... 94
I 700 Tie-in operations above water ................................. 94
I 800 Tie-in operations below water ................................ 94

J. As-Laid Survey ........................................................ 94
J 100 General ............................................................. 94
J 200 Specification of as-laid survey ................................. 94
J 300 As-laid survey .................................................... 94
J 400 As-laid survey of corrosion protection systems ........... 94

K. Span Rectification and Pipeline Protection .......................... 94
K 100 General ............................................................. 94
K 200 Span rectification and protection specification ............. 95
K 300 Span rectification ................................................ 95
K 400 Trenching .......................................................... 95
K 500 Post-installation gravel dumping ............................... 95
K 600 Grout bags and concrete mattresses ......................... 95

L. Installation of Protective and Anchoring Structures .......... 96
L 100 General ............................................................. 96

M. Installation of Risers .................................................. 96
M 100 General ............................................................. 96
M 200 Installation Manual .............................................. 96
M 300 Qualification of the Installation Manual ..................... 96
M 400 Operating limit conditions ...................................... 96
M 500 Contingency procedures ....................................... 96
M 600 Requirements for Installation .................................. 96

N. As-Built Survey ........................................................ 96
N 100 General ............................................................. 96
N 200 Specification of as-built survey ................................. 97
N 300 As-built survey requirements ................................ 97
N 400 Inspection of impressed current cathodic corrosion protection system ........................................... 97
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Calibration</td>
<td>162</td>
</tr>
<tr>
<td>E</td>
<td>Field Inspection</td>
<td>162</td>
</tr>
<tr>
<td>F</td>
<td>Re-examination</td>
<td>163</td>
</tr>
<tr>
<td>G</td>
<td>Evaluation and Reporting</td>
<td>163</td>
</tr>
<tr>
<td>H</td>
<td>Qualification</td>
<td>163</td>
</tr>
<tr>
<td>I</td>
<td>Validity of Qualification</td>
<td>165</td>
</tr>
<tr>
<td>J</td>
<td>Annex A. Transducer requirements</td>
<td>165</td>
</tr>
<tr>
<td>K</td>
<td>Annex B. Determination of shear wave velocity in pipe steels</td>
<td>166</td>
</tr>
</tbody>
</table>

- **D. Calibration**: 162
  - Initial static calibration: 162
  - Dynamic calibration: 162

- **E. Field Inspection**: 162
  - Inspection requirements: 162
  - Operational checks: 163

- **F. Re-examination**: 163
  - General: 163

- **G. Evaluation and Reporting**: 163
  - General: 163
  - Examination reports: 163
  - Inspection records: 163

- **H. Qualification**: 163
  - General: 163
  - Requirements: 163
  - Qualification programme: 164
  - Test welds: 164
  - Qualification testing: 164
  - Validation testing: 164
  - Analysis: 165
  - Reporting: 165

- **I. Validity of Qualification**: 165
  - Validity: 165
  - Essential variables: 165

- **J. Annex A. Transducer requirements**: 165
  - Identification: 165
  - Beam angle: 165
  - Beam size: 165
  - Overall gain: 165
  - Index point: 165
  - Squint: 165
  - Longitudinal angle beam: 165
  - Surface waves: 165
  - Side lobes: 165
  - Subsidiary maxima: 165
  - Pulse shape: 166
  - Frequency: 166
  - Pulse length: 166
  - Signal to noise: 166

- **K. Annex B. Determination of shear wave velocity in pipe steels**: 166
  - General: 166
  - Equipment: 166
  - Specimens: 166
  - Test method: 166
  - Accuracy: 166
  - Recording: 166
SECTION 1

GENERAL

A. General

A 100 Introduction

101 This standard gives criteria and guidance on design, materials, fabrication, installation, testing, commissioning, operation, maintenance, re-qualification, and abandonment of pipeline systems.

A 200 Objectives

201 The objectives of this standard are to:

— provide an internationally acceptable standard of safety for submarine pipeline systems by defining minimum requirements for the design, materials, fabrication, installation, testing, commissioning, operation, repair, re-qualification, and abandonment;
— serve as a technical reference document in contractual matters between purchaser and Contractor; and
— serve as a guideline for designers, Purchaser, and Contractors.

A 300 Scope and Application

301 This standard applies to rigid metallic submarine pipeline systems as defined in C 200, for the transportation of fluids of categorisation as defined in Section 2 and made of linepipe material as given in Section 6.

302 This standard applies to the design, materials, fabrication, installation, testing, commissioning, operation, repair, re-qualification, and abandonment of submarine pipeline systems used in the petroleum and natural gas industries.

303 This standard is applicable to single systems, pipeline bundles of the piggyback type, and pipeline bundles encased within a carrier pipe.

304 This standard is not applicable to flexible pipes or dynamic or compliant risers.

Guidance note:
The above limitation is due to the difference in load effects on a riser connected by clamps, or similar, to a fixed structure compared to a compliant riser which may move in the fluid. This excludes risers such as catenary risers or risers connected to a Tension Leg Platform (TLP).

305 Umbilicals intended for control of subsea installations are not included in this standard. Individual pipes, within an umbilical, made of materials applicable to this standard, may be designed according to this standard.

Guidance note:
Even though this standard may be applied to umbilicals, the non-typical geometry, as compared to that of an ordinary pipeline, may be outside the validity range for certain requirements and care shall be taken for such applications.

306 This standard is applicable for installation by S-lay, J-lay, towing and laying methods introducing plastic deformations. Installation requirements for risers as well as protective and anchoring structures are also included.

A 400 Other codes

401 In case of conflict between requirements of this standard and a reference document, the requirements of this standard shall prevail.

402 Where reference is made to codes other than DNV documents, the valid revision shall be taken as the revision which was current at the date of issue of this standard, unless otherwise noted.

403 This standard is intended to comply with the ISO standard 13623: Petroleum and natural gas industries - Pipeline transportation systems, specifying functional requirements for offshore pipelines and risers.

Guidance note:
The following major deviations to the ISO standard are known:

— applying the supplementary requirements U, for increased utilisation, this standard allows higher pressure containment utilisation than the ISO standard;
— the equivalent stress criterion in the ISO standard sometimes allows higher utilisation than this standard;
— requirements to system pressure test (pressure test); and
— minor differences may appear depending on how the pipeline has been defined in safety classes, the ISO standard does not use the concept of safety classes.

This standard requires that the line pipe and fabrication has been produced and fabricated to this standard.

404 The linepipe requirements of this standard are based on the ISO standard 3183-3 Petroleum and natural gas industries - Steel pipe for pipelines - technical delivery conditions - part 3 “Pipe of requirement class C”, with, in some respects, more stringent requirements.

This offshore standard gives also requirements for five supplementary requirements and an additional level of NDT requirements which are linked up to the design criteria and content.

Guidance note:
Additional requirements to the ISO standard on linepipe are given in Appendix A.

B. Normative References

B 100 Offshore Service Specifications

The latest revision of the following documents applies:

DNV OSS-301 Certification and Verification of Pipelines

B 200 Offshore Standards

(Empty)

B 300 Recommended practices

The latest revision of the following documents applies:

DNV RP-F101 Corroded Pipelines
DNV RP-F104 Mechanical pipeline couplings
DNV RP-F106 Factory applied pipeline coatings for corrosion control
DNV RP B401 Cathodic Protection Design
DNV RP E305 On-bottom Stability Design of Submarine Pipelines
DNV RP O501 Erosive Wear in Piping Systems

B 400 Rules

The latest revision of the following documents applies:

DNV Rules for Certification of Flexible Risers and Pipes
DNV Rules for Planning and Execution of Marine operations
DNV Rules for Classification of Fixed Offshore Installations

B 500 Certification notes and Classification notes

The latest revision of the following documents applies:

- DNV CN 1.2 Conformity Certification Services, Type Approval
- DNV CN 1.5 Conformity Certification Services, Approval of Manufacturers, Metallic Materials
- DNV CN 7 Ultrasonic Inspection of Weld Connections
- DNV CN 30.2 Fatigue Strength Analysis for Mobile Offshore Units
- DNV CN 30.4 Foundations
- DNV CN 30.5 Environmental Conditions and Environmental Loads
- DNV CN 30.6 Structural Reliability Analysis of Marine Structures

B 600 Guidelines

The latest revision of the following documents applies:

- DNV Guidelines for Flexible Pipes, Rev. 02, November 1987
- DNV Guideline 13 Interference between Trawl Gear and Pipelines.
- DNV Guideline 14 Free spanning Pipelines

B 700 Other references

- BS 7910 Guide on methods for assessing the acceptability of flaws in fusion welded structures
- ISO/DIS 13623 Petroleum and natural gas industries - Pipeline transportation systems.
- ISO 3183-3 Petroleum and natural gas industries - Steel pipe for pipelines - Technical delivery conditions - Part 3 "Pipe of requirement class C".

Guidance note:
The latest revision of the DNV documents may be found in the publication list at the DNV website www.dnv.com.

---end-of-Guidance-note---

C. Definitions

C 100 Verbal forms

101 "Shall": Indicates requirements strictly to be followed in order to conform to this standard and from which no deviation is permitted.

102 "Should": Indicates that among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required. Other possibilities may be applied subject to agreement.

103 "May": Verbal form used to indicate a course of action permissible within the limits of the standard.

104 "Agreement", "by agreement": Unless otherwise indicated, this means agreed in writing between Manufacturer/Contractor and Purchaser.

C 200 Definitions

201 As-built survey: Survey of the installed and completed pipeline system, that is performed to verify that the completed installation work meets the specified requirements, and to document deviations from the original design, if any.

202 As-laid survey: Survey performed either by continuous touchdown point monitoring or by a dedicated vessel during installation of the pipeline.

203 Atmospheric zone: The part of the pipeline system above the splash zone.

204 Buckling, global: Buckling mode which involves a substantial length of the pipeline, usually several pipe joints and not gross deformations of the cross section; upheaval buckling is an example thereof.

205 Buckling, local: Buckling mode confined to a short length of the pipeline causing gross changes of the cross section; collapse, localised wall wrinkling and kinking are examples thereof.

206 Characteristic load: The reference value of a load to be used in the determination of load effects. The characteristic load is normally based upon a defined fractile in the upper end of the distribution function for load.

207 Characteristic strength: The reference value of structural strength to be used in the determination of the design strength. The characteristic strength is normally based upon a defined fractile in the lower end of the distribution function for load. For local buckling, the characteristic value usually corresponds to the expected value. The local buckling resistance divided by the material partial factor, usually constitutes a lower fractile.

208 Characteristic strength: The nominal value of material strength to be used in the determination of the design strength. The characteristic strength is normally based upon a defined fractile in the lower end of the distribution function for load.

209 Clad pipe (C): Pipe with internal liner where the bond between (linepipe) base and cladding material is metallurgical.

210 Commissioning: In relation to pipelines, refers to activities which take place after pressure testing and prior to operation, comprising de-watering, cleaning, drying and filling with product.

211 Condition load effect factor: A load effect factor included in the buckling calculation to account for specific load conditions.

212 Construction phase: All phases during construction, including fabrication, installation, testing and commissioning, up until the installation or system is safe and operable for intended use. In relation to pipelines, this includes transportation, on-shore and on-barge welding, laying, rectification, tie-in, pressure testing, commissioning and repair.

213 Contractor: A party contractually appointed by the Purchaser to fulfill all, or any of, the activities associated with design, construction and operation.

214 Corrosion allowance: Extra wall thickness added during design to compensate for any reduction in wall thickness by corrosion(internally/externally) during operation.

215 Design life: The initially planned time period from initial installation or use until permanent decommissioning of the equipment or system. The original design life may be extended after a re-qualification.

216 Design premises: A set of project specific design data and functional requirements which are not specified or which are left open in the standard.

217 Design: All related engineering to design the pipeline including both structural as well as material and corrosion.

218 Design temperature, maximum: The highest possible temperature to which the equipment or system may be exposed to during installation and operation. Environmental as well as operational temperatures shall be considered.

219 Design temperature, minimum: The lowest possible temperature to which the equipment or system may be exposed to during installation and operation, irrespective of the pressure. Environmental as well as operational temperatures shall be considered.

Erosion: Material loss due to repeated impact of sand particles or liquid droplets.

Fabrication: Activities related to the assembly of objects with a defined purpose. In relation to pipelines, fabrication refers to e.g. risers, expansion loops, bundles, reels, etc.

Fabrication factor: Factor on the material strength in order to compensate for material strength reduction from cold forming during manufacturing of linepipe.

Fabricator: The party performing the fabrication.

Failure: An event affecting a component or system and causing one or both of the following effects:
- loss of component or system function; or
- deterioration of functional capability to such an extent that the safety of the installation, personnel or environment is significantly reduced

Fatigue: Cyclic loading causing degradation of the material.

Fluid categorisation: Categorisation of the transported fluid according to hazard potential as defined in Section 2.

Fractile: The p-fractile (or percentile) and the corresponding fractile value \( x_p \) is defined as:

\[ F(x_p) = p \]

\( F \) is the distribution function for \( x_p \)

Hydrogen Pressure Induced Cracking (HPIC): Internal cracking of wrought materials due to a build-up of hydrogen pressure in micro-voids (Related terms: hydrogen induced cracking, stepwise cracking)

Hydro-test or Hydrostatic test: See Mill pressure test

Inspection: Activities such as measuring, examination, testing, gauging one or more characteristics of a product or service and comparing the results with specified requirements to determine conformity.

Installation (activity): The operations related to installing the equipment, pipeline or structure, e.g. pipeline laying, tie-in, piling of structure etc., including final testing and preparation for operation.

Installation (object): See Offshore installation.

Installation Manual (IM): A document prepared by the Contractor to describe and demonstrate that the installation method and equipment used by the Contractor will meet the specified requirements and that the results can be verified.

J-tube: A J-shaped tube installed on a platform, through which a pipe can be pulled to form a riser. The J-tube extends from the platform deck to and inclusive of the bottom bend at the sea floor. The J-tube supports the J-tube to the supporting structure.

Limit state: A state beyond which the structure no longer satisfies the requirements. The following categories of limit states are of relevance for pipeline systems:

SLS = Serviceability Limit State
ULS = Ultimate Limit State
FLS = Fatigue Limit State
ALS = Accidental Limit State.

Lined pipe (L): Pipe with internal liner where the bond between (linepipe) base and cladding material is mechanical.

Load: Any action causing stress, strain, deformation, displacement, motion, etc. to the equipment or system.

Load combination: The local buckling limit state criteria for combined loading shall be checked for two load combinations a and b. Load combination a is a system check and shall only be applied when system effects are present.

Load effect: Effect of a single load or combination of loads on the equipment or system, such as stress, strain, deformation, displacement, motion, etc.

Load effect factor: The partial safety factor by which the characteristic load effect is multiplied to obtain the design load effect.

Location class: A geographic area of pipeline system classified according to human activity.

Lot: A number of pipes from the same heat, the same heat treatment batch and with the same diameter and wall thickness.

Manufacture: Making of articles or materials, often in large volumes. In relation to pipelines, refers to activities for the production of linepipe, anodes and other components and application of coating, performed under contracts from one or more Contractors.

Manufacturer: The party who is contracted to be responsible for planning, execution and documentation of manufacturing.

Manufacturing Procedure Specification (MPS): A manual prepared by the Manufacturer to demonstrate how the specified properties may be achieved and verified through the proposed manufacturing route.

Material resistance factor: Partial safety factor transforming a characteristic resistance to a lower fractile resistance.

Material strength factor: Factor for determination of the characteristic material strength reflecting the confidence in the yield stress.

Mill pressure test: The hydrostatic strength test performed at the mill, see Section 5B 200.

NDT level: The extent and acceptance criteria for the NDT of the linepipe are given for two levels. Level one, which is more stringent, is required for displacement controlled design criteria.

Nominal outside diameter: The specified outside diameter. This shall mean the actual outside diameter, e.g. 12.75" for a 12" pipe (clarification).

Nominal pipe wall thickness: The specified non-corroded pipe wall thickness of a pipe, which is equal to the minimum steel wall thickness plus the manufacturing tolerance.

Offshore installation (object): General term for mobile and fixed structures, including facilities, which are intended for exploration, drilling, production, processing or storage of hydrocarbons or other related activities/fluids. The term includes installations intended for accommodation of personnel engaged in these activities. Offshore installation covers subsea installations and pipelines. The term does not cover traditional shuttle tankers, supply boats and other support vessels which are not directly engaged in the activities described above.

Operation, Incidental: Conditions which are not part of normal operation of the equipment or system. In relation to pipeline systems, incidental conditions may lead to incidental pressures, e.g. pressure surges due to sudden closing of valves, or failure of the pressure regulation system and activation of the pressure safety system.

Operation, Normal: Conditions that arise from the intended use and application of equipment or system, including associated condition and integrity monitoring, maintenance, repairs etc. In relation to pipelines, this should include steady flow conditions over the full range of flow rates, as well as possible packing and shut-in conditions where these occur as part of routine operation.

Out of roundness: The deviation of the linepipe perimeter...
ter from a circle. This can be stated as ovalisation (%), or as local out of roundness, e.g. flattening, (mm).

257 Ovalisation: The deviation of the perimeter from a circle. This has the form of an elliptic cross section.

258 Owner: The party ultimately responsible for design, construction and operation.

259 Partial safety factor: A factor by which the characteristic value of a variable is modified to give the design value (i.e. a load effect, condition load effect, material resistance or safety class resistance factor).

260 Pipe, High Frequency Welded (HFW): Pipe manufactured by forming from strip and with one longitudinal seam formed by welding without the addition of filler metal. The longitudinal seam is generated by high frequency current (minimum 100 kHz) applied by induction or conduction. The weld area or the entire pipe shall be heat treated.

261 Pipe, Seamless (SML): Pipe manufactured in a hot forming process resulting in a tubular product without a welded seam. The hot forming may be followed by sizing or cold finishing to obtain the required dimensions.

262 Pipe, Submerged Arc-Welded Longitudinal or Helical (SAWL or SAWH): Pipe manufactured by forming from strip or plate, and with one longitudinal (SAWL) or helical (SAWH) seam formed by the submerged arc process with at least one pass made on the inside and one pass from the outside of the pipe. An intermittent or continuous single pass tack weld made by the gas metal arc welding method is permitted.

263 Pipeline: A pipeline is defined as the part of a pipeline system which is located below the water surface at maximum tide, except for pipeline risers. The pipeline may be resting wholly or intermittently on, or buried below, the sea bottom.

264 Pipeline Components: Any items which are integral parts of the pipeline system such as flanges, tees, bends, reducers and valves.

265 Pipeline System: An interconnected system of submarine pipelines, their risers, supports, isolation valves, all integrated piping components, associated safety systems and the corrosion protection system. Unless specified otherwise, the pipeline system limits are as follows:

- up to and including the pig launcher/pig receiver on an installation. If no pigging facilities are present, the pipeline system terminates at the first valve within the facilities.
- on a subsea installation, the pipeline system normally ends at the point of connection to the christmas tree or butterfly valve. The christmas tree is not considered to be a part of the pipeline system. On a subsea installation, where the above definition is not applicable, the pipeline system ends at the connection point to the subsea installation. The connection is part of the submarine pipeline.
- the pipeline system ends at the first flange/valve on shore approach.

266 Pressure control system: In relation to pipelines, this is the system for control of the pressure in pipelines, comprising the pressure regulating system, pressure safety system and associated instrument and alarm systems, see Figure 1.

267 Pressure regulating system: In relation to pipelines, this is the system which ensures that, irrespective of the upstream pressure, a set pressure is maintained (at a given reference point) for the pipeline.

268 Pressure safety system: The system which, independent of the pressure regulating system, ensures that the allowable incidental pressure is not exceeded.

269 Pressure test: See System pressure test

270 Pressure, Collapse: Characteristic resistance against external over-pressure.

271 Pressure, Design: In relation to pipelines, this is the maximum internal pressure during normal operation, referred to a specified reference height, to which the pipeline or pipeline section shall be designed. The design pressure must take account of steady flow conditions over the full range of flow rates, as well as possible packing and shut-in conditions, over the whole length of the pipeline or pipeline section which is to have a constant design pressure.

272 Pressure, Hydro- or Hydrostatic test: See Pressure, Mill test.

273 Pressure, Incidental: In relation to pipelines, this is the maximum internal pressure the pipeline or pipeline section is designed to withstand during any incidental operating situation, referred to the same reference height as the design pressure.

274 Pressure, Initiation: The external over-pressure required to initiate a propagating buckle from an existing local buckle or dent.

275 Pressure, Local; Local Design, Local Incidental or Local Test: In relation to pipelines, this is the internal pressure at any point in the pipeline system or pipeline section for the corresponding design pressure, incidental pressure or test pressure. This is equal to the design/incidental/test pressure at the reference height plus the static head of the transported/test medium due to the difference between the reference height and the height of the section being considered.

276 Pressure, Maximum Allowable Incidental (MAIP): In relation to pipelines, this is the maximum pressure at which the pipeline system shall be operated during incidental (i.e. transient) operation. The maximum allowable incidental pressure is defined as the maximum incidental pressure less the positive tolerance of the pressure safety system.

277 Pressure, Maximum Allowable Operating (MAOP): In relation to pipelines, this is the maximum pressure at which the pipeline system shall be operated during normal operation. The maximum allowable operating pressure is defined as the design pressure less the positive tolerance of the pressure regulating system.

278 Pressure, Mill test: The test pressure applied to pipe
joints and pipe components upon completion of manufacture and fabrication, see Section 5 B200.

279  **Pressure, Propagating**: The lowest pressure required for a propagating buckle to continue to propagate.

279b  **Pressure, shut-in**: The maximum pressure that can be attained at the wellhead during closure of valves closest to the wellhead (wellhead isolation). This implies that pressure transients due to valve closing shall be included.

280  **Pressure, System test**: In relation to pipelines, this is the internal pressure applied to the pipeline or pipeline section during testing on completion of installation work to test the pipeline system for tightness (normally performed as hydrostatic testing).

281  **Pressure, Test**: See Pressure, System test.

282  **Purchaser**: The owner or another party acting on his behalf, who is responsible for procuring materials, components or services intended for the design, construction or modification of a installation or a pipeline.

283  **Quality Assurance (QA)**: Planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

284  **Quality Plan (QP)**: The document setting out the specific quality practices, resources and sequence of activities relevant to a particular product, project or contract. A quality plan usually makes reference to the part of the quality manual applicable to the specific case.

285  **Ratcheting**: Accumulated deformation during cyclic loading, especially for diameter increase.

286  **Reliability**: The probability that a component or system will perform its required function without failure, under stated conditions of operation and maintenance and during a specified time interval.

287  **Re-qualification**: The re-assessment of a design due to modified design premises and/or sustained damage.

288  **Resistance**: The capability of a structure, or part of a structure, to resist load effects.

289  **Riser**: A riser is defined as the connecting piping or flexible pipe between a submarine pipeline on the sea bottom and installations above water. The riser extends to the above sea emergency isolation point between the import/export line and the installation facilities, i.e. riser ESD valve.

290  **Riser support/clamp**: A structure which is intended to keep the riser in place.

291  **Riser system**: A riser system is considered to comprise riser, its supports, all pipelining components, and corrosion protection system.

292  **Risk**: The qualitative or quantitative likelihood of an accidental or unplanned event occurring, considered in conjunction with the potential consequences of such a failure. In quantitative terms, risk is the quantified probability of a defined failure mode times its quantified consequence.

293  **Safety Class (SC)**: In relation to pipelines; a concept adopted to classify the significance of the pipeline system with respect to the consequences of failure.

294  **Safety class resistance factor**: Partial safety factor which transforms the lower fractile resistance to a design resistance reflecting the safety class.

295  **Slamming**: Impact load on an approximately horizontal member from a rising water surface as a wave passes. The direction is mainly vertical.

296  **Slapping**: Impact load on an approximately vertical surface due to a breaking wave. The direction is mainly horizontal.

297  **Specified Minimum Tensile Strength (SMTS)**: The minimum tensile strength prescribed by the specification or standard under which the material is purchased.

298  **Specified Minimum Yield Stress (SMYS)**: The minimum yield stress prescribed by the specification or standard under which the material is purchased.

299  **Splash zone**: External surfaces of a structure or pipeline that are periodically in and out of the water by the influence of waves and tides.

300  **Definitions (continued)**

300  **Splash Zone Height**: The vertical distance between splash zone upper limit and splash zone lower limit.

301  **Splash Zone Lower Limit (LSZ)** is determined by:

\[
LSZ = [L1] - [L2] - [L3]
\]

L1 = lowest astronomic tide level (LAT)
L2 = 30% of the Splash zone wave-related height defined in 303.
L3 = upward motion of the riser, if applicable.

302  **Splash Zone Upper Limit (USZ)** is determined by:

\[
USZ = |U1| + |U2| + |U3|
\]

U1 = highest astronomic tide level (HAT)
U2 = 70% of the splash zone wave-related height defined in 303.
U3 = settlement or downward motion of the riser, if applicable.

303  **Splash zone wave-related height**: The wave height with a probability of being exceeded equal to 10⁻², as determined from the long term distribution of individual waves. If this value is not available, an approximate value of the splash zone height may be taken as:

\[
0.46 H_{100}^k
\]

where

\[
H_{100}^k = \text{significant wave height with a 100 year return period}\]

304  **Submarine pipeline**: See definition for pipeline.

305  **Submerged zone**: The part of the pipeline system or installation below the splash zone, including buried parts.

306  **Supplementary requirements**: Requirements for material properties of linepipe that are additional to the basic requirements, and that are intended to apply to pipe used for specific applications.

307  **System effects**: System effects are relevant in cases where many pipe sections are subjected to an invariant loading condition, and potential structural failure may occur in connection with the lowest structural resistance among the pipe sections.

308  **System pressure test**: Final test of the complete pipeline system, see Section 5B 200.

309  **Target safety level**: A nominal acceptable probability of structural failure. Gross errors are not included.

310  **Ultimate Tensile Strength (UTS)**: The measured ultimate tensile strength.

311  **Verification**: An examination to confirm that an activity, a product or a service is in accordance with specified requirements.

312  **Work**: All activities to be performed within relevant contract(s) issued by Owner, Operator, Contractor or Manufacturer.

313  **Yield Stress (YS)**: The measured yield tensile stress.
## D. Abbreviations and Symbols

### D 100 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS</td>
<td>Accidental Limit State</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>ASD</td>
<td>Allowable Stress Design</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>AUT</td>
<td>Automatic Ultrasonic Testing</td>
</tr>
<tr>
<td>BM</td>
<td>Base material</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>C</td>
<td>Clad pipe</td>
</tr>
<tr>
<td>C-Mn</td>
<td>Carbon Manganese</td>
</tr>
<tr>
<td>CRA</td>
<td>Corrosion Resistant Alloy</td>
</tr>
<tr>
<td>CTOD</td>
<td>Crack Tip Opening Displacement</td>
</tr>
<tr>
<td>DFI</td>
<td>Design, Fabrication and Installation</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>DP</td>
<td>Dynamic Positioning</td>
</tr>
<tr>
<td>EBW</td>
<td>Electronic Beam Welded</td>
</tr>
<tr>
<td>ECA</td>
<td>Engineering Criticality Assessment</td>
</tr>
<tr>
<td>ESD</td>
<td>Emergency Shut Down</td>
</tr>
<tr>
<td>FLS</td>
<td>Fatigue Limit State</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode Effect Analysis</td>
</tr>
<tr>
<td>HAT</td>
<td>Highest Astronomical Tide</td>
</tr>
<tr>
<td>HAZ</td>
<td>Heat Affected Zone</td>
</tr>
<tr>
<td>HAZOP</td>
<td>Hazard and Operability Study</td>
</tr>
<tr>
<td>HFW</td>
<td>High Frequency Welding</td>
</tr>
<tr>
<td>HPIC</td>
<td>Hydrogen Pressure Induced Cracking</td>
</tr>
<tr>
<td>IM</td>
<td>Installation Manual</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>J-R curve</td>
<td>Plot of resistance to stable crack growth for establishing crack extension</td>
</tr>
<tr>
<td>KV</td>
<td>Charpy value</td>
</tr>
<tr>
<td>KVL</td>
<td>Charpy value in pipe longitudinal direction</td>
</tr>
<tr>
<td>KVT</td>
<td>Charpy value in pipe transversal direction</td>
</tr>
<tr>
<td>L</td>
<td>Lined pipe</td>
</tr>
<tr>
<td>L</td>
<td>Load effect</td>
</tr>
<tr>
<td>LAT</td>
<td>Lowest Astronomical Tide</td>
</tr>
<tr>
<td>LRFD</td>
<td>Load and Resistance Factor Design</td>
</tr>
<tr>
<td>LSZ</td>
<td>Splash Zone Lower Limit</td>
</tr>
<tr>
<td>LBW</td>
<td>Laser Beam Welded</td>
</tr>
<tr>
<td>MAIP</td>
<td>Maximum Allowable Incidental Pressure</td>
</tr>
<tr>
<td>MAPI</td>
<td>Maximum Allowable Operating Pressure</td>
</tr>
<tr>
<td>MDS</td>
<td>Material Data Sheet</td>
</tr>
<tr>
<td>MIP</td>
<td>Maximum Incidental Pressure</td>
</tr>
<tr>
<td>MPOT</td>
<td>Manufacturing Procedure Qualification Test</td>
</tr>
<tr>
<td>MPS</td>
<td>Manufacturing Procedure Specification</td>
</tr>
<tr>
<td>MSA</td>
<td>Manufacturing Survey Arrangement</td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
</tr>
<tr>
<td>NDT</td>
<td>Non-Destructive Testing</td>
</tr>
<tr>
<td>P</td>
<td>Production</td>
</tr>
<tr>
<td>PRE</td>
<td>Pitting Resistance Equivalent</td>
</tr>
<tr>
<td>PWHT</td>
<td>Post weld heat treatment</td>
</tr>
<tr>
<td>Q</td>
<td>Qualification</td>
</tr>
<tr>
<td>QA</td>
<td>Quality Assurance</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>QP</td>
<td>Quality Plan</td>
</tr>
<tr>
<td>QRA</td>
<td>Quantitative Risk Analysis</td>
</tr>
<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
</tr>
<tr>
<td>RT</td>
<td>Radiographic testing</td>
</tr>
<tr>
<td>SAWH</td>
<td>Submerged Arc-welding Helical</td>
</tr>
<tr>
<td>SAWL</td>
<td>Submerged Arc-welding Longitudinal</td>
</tr>
<tr>
<td>SC</td>
<td>Safety Class</td>
</tr>
<tr>
<td>SCF</td>
<td>Stress Concentration Factor</td>
</tr>
<tr>
<td>SLS</td>
<td>Serviceability Limit State</td>
</tr>
<tr>
<td>SMI</td>
<td>Seamless Pipe</td>
</tr>
<tr>
<td>SMTS</td>
<td>Specified Minimum Tensile Strength</td>
</tr>
<tr>
<td>SMYS</td>
<td>Specified Minimum Yield Stress</td>
</tr>
<tr>
<td>SNCF</td>
<td>Strain Concentration Factor</td>
</tr>
<tr>
<td>SRA</td>
<td>Structural Reliability Analysis</td>
</tr>
<tr>
<td>SSC</td>
<td>Stress Sulphide Cracking</td>
</tr>
<tr>
<td>ST</td>
<td>Surface testing</td>
</tr>
<tr>
<td>TOFD</td>
<td>Time Of Flight Diffraction</td>
</tr>
<tr>
<td>TRB</td>
<td>Three Roll Bending</td>
</tr>
<tr>
<td>ULS</td>
<td>Ultimate Limit State</td>
</tr>
<tr>
<td>UOE</td>
<td>Pipe fabrication process for welded pipes, expanded</td>
</tr>
<tr>
<td>USZ</td>
<td>Splash Zone Upper Limit</td>
</tr>
<tr>
<td>UT</td>
<td>Ultrasonic testing</td>
</tr>
<tr>
<td>UTS</td>
<td>Ultimate Tensile Strength</td>
</tr>
<tr>
<td>WPS</td>
<td>Welding Procedure Specification</td>
</tr>
<tr>
<td>YS</td>
<td>Yield Stress</td>
</tr>
</tbody>
</table>

### D 200 Symbols

#### 201 Latin characters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cross section area</td>
</tr>
<tr>
<td>A_i</td>
<td>( \frac{\pi}{4} (D - 2t)^2 )</td>
</tr>
<tr>
<td>A_c</td>
<td>( \frac{\pi}{4} D^2 )</td>
</tr>
<tr>
<td>E</td>
<td>Young's Modulus</td>
</tr>
<tr>
<td>D</td>
<td>Nominal outside diameter</td>
</tr>
<tr>
<td>D_{max}</td>
<td>Greatest measured inside or outside diameter</td>
</tr>
<tr>
<td>D_{min}</td>
<td>Smallest measured inside or outside diameter</td>
</tr>
<tr>
<td>D_i</td>
<td>Nominal internal diameter</td>
</tr>
<tr>
<td>D_{nom}</td>
<td>Nominal external diameter</td>
</tr>
<tr>
<td>i</td>
<td>Characteristic internal pressure</td>
</tr>
<tr>
<td>p</td>
<td>Pressure</td>
</tr>
<tr>
<td>p_c</td>
<td>Characteristic collapse pressure</td>
</tr>
<tr>
<td>p_d</td>
<td>Design pressure</td>
</tr>
<tr>
<td>p_e</td>
<td>External pressure</td>
</tr>
<tr>
<td>p_f</td>
<td>Elastic collapse pressure</td>
</tr>
<tr>
<td>p_h</td>
<td>Test pressure (mill test)</td>
</tr>
<tr>
<td>p_{inc}</td>
<td>Incidental pressure</td>
</tr>
<tr>
<td>p_{init}</td>
<td>Initiation pressure</td>
</tr>
<tr>
<td>p_{init}</td>
<td>Local design pressure</td>
</tr>
<tr>
<td>p_{inc}</td>
<td>Local incidental pressure</td>
</tr>
<tr>
<td>p_{test}</td>
<td>Local test pressure (system test)</td>
</tr>
<tr>
<td>p_{mao}</td>
<td>Maximum allowable operating pressure</td>
</tr>
<tr>
<td>p_{m}</td>
<td>Hydrostatic mill test pressure</td>
</tr>
<tr>
<td>p_{pl}</td>
<td>Plastic collapse pressure</td>
</tr>
<tr>
<td>p_{prop}</td>
<td>Propagating pressure</td>
</tr>
<tr>
<td>p_{t}</td>
<td>Test pressure</td>
</tr>
<tr>
<td>R</td>
<td>Global bending radius of pipe</td>
</tr>
<tr>
<td>R_{m}</td>
<td>Tensile strength</td>
</tr>
<tr>
<td>R_{pl}</td>
<td>Strength equivalent to a permanent elongation of x% (actual stress)</td>
</tr>
<tr>
<td>S</td>
<td>Effective axial force (Tension is positive)</td>
</tr>
<tr>
<td>T</td>
<td>Operating temperature</td>
</tr>
</tbody>
</table>

---

**Note:** The symbols and abbreviations are provided for reference and may not be exhaustive. Always refer to the specific standard or source for comprehensive and accurate information.
\( T_{\text{max}} \) = Maximum design temperature
\( T_{\text{min}} \) = Minimum design temperature
\( T_0 \) = Testing temperature
\( t_1, t_2 \) = Pipe wall thickness, see Section 5C 300
\( t_{\text{corr}} \) = Corrosion allowance
\( t_{\text{fab}} \) = Fabrication thickness tolerance
\( t_{\text{min}} \) = Minimum thickness
\( t_{\text{min}} \) = Measured minimum thickness, see Table 6-14, Table 6-15
\( t, t_{\text{nom}} \) = Nominal wall thickness of pipe (un-corroded)
\( W \) = Section modulus
\( z \) = Height from the pipeline part considered to the pipeline reference point for design pressure

**D 300 Greek characters**

301 Greek Characters

\( \alpha \) = Thermal expansion coefficient
\( \alpha_A \) = Anisotropy factor
\( \alpha_c \) = Flow stress parameter, ref. Section 5D 300
\( \alpha_{\text{fab}} \) = Fabrication factor, ref. Section 5D 300, Section 5B 600
\( \alpha_{\text{fat}} \) = Allowable damage ratio for fatigue
\( \alpha_{\text{gw}} \) = Girth weld factor (strain resistance)
\( \alpha_0 \) = \( \frac{YS}{UTS} \) Minimum strain hardening
\( \alpha_U \) = Material strength factor
\( \varepsilon \) = Strain
\( \varepsilon_M \) = Characteristic bending strain resistance
\( \varepsilon_p \) = Accumulated plastic strain resistance
\( \gamma_A \) = Load effect factor for accidental load
\( \kappa \) = Condition load effect factor

\( \gamma_E \) = Load effect factor for environmental load
\( \gamma_C \) = Pressure load effect factor
\( \gamma_F \) = Functional load
\( \gamma_{\text{inc}} \) = Incidental to design pressure ratio
\( \gamma_{\text{m}} \) = Material resistance factor
\( \gamma_{\text{p}} \) = Pressure load effect factor
\( \gamma_{\text{SC}} \) = Safety class resistance factor

**D 400 Subscripts**

A = Accidental load
c = characteristic resistance
d = Design value
E = Environmental load
F = Functional load
h = Circumferential direction (hoop direction)
i = Internal
l = axial (longitudinal) direction
M = Moment
p = Plastic
s = Steel
S = SLS
U = ULS
SECTION 2
DESIGN PHILOSOPHY

A. General

A 100 Objective
101 The purpose of this section is to present the safety philosophy and corresponding design format applied in this standard.

A 200 Application
201 This section applies to all pipeline systems which are to be built in accordance with this standard.
202 This section also provides guidance for extension of this standard in terms of new criteria etc.

B. Safety Philosophy

B 100 General
101 The integrity of a pipeline system constructed to this standard is ensured through a safety philosophy integrating different parts as illustrated in Figure 2-1.

B 200 Safety objective
201 An overall safety objective shall be established, planned and implemented, covering all phases from conceptual development until abandonment.

Guidance note:
All companies have some sort of policy regarding human aspects, environment and financial issues. These are typically on an overall level, but they may be followed by more detailed objectives and requirements in specific areas. These policies should be used as a basis for defining the Safety Objective for a specific pipeline system. Typical statements can be:

— The impact on the environment shall be reduced to as far as reasonably possible;
— No releases will be accepted during operation of the pipeline system;
— There shall be no serious accidents or loss of life during the construction period;
— The pipeline installation shall not, under any circumstances impose any threat to fishing gear;
— Diverless installation and maintenance; etc.

Statements such as those above may have implications for all or individual phases only. They are typically more relevant for the work execution (i.e. how the Contractor executes his job) and specific design solutions (e.g. burial or no burial). Having defined the Safety Objective, it can be a point of discussion as to whether this is being accomplished in the actual project. It is therefore recommended that the overall Safety Objective be followed up by more specific, measurable requirements.

If no policy is available, or if it is difficult to define the safety objective, one could also start with a risk assessment. The risk assessment could identify all hazards and their consequences, and then enable back-extrapolation to define acceptance criteria and areas that need to be followed up more closely.

In this standard, the structural failure probability is reflected in the choice of three safety classes (see B 400). The choice of safety class should also include consideration of the expressed safety objective.

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B 300 Systematic review
301 As far as practical, all work associated with the design, construction and operation of the pipeline system shall be such as to ensure that no single failure will lead to life-threatening situations for any person, or to unacceptable damage to the facilities or the environment.
302 A systematic review or analysis shall be carried out at all phases in order to identify and evaluate the consequences of single failures and series of failures in the pipeline system, such that necessary remedial measures can be taken. The extent of the review or analysis shall reflect the criticality of the pipeline system, the criticality of a planned operation, and previous experience with similar systems or operations.

Guidance note:
A methodology for such a systematic review is quantitative risk analysis (QRA). This may provide an estimation of the overall risk to human health and safety, environment and assets and comprises:

— hazard identification,
— assessment of probabilities of failure events,
— accident developments, and
— consequence and risk assessment.

It should be noted that legislation in some countries requires risk analysis to be performed, at least at an overall level to identify critical scenarios that might jeopardise the safety and reliability of a pipeline system. Other methodologies for identification of potential hazards are Failure Mode and Effect Analysis (FMEA) and Hazard and Operability studies (HAZOP).

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303 Special attention shall be given to sections close to installations or shore approaches where there is frequent human activity and thus a greater likelihood and consequence of damage to the pipeline. This also includes areas where pipelines are installed parallel to existing pipelines and pipeline crossings.

B 400 Safety class methodology
401 In this standard, structural safety of the pipeline system is ensured by use of a safety class methodology. The pipeline system is classified into one or more safety classes based on failure consequences, normally given by the content and loca-
tion. For each safety class, a set of partial safety factors is assigned to each limit state.

**B 500 Quality assurance**

501 The safety format within this standard requires that gross errors (human errors) shall be controlled by requirements for organisation of the work, competence of persons performing the work, verification of the design, and quality assurance during all relevant phases.

502 For the purpose of this standard, it is assumed that the owner of a pipeline system has established a quality objective. The owner shall, in both internal and external quality related aspects, seek to achieve the quality level of products and services intended in the quality objective. Further, the owner shall provide assurance that intended quality is being, or will be, achieved.

503 A quality system shall be applied to assist compliance with the requirements of this standard.

Guidance note:
ISO 9000 give guidance on the selection and use of quality systems.

---end-of-Guidance note---

**B 600 Health, safety and environment**

601 The objective of this standard is that the design, materials, fabrication, installation, commissioning, operation, repair, re-qualification, and abandonment of pipeline systems are safe and conducted with due regard to public safety and the protection of the environment.

**C. Design Format**

**C 100 General**

101 The design format within this standard is based upon a limit state and partial safety factor methodology, also called Load and Resistance Factor Design format (LRFD).

**C 200 Categorisation of fluids**

201 Fluids to be transported by the pipeline system shall be categorised according to their hazard potential as given by Table 2-1.

<table>
<thead>
<tr>
<th>Table 2-1 Classification of fluids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
</tbody>
</table>

202 Gases or liquids not specifically identified in Table 2-1 shall be classified in the category containing substances most similar in hazard potential to those quoted. If the fluid category is not clear, the most hazardous category shall be assumed.

**C 300 Location classes**

301 The pipeline system shall be classified into location classes as defined in Table 2-2.

<table>
<thead>
<tr>
<th>Table 2-2 Classification of location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

**C 400 Safety classes**

401 Pipeline design shall be based on potential failure consequence. In this standard, this is implicit by the concept of safety class. The safety class may vary for different phases and locations. The safety classes are defined in Table 2-3.

<table>
<thead>
<tr>
<th>Table 2-3 Classification of safety classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety class</td>
</tr>
<tr>
<td>Low</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>High</td>
</tr>
</tbody>
</table>

The partial safety factors related to the safety class are given in Section 5D 200.

402 For normal use, the safety classes in Table 2-4 apply:

<table>
<thead>
<tr>
<th>Table 2-4 Normal classification of safety classes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase</td>
</tr>
<tr>
<td>Location Class</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Temporary</td>
</tr>
<tr>
<td>Operational</td>
</tr>
</tbody>
</table>

Note:
1) Installation until pre-commissioning (temporary phase) will normally be classified as safety class Low.
2) For safety classification of temporary phases after commissioning, special consideration shall be made to the consequences of failure, i.e. giving a higher safety class than Low.
3) Risers during normal operation will normally be classified as safety class High.

* Other classifications may exist depending on the conditions and criticality of failure the pipeline. For pipelines where some consequences are more severe than normal, i.e. when the table above does not apply, the selection of a higher safety class shall also consider the implication, on the total gained safety. If the total safety increase is marginal, the selection of a higher safety class may not be justified.

**C 500 Partial Safety Factor methodology**

501 The fundamental principle of the partial safety factor design methodology is to verify that factored design loads do not exceed factored design resistance for any of the considered failure modes. A factored design load effect is obtained by multiplying a characteristic load effect by a load effect factor. A factored resistance is obtained by dividing the characteristic
The level of safety is considered to be satisfactory if the design load effect ($L_d$) does not exceed the design resistance ($R_d$):

$$L_d(L_F, L_{E}, L_A, \gamma_F, \gamma_A, \gamma_C) \leq R_d(R_k, \gamma_{SC}, \gamma_m) \quad (2.1)$$

The design load effect is based on, or is a function of, factored load effects adjusted by the condition specific load effect factor, $\gamma_C$, where appropriate. The factored load effects are combined according to the limit state function for the particular failure mode.

The load effect factors, safety class resistance factors and material resistance factors related to the limit states presented in this standard are calibrated using a reliability-based methodology for the different safety classes.

The characteristic values for load effects and resistance in this standard are usually given as percentile values of the respective probability distributions. They shall be based on reliable data, using recognised statistical techniques.

Guidance note:
The characteristic resistances in this standard do not necessarily reflect either mean values or certain percentile values. The resulting design formulas provide design criteria as a totality of model uncertainty, bias loads etc. Hence, care shall be taken when recalibrating these formulas to ensure this totality.

Load combinations and corresponding load effect factors are given in Section 5D 300. Limit states and corresponding resistance factors are given in Section 5D 200.

C 600 Reliability analysis

As an alternative to the LRFD format specified and used in this standard, a recognised structural reliability analysis (SRA) based design method may be applied provided that:

- it is used for calibration of explicit limit states outside the scope of this standard;
- the method complies with DNV Classification Note no. 30.6 "Structural reliability analysis of marine structures"; and
- the approach is demonstrated to provide adequate safety for familiar cases, as indicated by this standard.

Guidance note:
In particular, this implies that reliability based limit state design shall not be used to replace the pressure containment criteria in Section 5.

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Suitably competent and qualified personnel shall perform the structural reliability analysis, and extension into new areas of application shall be supported by technical verification.

As far as possible, target reliability levels shall be calibrated against identical or similar pipeline designs that are known to have adequate safety on the basis of this standard. If this is not feasible, the target safety level shall be based on the failure type and safety class as given in Table 2-5.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

### Table 2-5 Acceptable failure probabilities vs. safety classes

<table>
<thead>
<tr>
<th>Limit States</th>
<th>Probability Bases</th>
<th>Safety Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>SLS</td>
<td>Annual per Pipeline $^1$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>ULS</td>
<td>Annual per Pipeline $^1$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>FLS</td>
<td>Annual per Pipeline $^2$</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>ALS</td>
<td>Annual per Pipeline $^3$</td>
<td>$10^{-3}$</td>
</tr>
</tbody>
</table>

1) Or the time period of the temporary phase
2) The failure probability will effectively be governed by the last year in operation or prior to inspection depending on the adopted inspection philosophy.
3) Refers to the overall allowable probability of severe consequences.
SECTION 3
DESIGN PREMISES AND DOCUMENTATION

A. General

A 100 Objective

101 The purpose of this section is to identify and provide a basis for definition of relevant field development characteristics. Further, key issues required for design, construction, operation, and re-qualification of pipeline systems are identified.

102 This section also specifies minimum requirements to documentation for design, manufacture, installation and operation.

A 200 Concept development

201 Data and description of field development and general arrangement of the pipeline system shall be established.

202 The data and description shall include the following, as applicable:

— safety objective;
— location, inlet and outlet conditions;
— pipeline system description with general arrangement and battery limits;
— functional requirements including field development restrictions, e.g., safety barriers and subsea valves;
— installation, repair and replacement of pipeline elements, valves, actuators and fittings;
— project plans and schedule, including planned period of the year for installation;
— design life including specification for start of design life, e.g. final commissioning, installation etc.;
— data of product to be transported including possible changes during the pipeline system’s design life;
— transport capacity and pipeline sizing data;
— attention to possible code breaks in the pipeline system;
— geometrical restrictions such as specifications of constant internal diameter, requirement for fittings, valves, flanges and the use of flexible pipe or risers;
— pigging requirements such as bend radius, pipe ovality and distances between various fittings affecting design for pigging applications;
— sand production; and
— second and third party activities.

A 300 Execution plan

301 An execution plan shall be developed, including the following topics:

— general information, including project organisation, scope of work, interfaces, project development phases and production phases;
— contacts with Purchaser, authorities, third party, engineering, verification and construction Contractors; and
— legal aspects, e.g. insurance, contracts, area planning.

A 400 Installation, operation and abandonment

401 The design and planning for a pipeline system shall cover all development phases including construction, operation and abandonment.

Installation

402 Detailed plans, drawings and procedures shall be prepared for all installation activities. The following shall as a minimum be covered:

— pipeline route survey,
— marine operations,
— pipeline installation,
— tie-in operations,
— as-laid survey,
— span rectification and pipeline protection,
— installation of protective and anchoring structures,
— installation of risers,
— as-built survey, and
— final testing and preparation for operation.

Operation

403 Plans for pipeline operation, inspection, maintenance and repair shall be prepared prior to start of operation.

404 All operational aspects shall be considered when selecting the pipeline concept.

405 The pipeline system operational planning shall as a minimum cover:

— organisation and management;
— start-up and shut-down;
— operational limitations;
— maintenance;
— corrosion control, inspection and monitoring;
— general inspection; and
— special activities.

Abandonment

406 Pipeline abandonment shall be planned and prepared.

407 Selection of pipeline concept shall include identification of any significant impact on pipeline abandonment.

408 Pipeline abandonment evaluation shall include the following aspects:

— environment, especially pollution;
— obstruction for ship traffic;
— obstruction for fishing activities; and
— corrosion impact on other structures.

B. System Design Principles

B 100 System integrity

101 Pipeline systems shall be designed, constructed and operated in such a manner that they:

— fulfil the specified transport capacity,
— fulfil the defined safety objective and have the required resistance against loads during planned operational conditions, and
— have sufficient safety margin against accidental loads or unplanned operational conditions.

102 The possibility of changes in the type or composition of product to be transported during the lifetime of the pipeline system shall be assessed at the design phase.

103 Any re-qualification deemed necessary due to changes in the design conditions shall take place in accordance with provisions set out in Section 11.

B 200 Monitoring/inspection during operation

201 Parameters which could violate the integrity of a pipeline system shall be monitored and evaluated with a frequency which enables remedial actions to be carried out before the system is damaged.
Guidance note:
As a minimum the monitoring/inspection frequency should be such that the pipeline system will not be endangered due to any realistic degradation/deterioration that may occur between two consecutive inspection intervals.

--- end of Guidance note ---

202 Instrumentation of the pipeline system may be required when visual inspection or simple measurements are not considered practical or reliable, and available design methods and previous experience are not sufficient for a reliable prediction of the performance of the system.

203 The pressure in a pipeline system shall not exceed the design pressure during normal steady-state operation.

B 300 Pressure Control System

301 A pressure control system may be used to prevent the internal pressure at any point in the pipeline system rising to an excessive level. The pressure control system comprises the pressure regulating system, pressure safety system and associated instrumentation and alarm systems.

302 The purpose of the pressure regulating system is to maintain the operating pressure within acceptable limits during normal operation. The set pressure of the pressure regulating system shall be such that the local design pressure is not exceeded at any point in the pipeline system. Due account shall be given to the tolerances of the pressure regulating system and its associated instrumentation, see Figure 1-1.

303 The purpose of the pressure safety system is to protect the downstream system during incidental operation, i.e. in the event of failure of the pressure regulating system. The pressure safety system shall operate automatically and with a set pressure such that there is a low probability for the internal pressure at any point in the pipeline system to exceed the local incidental pressure.

Guidance note:
An annual probability for the pressure to exceed the maximum pressure of less than $10^{-4}$ is usually appropriate.

--- end of Guidance note ---

304 The set pressure of the pressure safety system, the maximum allowable incidental pressure, shall be such that the local incidental pressure is not exceeded at any point in the pipeline system. Due account shall be given to the tolerances of the pressure safety system. Hence, the maximum allowable incidental pressure is equal to the incidental pressure minus the pressure safety system operating tolerance.

305 The ratio between the incidental pressure and the design pressure, $\gamma_{inc}$, is normally 1.10 which also is the maximum allowed ratio. The local incidental pressure can be expressed as:

$$p_{inc} = p_d \cdot \gamma_{inc} = p_d \cdot \gamma_{inc} + \rho_{cont} \cdot g \cdot h$$

where

- $h$ is the height difference between the point and the reference point
- $\rho_{cont}$ is the density of the content of the pipeline

Provided that the requirements to the pressure safety system are satisfied, the incidental pressure to design pressure ratio, $\gamma_{inc}$, may be taken as less than 1.10, but minimum 1.05

306 A pressure safety system is not necessary if the pressure source to the pipeline cannot deliver a pressure in excess of the maximum incidental pressure. For the conditions given in Table 3-1, the given pressures shall be used as the incidental pressure.

--- end of Guidance note ---

### Table 3-1 Selection of incidental pressures for specific conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>$p_h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>When design pressure is equal to full shut-in pressure</td>
<td>$p_{d}$</td>
</tr>
<tr>
<td>System pressure test</td>
<td>$p_h$</td>
</tr>
</tbody>
</table>

307 The pipeline system may be divided into sections with different design pressures provided that the pressure control system ensures that, for each section, the local design pressure cannot be exceeded during normal operations and that the maximum incidental pressure cannot be exceeded during incidental operation.

308 When the pipeline system is connected to another system with different pressure definition, the conversion between the two system definitions shall be made based on the maximum incidental pressure.

C. Pipeline Route

C 100 Location

101 The pipeline route shall be selected with due regard to safety of the public and personnel, protection of the environment, and the probability of damage to the pipe or other facilities. Factors to take into consideration shall, at minimum, include the following:

- ship traffic;
- fishing activity;
- offshore installations;
- existing pipelines and cables;
- unstable seabed;
- subsidence;
- uneven seabed;
- turbidity flows;
- seismic activity;
- obstructions;
- dumping areas for waste, ammunition etc.;
- mining activities;
- military exercise areas;
- archaeological sites;
- exposure to environmental damage; and
- oyster beds.

102 Expected future marine operations and anticipated developments in the vicinity of the pipeline shall be considered when selecting the pipeline route.

C 200 Route survey

201 A survey shall be carried out along the planned pipeline route to provide sufficient data for design and installation related activities.

202 The survey corridor shall have sufficient width to define a pipeline corridor which will ensure safe installation and operation of the pipeline.

203 The required survey accuracy may vary along the proposed route. Obstructions, highly varied seabed topography, or special sub-surface conditions may dictate more detailed investigations.

204 An investigation to identify possible conflicts with existing and planned installations and possible wrecks and obstructions shall be performed. Examples of such installations include other submarine pipelines, and power and communication cables.

205 The results of the survey shall be presented on accurate route maps, showing the location of the pipeline and related facilities together with seabed properties and anomalies.
206 Special route surveys may be required at landfalls to determine:
    — environmental conditions caused by adjacent coastal features;
    — location of the landfall to facilitate installation; and
    — location to minimise environmental impact.

207 All topographical features which may influence the stability and installation of the pipeline shall be covered by the route survey, including but not limited to:
    — obstructions in the form of rock outcrops, large boulders, pock marks, etc., that could necessitate levelling or removal operations to be carried out prior to pipeline installation; and
    — topographical features that contain potentially unstable slopes, sand waves, deep valleys and erosion in the form of scour patterns or material deposits.

C 300 Seabed properties

301 Geotechnical properties necessary for evaluating the effects of relevant loading conditions shall be determined for the sea-bed deposits, including possible unstable deposits in the vicinity of the pipeline. For guidance on soil investigation for pipelines, reference is made to Classification Note No. 30.4 "Foundations".

302 Geotechnical properties may be obtained from generally available geological information, results from seismic surveys, sea bottom topographical surveys, and in-situ and laboratory tests. Supplementary information may be obtained from visual surveys or special tests, as e.g. pipe penetration tests.

303 Soil parameters of main importance for the pipeline response are:
    — shear strength parameters (intact and remoulded undrained shear strength for clay, and angle of friction for sands); and
    — relevant deformation moduli.

These parameters should preferably be determined from adequate laboratory tests or from interpretation of in-situ tests. In addition, classification and index tests should be considered, such as:
    — unit weight,
    — water content,
    — liquid and plastic limit,
    — grain size distribution,
    — carbonate content, and
    — other relevant tests.

304 It is primarily the characteristics of the upper few centimetres of soil that determine the response of the pipeline resting on the seabed. The determination of soil parameters for these very shallow soils may be relatively more uncertain than for deeper soils. Also the variations of the top soil between soil testing locations may add to the uncertainty. Therefore, soil parameters used in the design shall be defined with upper and lower limits. The characteristic value of a soil parameter used in the design shall be taken as the upper or lower value depending on which is more critical for the limit state in question.

305 In areas where the sea-bed material is subject to erosion, special studies of the current and wave conditions near the bottom including boundary layer effects may be required for the on-bottom stability calculations of pipelines and the assessment of pipeline spans.

306 Special investigation of the sea-bed material may be required to evaluate specific problems, as for example:
    — problems with respect to excavation and burial operations;
    — problems with respect to pipeline crossing;
    — problems with the settlement of pipeline system and/or the protection structure at the valve/tee locations;
    — possibilities of mud slides or liquefaction as the result of repeated loading, and
    — implications for external corrosion.

307 Pipeline components (e.g. valves, tees) in particular should not be located on the curved route sections of the pipeline.

D. Environmental Conditions

D 100 General

101 Effects of environmental phenomena relevant for the particular location and operation in question shall be taken into account. The principles and methods described in Classification Note No. 30.5 "Environmental Conditions and Environmental Loads" may be used as a basis for establishing the environmental conditions.

102 Environmental phenomena that might impair proper functioning of the system or cause a reduction of the reliability and safety of the system shall be considered, including:
    — wind,
    — tide,
    — waves,
    — internal waves and other effects due to differences in water density,
    — current,
    — ice,
    — earthquake,
    — soil conditions,
    — temperature, and
    — marine growth (fouling).

D 200 Collection of environmental data

201 The environmental data shall be representative for the geographical areas in which the pipeline system is to be installed. If sufficient data are not available for the geographical location in question, conservative estimates based on data from other relevant locations may be used.

202 For the assessment of environmental conditions along the pipeline route, the pipeline may be divided into a number of sections, each of which is characterised by a given water depth, bottom topography and other factors affecting the environmental conditions.

203 Environmental parameters shall be described using characteristic values based on statistical data or long-term observations.

204 Statistical data shall be utilised to describe environmental parameters of a random nature (e.g. wind, waves). The parameters shall be derived in a statistically valid manner using recognised methods.

205 The effect of statistical uncertainty due to the amount and accuracy of data shall be assessed and, if significant, shall be included in the evaluation of the characteristic load effect.

D 300 Wind

301 Wind effects shall be considered in the design of risers, including the possibility of wind induced vibrations of exposed free spans. Consideration shall be given to wind actions occurring in the construction phase.

302 For a riser adjacent to other structural parts, possible effects due to disturbance of the flow field shall be considered when determining the wind actions. Such effects may cause an increased or reduced wind speed, or a dynamic excitation by vortices being shed from adjacent structural parts.
D 400 Tide

401 Tide effects shall be considered when the water depth is a significant parameter, e.g. for the establishment of wave actions, planning of the pipe lay operation particularly near shore approaches/landfalls, determination of maximum or minimum water pressure, etc.

402 The assumed maximum tide shall include both astronomic tide and storm surge. Minimum tide estimates should be based upon the astronomic tide and possible negative storm surge.

D 500 Waves

501 The wave data to be used in the design of risers are in principle the same as the wave data used in the design of the offshore structure supporting the riser.

502 Direct and indirect wave effects shall be taken into consideration for both riser and pipeline.

Guidance note:

Examples of direct wave effects include the wave action on a riser, and on a pipeline during installation or when resting on the sea bottom. Examples of indirect wave effects include the imposed deformations on a riser via the riser supports due to wave induced platform displacements, and the movements of a pipeline during the laying operation caused by the lay vessel motions.

---end of Guidance note---

503 The wave theory used shall be capable of describing the wave kinematics at the particular water depth in question.

504 Consideration shall be given to wave refraction and shoaling, shielding, and reflecting effects.

505 Where the riser or pipeline is positioned adjacent to other structural parts, possible effects due to disturbance of the flow field shall be considered when determining the wave actions. Such effects may cause an increased or reduced velocity, or dynamic excitation by vortices being shed from the adjacent structural parts.

506 Where appropriate, consideration should be given to wave direction and short crestedness.

D 600 Current

601 The effect of current shall be taken into consideration for both riser and pipeline.

602 Current velocities shall include contributions from tidal current, wind induced current, storm surge current, density induced current, and other possible current phenomena. For near-shore regions, long-shore current due to wave breaking shall be considered.

603 For pipelines during installation and for in-place risers, the variations in current velocity magnitude and direction as a function of water depth shall be considered. For risers, the current velocity distribution should be the same as the one used in the design of the offshore structure supporting the riser.

D 700 Ice

701 For areas where ice may develop or drift, consideration shall be given to possible effects, including:

— ice forces on the pipeline system,
— impacts from drifting ice,
— sea-bed scouring, and
— ice problems during construction and installation, increased wave loading due to increased diameter.

D 800 Air and sea temperatures

801 Air and sea temperature statistics shall be provided giving representative design values. Minimum and maximum design temperatures should preferably be based upon an observation period of several years.

802 Monitoring of temperature may be required during construction, installation and commissioning phases if the effect of temperature or temperature variations has a significant impact on the safety of the pipeline system.

D 900 Marine growth

901 The effect of marine growth on pipeline systems shall be considered, taking into account both biological and other environmental phenomena relevant for the location.

902 The estimation of hydrodynamic loads on pipelines subject to accumulated marine growth shall account for the increase in effective diameter and surface roughness.

---end---of---Guidance---note---

E. External and Internal Pipe Condition

E 100 External operational conditions

101 For the selection and detailed design of external corrosion control, the following conditions relating to the environment shall be defined, in addition to those mentioned in D.102 above:

— exposure conditions, e.g. burial, rock dumping, etc.; and
— sea water and sediment resistivity.

102 Other conditions affecting external corrosion which shall be defined are:

— maximum and average operating temperature profile along the pipeline and through the pipe wall thickness;
— pipeline fabrication and installation procedures;
— requirements for mechanical protection, submerged weight and thermal insulation during operation;
— design life.

E 200 Internal installation conditions

201 A description of the internal pipe conditions during storage, construction, installation, pressure testing and commissioning shall be prepared. The duration of exposure to sea water or humid air, and the need for using inhibitors or other measures to control corrosion shall be considered.

E 300 Internal operational conditions

301 In order to assess the need for internal corrosion control, including corrosion allowance and provision for inspection and monitoring, the following conditions shall be defined:

— maximum and average operating temperature/pressure profile along the pipeline, and expected variations during the design life;
— flow velocity and flow regime;
— fluid composition (initial and anticipated variations during the design life) with emphasis on potentially corrosive components (e.g. hydrogen sulphide, carbon dioxide, water content and expected content of dissolved salts in produced fluids, residual oxygen and active chlorine in sea water);
— chemical additions and provisions for periodic cleaning;
— provision for inspection of corrosion damage and expected capabilities of inspection tools (i.e. detection limits and sizing capabilities for relevant forms of corrosion damage); and
— the possibility of erosion by any solid particles in the fluid shall be considered. Reference is made to RP O501 "Erosive Wear in Piping Systems", 1996.
F. Documentation

F 100 General

101 This section specifies the requirements for documentation of pipeline design, manufacturing / fabrication, installation / commissioning and operation.

102 All documentation requirements shall be reflected in a document register. The documentation shall cover design, manufacturing, fabrication, installation and commissioning. As a minimum, the register shall reflect activities from the start of design to start-up of the pipeline system.

103 The documentation shall be submitted to the relevant parties for acceptance or information as agreed.

F 200 Conceptual and detail engineering

Structural

201 A design basis for a pipeline system shall be established, including, but not limited to:

— all items listed in A.202;
— topographical and bathymetrical conditions along the intended pipeline route;
— geotechnical conditions;
— environmental conditions;
— operational conditions such as pressure, temperature, fluid components, flow rate, etc.;
— principles for strength and in-place analysis, and
— corrosion control philosophy.

202 The design shall be adequately documented to enable second and/or third party verification. As a minimum, the following items shall be addressed:

— pipeline routing;
— physical and chemical characteristics of fluid;
— materials selection (linepipe and pipeline components);
— temperature/pressure profile and pipeline expansion;
— strength analyses for riser and riser supports;
— strength and in-place stability analyses for pipeline;
— risk analysis as applicable;
— corrosion control (internal and external); and
— installation and commissioning.

203 Drawings shall be provided for the fabrication and installation of the pipeline system, including but not limited to:

— pipeline route drawings including information on, e.g. seabed properties and topology, existing and future platforms, pipelines/cables, subsea well heads, ship lanes, etc.;
— detailed pipeline crossing drawings;
— platform layout drawings with risers, riser protection systems, loading zones, boat landing areas, rescue areas, etc. as applicable;
— spool fabrication drawing;
— pipeline protection drawings; and
— riser and riser clamp fabrication drawings.

Linepipe and pipeline components

204 The following documentation shall be prepared:

— material manufacturing specifications, and
— material take off/data sheets.

Corrosion control systems and weight coating

205 The following documentation shall be prepared, as applicable:

— cathodic protection design report,
— anode manufacturing and installation specifications,
— coating manufacturing specifications,
— field joint coating specification(s),
— corrosion monitoring system specification, and
— material take off/data sheets.

Installation

206 The following documentation shall be prepared:

— Failure Mode Effect Analysis (FMEA) and HAZOP studies;
— installation and testing specifications and drawings;
— Installation Manuals (IM);
— welding procedure specifications/qualification;
— records;
— operational procedures; and
— contingency procedures.

F 300 Linepipe and pipeline component manufacturing

301 The documentation to be submitted for review prior to start or during start-up of manufacturing shall include, but not be limited to:

— Manufacturing Procedure Specification (MPS);
— manufacturing procedures, including test requirements and acceptance criteria, repairs, personnel qualification records, etc.;
— material specifications;
— Quality Plans;
— Welding Procedure Specifications (WPS) /Welding Procedure Qualification Records (WPQR);
— NDT procedures;
— Manufacturing Procedure Qualification Test (MPQT) results; and
— Manufacturer's/fabricator's quality system manual.

302 The as built documentation to be submitted after manufacturing shall include but not be limited to:

— manufacturing procedures, including test requirements and acceptance criteria, repairs, personnel qualification records, etc.;
— material certificates;
— production test records (visual, NDT, tests on samples, dimensional, heat treatment, etc.);
— hydrostatic testing report;
— complete statistics of chemical composition, mechanical properties and dimensions for the quantity delivered;
— weld log records.

F 400 Corrosion control system and weight coating manufacturing

401 The documentation to be submitted for review prior to start of manufacturing shall include:

— manufacturing procedures, including inspection/test requirements and acceptance criteria, repairs, documentation, etc.;
— documentation of materials and concrete mix design;
— Manufacturing Procedure Qualification Tests results;
— quality plan with referenced procedures for inspection, testing and calibrations; and
— outline drawing of anodes.

402 The as built documentation to be submitted after manufacturing shall include, but not be limited to:

— manufacturing procedures, including test requirements and acceptance criteria, repairs, personnel qualification records, etc.;
— material certificates;
— production test records;
— complete statistics of coating dimensions, weight and negative buoyancy for the each joint delivered;
— repair log; and
— electrical resistance test log.
F 500 Installation and commissioning

501 The documentation to be submitted for review prior to start of installation shall include but not be limited to:

- installation procedures, including acceptance criteria, test certificates for equipment, qualification records for personnel (e.g. welding, coating), etc.;
- trenching specification;
- intervention procedure;
- commissioning procedure;
- survey procedure;
- procedure for installation of protective and anchoring structures; and
- procedure for installation of risers and spools.

502 The as built documentation to be submitted after installation and commissioning shall include, but not be limited to:

- records;
- survey reports;
- intervention reports; and
- commissioning reports.

F 600 DFI Résumé

601 A DFI Résumé shall be prepared to provide information for operation of the pipeline system and for preparation of plans for periodic inspection. The DFI Résumé shall contain all documentation required for normal operation, ROV surveys and maintenance and provide references to the documentation needed for any repair, modification or re-qualification of the pipeline system.

602 Documentation referred to in the DFI Résumé shall be kept for the lifetime of the pipeline system and shall be easily retrievable at any time.

603 As a minimum, the DFI Résumé shall contain the following:

- brief description of the pipeline system;
- design basis including design life, conditions along the pipeline route, environmental and geotechnical conditions, pressure, flow rate, design temperature, design pressure, incidental pressure, corrosion allowance, fluid composition, etc;
- relevant design assumptions and conditions including applicable limitations;
- any special requirements affecting safety or reliability found during design, fabrication or installation phases;
- design resume including reference to and description of analyses from the design phase, evaluation of critical or problem areas, highly utilised and critical areas of the system and highlighting points that require special attention during subsequent phases;
- reference to accepted calculations and other documents verifying compliance with governing technical requirements for all temporary and permanent phases;
- fabrication resume giving a summary description of the manufacturing/fabrication history, reference to specifications, drawings etc., discussion of problem areas, deviations from specifications and drawings, of importance for the operational phase;
- drawings and photos of special components;
- installation resume giving a summary description of the installation history, reference to specifications, drawings etc., discussion of problem areas, deviations from specifications and drawings, of importance for the operational phase;
- as-installed route drawings;
- identification of waivers and deviations from the governing technical requirements; and
- identification of areas deemed to require special attention during normal operation and maintenance of the pipeline system.

F 700 Operation

701 In order to carry out the periodical surveys, the minimum documentation shall include:

- personnel responsible for the operation of pipeline system;
- history of pipeline system operation with reference to events which may have significance to design and safety;
- installation condition data as necessary for understanding pipeline system design and configuration, e.g. previous survey reports, as-laid / as-built installation drawings and test reports;
- physical and chemical characteristics of transported media and sand detection facilities (if any);
- inspection and maintenance schedules and their records;
- inspection procedure and results covering the inspection aspects described in Section 10, including supporting records such as diver survey reports and video films.

702 In case of mechanical damage or other abnormalities that might impair the safety, reliability, strength and stability of the pipeline system, the following documentation shall, as a minimum, be prepared prior to start-up of the pipeline:

- description of the damage to the pipeline, its systems or components with due reference to location, type, extent of damage and temporary measures, if any;
- plans and full particulars of repairs, modifications and replacements, including contingency measures; and
- further documentation with respect to particular repair, modification and replacement, as agreed upon in line with those for the construction or installation phase.

F 800 Filing of documentation

801 Maintenance of complete files of all relevant documentation during the life of the pipeline system is the responsibility of the owner.

802 The engineering documentation shall be filed by the Owner or by the engineering Contractor for a minimum of 10 years. Design basis and key data for the pipeline system shall by filed for the lifetime of the system. This includes documentation from design to start-up and also documentation from possible major repair or re-construction of the pipeline system.

803 Files to be kept from the operational and maintenance phases of the pipeline system shall, as a minimum, include final in-service inspection reports from start-up, periodical and special inspections, condition monitoring records, and final reports of maintenance and repair, see Section 10.
SECTION 4
LOADS

A. General

A 100 Objective

101 This section defines the load conditions and characteristic load effects to be used in the design of pipeline systems, for both the construction and operational phase.

102 The loads are classified into different load categories. The aim of the load classification is to relate the load effect to the different uncertainties and occurrences.

Guidance note:
The load classification is closely linked with the adopted LRFD format. An environmental load classification is more conservative than a functional load classification, due to the higher load factor. This is in contradiction with normally applied ASD formats.

---end-of-Guidance note---

A 200 Application

201 This section describes the loads to be applied in the adopted LRFD criteria.

A 300 Loads

301 Loads shall be classified as follows:

— functional loads;
— environmental loads;
— construction loads, subdivided into functional and environmental; and
— accidental loads.

302 Simplified methods or analyses may be used to calculate the load effects provided that they are conservative. Model tests may be used in combination with, or instead of, theoretical calculations. In cases where theoretical methods are inadequate, model or full-scale tests may be required.

B. Functional Loads

B 100 General

101 Loads arising from the physical existence of the pipeline system and its intended use shall be classified as functional loads.

102 All functional loads which are essential for ensuring the integrity of the pipeline system, during both the construction and the operational phase, shall be considered.

103 Effects from the following phenomena are the minimum to be considered when establishing functional loads:

— weight;
— external hydrostatic pressure;
— temperature of contents;
— reactions from components (flanges, clamps etc.);
— cover (e.g. soil, rock, mattresses);
— internal pressure during normal operation;
— reaction from sea floor (friction and rotational stiffness);
— pre-stressing;
— permanent deformation of supporting structure;
— permanent deformations due to subsidence of ground, both vertical and horizontal;
— possible loads due to ice bulb growth around buried pipelines near fixed points (in-line valves/tees, fixed plants etc.), caused by cooling of the contained gas/liquid; and
— loads induced by frequent pigging operations.

104 The weight shall include weight of pipe, buoyancy, contents, coating, anodes, marine growth and all attachments to the pipe.

105 The soil pressure acting on buried pipelines shall be taken into account if significant.

106 End cap forces due to pressure shall be considered, as well as any transient pressure effects during normal operation (e.g. due to closure of valves).

107 Fluctuations in temperature shall be taken into account when checking fatigue strength.

108 Pre-stressing, such as permanent curvature or a permanent elongation introduced during installation, shall be taken into account if the capacity to carry other loads is affected by the pre-stressing. Pretension forces induced by bolts in flanges, connectors and riser supports and other permanent attachments, shall be classified as functional loads.

B 200 Characteristic load effects

201 The characteristic functional load effect should be defined as the most probable maximum value in considered time period.

202 In cases where external pressure increases the capacity, the external pressure shall not be taken as higher than the water pressure at the considered location corresponding to low tide.

203 In cases where the external pressure decreases the capacity, the external pressure shall not be taken as less than the water pressure at the considered location corresponding to high tide.

204 Design pressure and maximum or minimum design temperature (whichever is more conservative) shall be used in all calculations for operational condition, except for the following situations when normal operating pressure and normal operating temperature may be used:

— fatigue analyses, and
— environmental load dominated situations.

Guidance note:
For pressure, the local design pressure shall be used except for when normal operating pressure is referred to, when the beneficial effect of the steady flow pressure profile should be used.

Regarding temperature, the "local" max (min) design temperature, i.e. the temperature profile corresponding to maximum (minimum) design temperature based on conservative insulation values, shall be used. The corresponding temperature profile for normal operating temperature should be used when this is referred to.

---end-of-Guidance note---

C. Environmental Loads

C 100 General

101 For calculation of characteristic environmental loads, reference is made to the principles given in Classification Note No. 30.5, "Environmental Conditions and Environmental Loads".

102 Environmental loads are defined as those loads on a pipeline system which are caused by the surrounding environment, and that are not otherwise classified as functional or ac-
cidental loads.

103 Trawl gear loads shall be classified in accordance with the requirements in F below.

C 200 Wind loads

201 Wind loads shall be determined based on available wind data using recognised theoretical principles. Alternatively, direct application of data from adequate tests may be used.

202 The possibility of vibrations and instability due to wind induced cyclic loads shall be considered (e.g. vortex shedding).

C 300 Hydrodynamic loads

301 Hydrodynamic loads are defined as flow-induced loads caused by the relative motion between the pipe and the surrounding water. When determining the hydrodynamic loads, the relative liquid particle velocities and accelerations used in the calculations shall be established, taking into account contributions from waves, current and pipe motions if significant.

302 The following hydrodynamic loads shall be considered, but not limited to:

— drag and lift forces which are in phase with the absolute or relative water particle velocity,
— inertia forces which are in phase with the absolute or relative water particle acceleration,
— flow-induced cyclic loads due to vortex shedding and other instability phenomena,
— impact loads due to wave slaming and slapping, and
— buoyancy variations due to wave action.

C 400 Wave and current loads

401 Wave-and current induced loads acting on a submerged pipe section shall be calculated according to recognised methods.

402 Data from model testing or acknowledged industry practice may be used in the determination of the relevant hydrodynamic coefficients.

403 The current-induced drag and lift forces on risers and pipelines shall be determined and combined with the wave-induced forces using recognised theories for wave-current interaction. A vector combination of the current and wave-induced water particle velocities may be used. If available, however, calculation of the total particle velocities and accelerations based upon more exact theories on wave-current interaction is preferable.

404 If the riser is built up of a number of closely spaced pipes, then interaction and solidification effects shall be taken into account when determining the mass and drag coefficients for each individual pipe or for the whole bundle of pipes. If sufficient data is not available, large-scale model tests may be required.

405 For pipelines on or close to a fixed boundary (e.g. pipeline spans) or in the free stream (e.g. risers), lift forces perpendicular to the axis of the pipe and perpendicular to the velocity vector shall be taken into account.

406 Possible influence of adjacent structural parts shall be taken into account when determining the wave and current loads. The increased accelerations and flow velocities in the flow around a cylinder, e.g. jacket leg/member or columns, can lead to additional forces on the risers and riser supports.

407 In connection with vortex shedding-induced transverse vibrations, the increase in drag coefficient shall be taken into account.

408 The effect of possible wave and current loading on a riser system in the air gap zone shall be included.

Guidance note:
Maximum wave load effects may not always be experienced during the passing of the design wave. The maximum wave loads may be due to waves of a particular length, period or steepness. The initial response to impulsive wave slam or slap usually occurs before the exposed part of the pipeline system is significantly immersed. Therefore, other fluid loading on the system need not normally be applied with the impulsive load. However, due to structural continuity of the riser, global wave loading on other parts of the system must be considered in addition to the direct wave loading.

Wave slam occurs when an approximately horizontal member is engulfed by a rising water surface as a wave passes. The highest slaming forces occur for members at mean water level and the slam force directions are close to the vertical.

Wave slap is associated with breaking waves and can affect members at any inclination, but in the plane perpendicular to the wave direction. The highest forces occur on members above mean water level.

Both slam and slap loads are applied impulsively (over a short instant of time) and the dynamic response of the pipeline system shall be considered.

409 Parts of the pipeline system, located above the normal wave impact zone, may be exposed to wave loading due to wave run-up. Loads due to this effect shall be considered if relevant.

C 500 Ice loads

501 In areas where ice may develop or drift, the possibility of ice loads on the pipeline system shall be considered. Such loads may partly be due to ice frozen on the pipeline system itself, and partly due to floating ice. For shore approaches and areas of shallow water, the possibility of ice scouring and impacts from drifting ice shall be considered.

502 In case of ice frozen to above-water parts of the system, (e.g. due to sea spray) the following forces shall be considered:

— weight of the ice,
— impact forces due to thaw of the ice,
— forces due to expansion of the ice, and
— increased wind and wave forces due to increased exposed area.

503 Forces from floating ice shall be calculated according to recognised theory. Due attention shall be paid to the mechanical properties of the ice, contact area, shape of structure, direction of ice movements, etc. The oscillating nature of the ice forces (built-up of lateral force and fracture of moving ice) shall be taken into account in the structural analysis. When forces due to lateral ice motion will govern structural dimensions, model testing of the ice-structure interaction may be required.

C 600 Characteristic load effects

601 For each load and design condition the most unfavourable relevant combination, position and direction of simultaneously acting loads shall be used in documenting the integrity of the complete pipeline system.

602 The characteristic environmental load during installation of the pipeline system shall be taken as the most probable largest value in a given sea-state for the considered period defined by $(H_s, T_p)$ and appropriate current and wind conditions. The characteristic load effect is defined as the most probable largest load effect, (i.e. from wave, current and wind) $L_E$, given by:

$$F(L_E) = 1 - \frac{1}{N}$$  \hspace{1cm} (4.1)

where:

$F(L_E)$ is the probability distribution function of $L_E$

Guidance note:
—e-n-d--o-f-G-u-i-d-a-n-c-e--n-o-t-e--
$N$ is the number of load effect cycles in a sea-state of a duration not less than 3 hours.

**Guidance note:**

The given sea state for the considered period may be interpreted as the sea state for the relevant location and installation period. Normal requirement is that the length of the period shall be sufficiently long in order to include possible delays. The installation period shall not exceed this time period.

---end-of-Guidance-note---

603 The characteristic combined environmental load effect for operational conditions, shall be taken as a value having a $10^{-2}$ probability of exceedance in a period of one year. When the correlation among the different load components (i.e. wind, wave, current or ice) are unknown, the load combinations (simultaneously acting loads) in Table 4-1 apply.

<table>
<thead>
<tr>
<th>Table 4-1</th>
<th>Combinations of characteristic environmental loads in terms of annual exceedance probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Waves</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>

604 For the on-bottom pipeline in temporary conditions the characteristic combined environmental load effect should be taken as follows:

— for a time period less than 3 days, the characteristic load effects may be based on reliable weather forecasts, and
— for the on-bottom pipe in temporary conditions, a 10 year return period value for the considered time period shall be applied. The relevant time period is not to be taken less than a season (3 months). If the joint distribution for environmental loads is unknown, the combined characteristic load may be taken from a table similar to that for operation.

**Guidance note:**

"Similar to that for operation" implies, e.g. '10 year wave + 1 year current' or '1 year wave + 10 year current'.

---end-of-Guidance-note---

### D. Construction Loads

**D 100 General**

101 Loads which arise as a result of the construction of the pipeline system, comprising installation, pressure testing, commissioning, maintenance and repair, shall be classified into functional and environmental loads.

102 All significant loads acting on pipe joints or pipe sections during transport, fabrication, installation, maintenance and repair activities shall be considered.

103 Functional Loads shall consider forces generated due to imposed tension during pipeline installation, maintenance and repair.

104 Environmental loads shall consider forces induced on the pipeline due to wind, waves and current, including deflections and dynamic loads due to vessel movement.

105 Accidental loads shall consider inertia forces due to sudden waterfilling, excessive deformation in overbend and sag-bend, and forces due to operation errors or failures in equipment that could cause or aggravate critical conditions, see Section 9A 300.

106 Other loads to be considered are:

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### E. Accidental Loads

**E 100 General**

101 Loads which are imposed on a pipeline system under abnormal and unplanned conditions shall be classified as accidental loads.

102 The main criteria for classifying a load as accidental is the probability of occurrence in line with Section 5D 1200.

103 Typical accidental loads can be caused by:

— vessel impact or other drifting items (collision, grounding, sinking);
— dropped objects;
— mud slides;
— explosion;
— fire and heat flux;
— operational malfunction; and
— dragging anchors.

104 Size and frequency of accidental loads, for a specific pipeline system, may be defined through risk analyses.

### F. Other loads

**F 100 Trawling loads**

101 For calculation of characteristic trawling loads, reference is made to the principles given in the Guideline 13: "In-
The requirement for designing pipelines for trawling loads shall be determined based upon trawling frequency studies and assessment of the potential damage due to trawling, in order to ensure that the integrity of the pipeline is not compromised.

Trawling loads may be imposed either by trawl boards or trawl beams depending on what is the preferred fishing tool in the area.

Fishing gear and hence trawl loads may vary significantly, not only between pipeline systems, but also along a pipeline system. Trawl loads will depend on the type, mass, velocity, warp line (line stiffness, catenary effects, and line length) and size of the trawl board or beam. Variations in pipeline supporting conditions along the pipeline route will also have varying response to trawling gear.

The following trawling data shall be determined:

- the maximum trawling equipment size normally used in the area;
- future trends (new types, (gear) mass, trawling velocity, shape); and
- the frequency of the trawling activity in the area.

The trawling load effects can be divided in accordance with the three crossing phases:

a) **Trawl impact**, i.e. the initial impact from the trawl board or beam which may cause local dents on the pipe or damage to the coating. This should be classified as an environmental load.

b) **Over-trawling**, often referred to as pull-over, i.e. the second phase caused by the wire and trawl board or beam sliding over the pipe. This will usually give a more global response of the pipeline. This should be classified as an environmental load.

c) **Hooking**, i.e. the trawl board is stuck under the pipe and in extreme cases, forces as large as the breaking strength of the trawl wire are applied to the pipeline. This should be classified as an accidental load.

The impact energy shall be determined considering, as a minimum:

- the trawl board or trawl beam mass and velocity, and
- the effective added mass and velocity.

Load effects imposed by earthquake, either directly or indirectly, shall be classified into accidental or environmental loads, depending on the probability of earthquake occurrence in line with accidental loads in Section 5D 1200.
SECTION 5
DESIGN CRITERIA

A. General

A 100 Objective

101 The purpose of this section is to provide design and acceptance criteria for the possible modes of structural failure in pipeline systems.

A 200 Application

201 This standard includes no limitations on water depth. However, when this standard is applied in deep water where experience is limited, special consideration shall be given to:

- other failure mechanisms,
- validity of parameter range,
- other characteristic loads and load combinations, and
- dynamic effects.

202 This standard does not specify any explicit limitations with respect to elastic displacements or vibrations, provided that the effects of large displacements and dynamic behaviour, including fatigue effect of vibrations, operational constraints and ratcheting, are taken into account in the strength analyses.

203 Special considerations shall be made for parts of the pipeline system which extend onshore. These shall typically include aspects such as:

- population density,
- personnel,
- traffic,
- corrosion, and
- fracture arrest.

This may require a higher safety level than reflected by the safety classes.

204 For spiral welded pipes, the following requirements apply:

- when supplementary requirement F (fracture arrest properties) is required, the possibility for a running fracture to continue from a weld in one pipe joint to the weld of the next pipe joint shall be assessed;
- external pressure resistance should be documented; and
- the design shall be based on the load controlled condition unless the feasibility for use of displacement controlled condition can be documented.

Guidance note:
The limitations to fracture arrest and load controlled condition are due to limited experience with spiral welded pipes subjected to running fracture or large strains.

---end-of-Guidance-note---

B. Design Principles and Materials

B 100 Pipeline layout

101 A pipeline should not be located close to other structures, other pipeline systems, wrecks, boulders, etc. The minimum distance should be determined based upon anticipated deflections, hydrodynamic effects, and upon risk-based evaluations. Wherever a pipeline system is located close to other structures, pipeline systems, wrecks, large boulders, etc., the detailed routing shall take into account possible deflections, movements and other risks to ensure a sufficient separation and margin against interference.

102 Crossing pipelines should be kept separated by a minimum vertical distance of 0.3 m.

103 Pipelines shall be protected against unacceptable damage caused by e.g. dropped objects, fishing gear, ships, anchoring etc., and the location of pipelines inside the loading zones of platforms should be avoided. Protection may be achieved by one or a combination of the following means:

- concrete coating,
- burial,
- cover (e.g. sand, gravel, mattress), and
- other mechanical protection.

104 Relative settlement between the protective structure and the pipeline system shall be properly assessed in the design of protective structures, and shall cover the full design life of the pipeline system. Adequate clearance between the pipeline components and the members of the protective structure shall be provided to avoid fouling.

105 Pipelines in C-Mn steel for potentially corrosive fluids of categories B, D and E should be designed for inspection pigging. In cases where the pipeline design does not allow inspection pigging, an analysis shall be carried out in accordance with recognised procedures to document that the risk of failure (i.e. the probability of failure multiplied by the consequences of failure) leading to a leak is acceptable. For corrosive fluids of other categories the benefit of inspection pigging on operational reliability shall be evaluated.

106 A pipeline may be divided into sections having different design pressure. The pipeline system shall in such cases be equipped with an adequate pressure control system, to ensure that the section or sections with a lower design pressure are not subjected to pressure above the allowable.

107 Risers and J-tubes should be routed inside the structure to avoid vessel impact, and shall be protected against impact loads from vessels and other mechanical interaction. Risers should not be located inside the loading zones of platforms.

108 Riser and J-tube supports shall be designed to ensure a smooth transition of forces between riser and support.

109 The routing of J-tubes shall be based on the following considerations:

- platform configuration and topsides layout,
- space requirements,
- movements of the J-tube,
- cable/pipeline approach,
- J-tube protection,
- in-service inspection and maintenance, and
- installation considerations.

B 200 Mill pressure test and system pressure test

201 The purposes of the mill test requirement are:

- to constitute a pressure containment proof test, and
- to ensure that all pipe sections have at least a minimum Yield stress.

Therefore, the mill test pressure is defined in terms of stress utilisation, rather than related to the design pressure.

202 With exception of 203, the pipeline system shall be system pressure tested after installation. The local test pressure (plt) during the system pressure test shall fulfil the following requirement:
Normal and High Safety Class during normal operation:

\[ p_{lt} = 1.05p_{li} \]  \hspace{1cm} (5.1)

Low Safety Class during normal operation:

\[ p_{lt} = 1.03p_{li} \]  \hspace{1cm} (5.2)

**Guidance note:**

Normally, i.e. with an incidental pressure of 10% above design pressure, the above gives a system test pressure of approximately 1.15 times the design pressure, given that the design pressure is referenced to the highest point of the pipeline system.

---end--of---Guidance---note---

**B 500 Materials selection**

**501** Materials for pipeline systems shall be selected with due consideration of the fluid to be transported, loads, temperature and possible failure modes during installation and operation. The selection of materials shall ensure compatibility of all components of the pipeline system. The following material characteristics shall be considered:

- mechanical properties,
- hardness,
- fracture toughness,
- fatigue resistance,
- weldability, and
- corrosion resistance.

**502** Materials selection shall include identification of the following supplementary requirements as required:

- supplementary requirement S, sour service;
- supplementary requirement F, fracture arrest properties;
- supplementary requirement P, linepipe exposed to plastic deformation exceeding 2%;
- supplementary requirement U, increased utilisation; and
- supplementary requirement D, more stringent dimensional requirements.

The supplementary requirements are given in Section 6D.

**503** Materials selection shall include the selection of linepipe NDT Level, see B 600. Linepipe NDT Level I is required for use of displacement controlled condition local buckling criteria (strain based design).

**504** Under conditions when water, oxygen and chloride can be present in the fluid, e.g. water injection, stainless steels can be susceptible to both localised corrosion and environmentally assisted cracking, and hence the corrosion resistance shall be considered for each specific application. For special applications, corrosion testing shall be performed to qualify the material for the intended application.

**505** Routing of well stimulation fluids through duplex or martensitic stainless steel pipeline systems requires special precautions.

**506** Special precautions are required to avoid corrosion damage to CRA pipelines, during system pressure testing using seawater.

**507** Duplex and martensitic stainless steel linepipe, and C-Mn steel linepipe with SMYS > 450 MPa require special considerations of the susceptibility of environmentally assisted cracking (including SSC and hydrogen induced cracking related to cathodic protection). In particular this applies to material subjected to significant plastic straining during fabrication, installation and operation.

**Guidance note:**

Linepipe NDT level I gives more stringent requirement to NDT than NDT level II.

The strength factor is 4% higher for supplementary requirement U, usually giving approximately 4% less material.
The relationship between the different material requirements and design is illustrated in the table below.

| Design resistance utilisation as function of NDT level and supplementary requirement U |
|------------------------------------------|---------|---------|---------|---------|---------|
| Linepipe NDT level                      | I       | II      | I       | II      |
| Supplementary req. U                   | Yes     | No      | Yes     | No      |
| Pressure containment                    | High    | Low     | High    | Low     |
| Load controlled buckling               | High    | Low     | High    | Low     |
| Displacement controlled bucking        | High    | Low     | N/A     |         |

Notes to table:
1) High and Low in the above table refers to the allowable utilisation.
2) Load controlled condition and displacement controlled condition are defined in C 100.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

B 600 Characteristic material properties

601 Characteristic material properties shall be used in the resistance calculations. The yield stress and tensile strength shall be based on the engineering stress-strain curve.

602 Supplementary requirement U ensures increased confidence in yield stress, which is reflected in a higher material strength factor, given in Table 5-1. The design strength is a function of this value and is given in 604.

Table 5-1 Material Strength factor, $\alpha_U$

<table>
<thead>
<tr>
<th>Factor</th>
<th>Normal</th>
<th>Supplementary requirement U</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_U$</td>
<td>0.96</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Note: For system pressure test, $\alpha_U$ shall be equal to 1.00, which gives an allowable hoop stress of 96% of SMYS both for materials fulfilling supplementary requirement U and those not.

603 The different material grades refer to mechanical properties at room temperature. Possible temperature effects on the material properties shall be considered at temperatures above 50°C, for C-Mn steel, and above 20°C for 22Cr and 25Cr. These properties shall be selected with due regard to material type and potential temperature-ageing effects and shall include:

- yield stress,
- tensile strength,
- Young’s modulus, and
- temperature expansion coefficient.

Guidance note:
Field joint coating application during installation may also impose temperatures in excess of the above and hence shall be considered.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

604 The characteristic material strength values to be used in the limit state criteria are given in Table 5-2.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Table 5-2 Characteristic material strength, $f_y$, $f_u$

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic yield stress</td>
<td>$f_y = (SMTS - f_{y, temp}) \cdot \alpha_U$</td>
</tr>
<tr>
<td>Characteristic tensile strength</td>
<td>$f_u = (SMTS - f_{u, temp}) \cdot \alpha_U \cdot \alpha_A$</td>
</tr>
</tbody>
</table>

Where:

- $f_{y, temp}$ and $f_{u, temp}$ is the derating value due to the temperature of the yield stress and the tensile strength respectively.
- $\alpha_U$ Material strength factor, ref. Table 5-1
- $\alpha_A$ Anisotropy factor,
  - $= 0.95$ for axial direction (i.e. $\alpha_c$ of Eq. (5.23)) due to relaxed testing requirements in linepipe specification (ref. Table 6-3),
  - Note 4
  - $= 1.0$ for other cases.

Guidance note:
If no other information on de-rating effects of the yield stress exists, the recommendations for C-Mn steel, 22Cr Duplex or 25Cr Duplex stainless steel in Figure 5-1 below may be used.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

605 Any difference in the de-rating effect of temperature for tension and compression shall be accounted for.

Guidance note:
Difference in de-rating effect for tension and compression has been experienced on 13% Cr steel material.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

606 For fabrication processes which introduce cold deformations giving different strength in tension and compression, a fabrication factor, $\alpha_{fab}$, shall be determined. If no other information exists, maximum fabrication factors for pipes manufactured by the UOE or UO processes are given in Table 5-3. These factors also apply to other fabrication processes which introduce similar cold deformations such as three roll bending (TRB).

The fabrication factor may be improved through heat treat-
B 700 Corrosion allowance

701 For C-Mn steel pipelines carrying potentially corrosive fluids and/or exposed to an external corrosive environment without cathodic protection, the use of an extra wall thickness to compensate for any corrosive degradation during operation ("corrosion allowance") shall be duly considered, (see also Section 8).

**Guidance note:**
A corrosion allowance is primarily used to compensate for forms of corrosion attack affecting the pipeline's pressure containment resistance, i.e. uniform attack and, to a lesser extent, corrosion damage as grooves or patches. However, a corrosion allowance may also enhance the operational reliability and increase the useful life if corrosion damage occurs as isolated pits; although such damage is unlikely to affect the pipeline's resistance, it will cause a pinhole leak when the full wall thickness is penetrated. However, the extra wall thickness will only delay leakage in proportion to the increase in wall thickness.

---end--of--G-u-i-d-a-n-c-e---n-o-t-e---

702 The needs for, and benefits of, a corrosion allowance shall be evaluated, taking into account the following factors as a minimum:

- design life and potential corrosivity of fluid and/or external environment;
- expected form of corrosion damage (see Guidance note above);
- expected reliability of planned techniques and procedures for corrosion mitigation (e.g. chemical treatment of fluid, external coating, etc.);
- expected sensitivity and damage sizing capability of relevant tools for integrity monitoring, time to first inspection and planned frequency of inspection;
- consequences of sudden leakage, requirements to safety and reliability; and
- potential for down-rating (or up-rating) of operating pressure.

703 Unless a sudden leakage of fluid is acceptable (may apply for pipelines of safety class Low), the magnitude of a corrosion allowance shall be sufficient to accommodate any realistic corrosive degradation that may occur in the period between two consecutive inspections for integrity monitoring (see Section 10).

704 Pipelines of safety class Normal and High in C-Mn steel carrying hydrocarbon fluids likely to contain liquid water during operation shall have an internal corrosion allowance of minimum 3 mm.

705 Subject to agreement, the general requirements for a minimum corrosion allowance of 3 mm may be waived if it is demonstrated that the design and/or procedures for corrosion control exclude any critical damage by corrosion.

706 An external corrosion allowance of 3 mm shall be applied to C-Mn steel risers of safety class Normal and High in the splash zone. For risers carrying hot fluids (more than 10°C above normal ambient seawater temperature) of the same safety classes the use of a corrosion allowance in excess of 3 mm shall be considered. Any allowance for internal corrosion shall be additional.

---end--of--G-u-i-d-a-n-c-e---n-o-t-e---

C. Load and Resistance Calculations

C 100 Load conditions

101 Differentiation is made between:
- Load Controlled condition (LC condition), and
- Displacement Controlled condition (DC condition).

Different design checks apply to these two conditions.

102 A load-controlled condition is one in which the structural response is primarily governed by the imposed loads.

103 A displacement-controlled condition is one in which the structural response is primarily governed by imposed geometric displacements.

104 A load controlled design criterion can always be applied in place of a displacement controlled design criterion.

**Guidance note:**
An example of a purely displacement-controlled condition is a pipeline bent into conformity with a continuous curved structure, such as a J-tube or a reel. In that case, the curvature of the pipe axis is imposed but the circumferential bending that leads to ovalisation is determined by the interaction between the curvature of the axis and the internal forces induced by the curvature. A less clear-cut example is a pipeline in contact with the rollers of a lay barge stinger. On a large scale, the configuration of the pipeline has to conform to the rollers, and in that sense is displacement controlled. On a local scale however, bending of the pipe between the rollers is determined by the interaction between weight and tension and is load-controlled. The stinger tip will, however, always be load controlled.

Another intermediate case is an expansion spool in contact with the seabed. Pipeline expansion induced by temperature and pressure imposes a displacement at the end of the spool. The structural response of the spool itself has little effect on the imposed expansion displacement, and the response is primarily displacement-controlled. However, the lateral resistance to movement of the spool across the seabed also plays a significant part and induces a degree of load control.

These examples show that in many cases a simple distinction between load control and displacement control is not seen. The choice should be based on an informed judgement about which components of the combined load are more important.

105 Liner pipe NDT level 1 is required for use of displacement controlled local buckling criteria.

C 200 Load effect calculation

201 The design analyses shall be based on accepted principles of statics, dynamics, strength of materials and soil mechanics.

202 Simplified methods or analyses may be used to calculate the load effects provided that they are conservative. Model tests may be used in combination with, or instead of, theoretical calculations. In cases where theoretical methods are inadequate, model or full-scale tests may be required.

203 All loads and forced displacements which may influence the pipeline integrity shall be taken into account. For each cross section or part of the system to be considered and for each possible mode of failure to be analysed, all relevant combinations of loads which may act simultaneously shall be considered.

204 When determining responses to dynamic loads, the dynamic effect shall be taken into account if deemed significant.

205 Load effect calculation shall be performed applying nominal cross section values.

206 Load effect calculations shall be based on characteristic values, ref. Section 4B 200 and C 600.

207 Possible beneficial strengthening effect of weight coat-
Stress Concentration Factors (SCF) shall be included if
C 400 Stress and strain calculations
E.404.

Wall thickness for stability calculations is given in
Minimum wall thickness requirement is given in B 400.

in the above calculation of thickness.
Corrosion prior to start of operation shall be considered

Construction (installation) and system pressure test
shall be calculated based on wall thickness as follows:
Operational condition
SNCF shall be adjusted for the non-linear stress-strain relation-
ing, which typically extend one diameter) will affect the pipe glo-
ally, and shall be accounted for in the bending buckling
evaluations as well as fatigue and fracture evaluations.

208 Possible beneficial strengthening effect of cladding or
liner on a steel pipe shall not be taken into account in the design,
unless the strengthening effect is documented.
209 The effective axial force that determines the global re-
response of a pipeline is denoted S. Counting tensile force as positive:

where:


210 In the as-laid condition, when the pipe temperature and
internal pressure are the same as when the pipe was laid,

Where H is the effective (residual) lay tension

211 Effective axial force of a totally restrained pipe in the
linear elastic stress range is (if it can be idealised as thin-
walled):

where:

C 300 Characteristic wall thickness
301 Pressure containment resistance shall be calculated
based on wall thickness as follows:
Mill pressure test and system pressure test condition

Operational condition

302 Resistances, except for pressure containment resistance,
shall be calculated based on wall thickness as follows:
Construction (installation) and system pressure test

Otherwise

303 Corrosion prior to start of operation shall be considered
in the above calculation of thickness.
304 Minimum wall thickness requirement is given in B 400.
305 Wall thickness for stability calculations is given in
E.404.

C 400 Stress and strain calculations
401 Stress Concentration Factors (SCF) shall be included if
relevant.

Guidance note:
Distinction should be made between global and local stress con-
centrations.
Local stress concentrations (that may be caused by welded at-
tachments, the weld itself, or very local discontinuities) will af-
flect the pipe only locally and are typically accounted for in
fatigue and fracture evaluations. Global stress concentrations

(such as stress amplifications in field joints due to concrete coat-
ing, which typically extend one diameter) will affect the pipe glo-
ally, and shall be accounted for in the bending buckling
evaluations as well as fatigue and fracture evaluations.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

402 Strain Concentration Factors (SNCF) shall be deter-
mined and accounted for if plastic strain is experienced. The
SNCF shall be adjusted for the non-linear stress-strain relation-
ship for the relevant load level.

403 Strain concentrations shall be accounted for when con-
sidering:

— uneven deformation caused by variations in actual materi-

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

404 Accumulated plastic strain is defined as the sum of plastic
strain increments, irrespective of sign and direction. Strain
increments shall be calculated from after the linepipe manufac-
turing.

405 Plastic strain increment shall be calculated from the point
where the material stress-strain curve deviates from a linear
relationship, ref. Figure 5-2.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Figure 5-2 Reference for plastic strain calculation

Guidance note:
The yield stress is defined as the stress at which the total strain is
0.5%. As an example for a 415 grade C-Mn steel, a unidirectional
strain of 0.5% corresponds to an elastic strain of approximately
0.2% and a plastic strain of 0.3%.

406 The equivalent plastic strain is defined as:

where

εp is the equivalent plastic strain
εpL is the plastic part of the principal longitudinal strain
εpH is the plastic part of the principal circumferential (hoop) strain
εpR is the plastic part of the principal radial strain
D. Limit States

D 100 General

101 All relevant failure modes formulated in terms of limit states shall be considered in design. The limit states shall be classified into one of the following four limit state categories:

— Serviceability Limit State (SLS): A condition which, if exceeded, renders the pipeline unsuitable for normal operations.
— Ultimate Limit State (ULS): A condition which, if exceeded, compromises the integrity of the pipeline.
— Fatigue Limit State (FLS): A ULS condition accounting for accumulated cyclic load effects.
— Accidental Limit State (ALS): A ULS due to accidental loads.

102 As a minimum requirement, risers and pipelines shall be designed against the following potential modes of failure:

Serviceability Limit State

— ovalisation/ratcheting limit state;
— accumulated plastic strain limit state; and
— damage due to, or loss of, weight coating.

Ultimate Limit State

— bursting limit state;
— ovalisation/ratcheting limit state (if causing total failure);
— local buckling limit state (pipe wall buckling limit state);
— global buckling limit state (normally for load-controlled condition);
— unstable fracture and plastic collapse limit state; and
— impact.

Fatigue Limit State

— fatigue due to cyclic loading.

Accidental Limit State

103 All limit states shall be satisfied for all specified load combinations. The limit state may be different for the load controlled condition and the displacement controlled condition.

104 Figure 5-3 gives an overview of the required design checks.

105 All limit states shall be satisfied for all relevant phases and conditions. Typical conditions to be covered in the design are:

— installation,
— as laid,
— system pressure test,
— operation, and
— shut-down

Figure 5-3 Flow diagram for structural design. The design loop shall be repeated for each relevant phase.

D 200 Limit state format

201 The design format in this standard is based on an LRFD format.

202 Based on potential failure consequences the pipeline shall be classified into a safety class see Section 2C 400. The
The safety class resistance factor, \( R \), limit state category and is defined in Table 5-4.

\[ L_d \leq R_d \quad (5.10) \]

The design load can generally be expressed in the following format:

\[ (L_d = L_F \cdot \gamma_F \cdot \gamma_C + L_E \cdot \gamma_E + L_A \cdot \gamma_A \cdot \gamma_C) \quad (5.11) \]

In specific forms, this corresponds to:

\[ M_d = M_F \cdot \gamma_F \cdot \gamma_C + M_E \cdot \gamma_E + M_A \cdot \gamma_A \cdot \gamma_C \quad (5.12) \]

\[ \varepsilon_d = \varepsilon_F \cdot \gamma_F \cdot \gamma_C + \varepsilon_E \cdot \gamma_E + \varepsilon_A \cdot \gamma_A \cdot \gamma_C \]

\[ S_d = S_F \cdot \gamma_F \cdot \gamma_C + S_E \cdot \gamma_E + S_A \cdot \gamma_A \cdot \gamma_C \]

\[ \Delta p_d = \gamma_p \cdot (p_{id} - p_e) \]

The load effect factors, \( \gamma_F \cdot \gamma_E \cdot \gamma_A \cdot \gamma_C \) are given in Table 5-5 and Table 5-6. These factors apply to all safety classes. Definition of characteristic functional and environmental load effect values are given in Section 4B 200 and C 600.

Guidance note:

The above load combinations are referred to explicitly in the design criteria, e.g. Eq. (5.23), and shall not be applied elsewhere, e.g. not in Eq. (5.14) or in Eq. (5.22).

Guidance note:

For the system pressure test condition, the local test pressure is considered as incidental pressure. In order to calculate the corresponding \( \Delta p_d \) included in \( \Delta p_d \) above, the local test pressure shall be calculated as:

\[ \Delta p_d = \gamma_p \left( \frac{p_{tl}}{\gamma_{inc}} + \rho \frac{gh_{ref}}{\gamma_{inc}} - p_e \right) \]

where \( h_{ref} \) is the vertical distance between the point in question and the reference height and \( \gamma_{inc} \) should be 1.1. The same approach applies to when the shut-in pressure is used.

The design resistance, \( R_d \), can normally be expressed in the following format:

\[ R_d = \frac{R_k (\gamma_k)}{\gamma_{SC} \cdot \gamma_m} \quad (5.13) \]

The characteristic material strength, \( f_k \), is given in B 600.

The material resistance factor, \( \gamma_m \), is dependent on the limit state category and is defined in Table 5-4.

The safety class resistance factor, \( \gamma_{SC} \), is dependent on safety class and given in Table 5-5.

<table>
<thead>
<tr>
<th>Table 5-5</th>
<th>Safety class resistance factors, ( \gamma_{ES} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety class</td>
<td>Low</td>
</tr>
<tr>
<td>Pressure containment</td>
<td>1.046</td>
</tr>
<tr>
<td>Other</td>
<td>1.04</td>
</tr>
</tbody>
</table>

1) For parts of pipelines in location class 1, resistance safety class normal may be applied (1.138).
2) The number of significant digits are given in order to comply with the ISO usage factors.
3) Safety class low will be governed by the system pressure test which is required to be 3% above the incidental pressure. Hence, for operation in safety class low, the resistance factor will effectively be 3% higher.
4) For system pressure test, \( \gamma_k \) shall be equal to 1.00, which gives an allowable hoop stress of 96% of SMYS both for materials fulfilling supplementary requirement U and those not.

D 300 Load effect factors and load combinations

Each part of the pipeline system shall be designed for the most unfavourable load combination given in Table 5-6. Load combination a and b are referred to in D 500 through definition in Eq. (5.12).

<table>
<thead>
<tr>
<th>Table 5-6</th>
<th>Load effect factors and load combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit State / Load combination</td>
<td>Functional loads</td>
</tr>
<tr>
<td></td>
<td>( \gamma_F )</td>
</tr>
<tr>
<td>SLS &amp; ULS</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
<tr>
<td>FLS</td>
<td>1.0</td>
</tr>
<tr>
<td>ALS</td>
<td>1.0</td>
</tr>
</tbody>
</table>

1) If the functional load effect reduces the combined load effects, \( \gamma_p \) shall be taken as 1/1.1.

D 302 Load combination a in Table 5-6 is required when system effects are present. It is therefore not required for local design checks, which normally means for \( \sigma_k > 0 \) in combination with other loads.

D 303 The loads listed in Section 4 shall be considered for all design phases relevant to the pipeline system.

D 304 The condition load effect factor applies to the conditions in Table 5-7. Condition load effect factors are in addition to the load effect factors and are referred to explicitly in Eq. (5.12).

<table>
<thead>
<tr>
<th>Table 5-7</th>
<th>Condition load effect factors, ( \gamma_C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>( \varphi )</td>
</tr>
<tr>
<td>Pipeline resting on uneven seabed or in a snaked condition</td>
<td>1.07</td>
</tr>
<tr>
<td>Continuously stiff supported</td>
<td>0.82</td>
</tr>
<tr>
<td>System pressure test</td>
<td>0.93</td>
</tr>
<tr>
<td>Otherwise</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Guidance note:

An uneven seabed condition is relevant in connection with free-spanning pipelines. The same factor shall be used even when the pipeline is in a snaked condition on an uneven seabed. Continuously stiff supported denotes conditions where the main part of the load is also displacement controlled. Examples may be reeling on the drum or J-tube pull-in. Several condition factors may be required simultaneously, e.g. for pressure testing of pipelines on uneven seabed, the resulting condition factor will be 1.07 · 0.93 = 1.00.

D 400 Pressure containment (bursting)

The following criteria are valid provided that the mill pressure test requirement in Section 6E 1100 has been met. If not, a corresponding decreased utilisation shall be applied.
402 The pressure containment shall fulfill the following criteria:

\[
p_{1i} - p_e \leq \frac{p_b(t_1)}{\gamma_{SC} \cdot \gamma_m} \tag{5.14}
\]

**Guidance note:**
Criterion for the incidental pressure is given in Section 3B 300
The concept of local pressure is given in Section 12E

403 The pressure containment resistance, \( p_b(x) \) is given by:

\[
p_b(x) = \text{Min}(p_{b,s}(x); p_{b,a}(x)) \tag{5.15}
\]

**Guidance note:**
In the above formulas, \( x \) shall be replaced by \( t_1 \) or \( t_2 \) as appropriate.

404 Reduction in pressure containment resistance due to true compressive forces (load controlled), \( N \), shall be considered.

**D 500 Local buckling**

501 Local buckling (pipe wall buckling) implies gross deformation of the cross section. The following criteria shall be fulfilled:

- system collapse (external pressure only);
- combined loading criteria, i.e. interaction between external or internal pressure, axial force and bending moment; and
- propagation buckling.

502 Large accumulated plastic strain may aggravate local buckling and shall be considered.

**System collapse criteria**

503 The characteristic resistance for external pressure \( p_{c} \) (collapse) shall be calculated as:

\[
(p_{c} - p_{el}) \cdot (p_{c} - p_{p}) = p_{c} p_{el} p_{p} \frac{D}{t_2} \tag{5.18}
\]

where:

\[
p_{el} = \frac{2E(t_2)^3}{1 - \nu^2} \tag{5.19}
\]

\[
p_{p} = 2 \cdot f_y \cdot \alpha_{lab} \cdot \frac{t_2}{D} \tag{5.20}
\]

\[
f_{o} = \frac{D_{\text{max}} - D_{\text{min}}}{D} \tag{5.21}
\]

\(<0.005(0.5\%)\)

**Guidance note:**
Ovalisation caused during the construction phase shall be included in the total ovality to be used in design. Ovalisation due to external water pressure or bending moment shall not be included.

504 The external pressure at any point along the pipeline shall meet the following criterion (system collapse check):

\[
p_e \leq \frac{p_c}{1.1 \cdot \gamma_m \cdot \gamma_{SC}} \tag{5.22}
\]

**Guidance note:**
If the pipeline is laid fully or partially liquid-filled or is otherwise under internal pressure, then the internal pressure may be taken into account provided that it can be continuously sustained.

**Combined Loading Criteria - Load controlled condition**

505 Pipe members subjected to bending moment, effective axial force and internal overpressure shall be designed to satisfy the following condition at all cross sections:

\[
\gamma_{SC} t_m \left( \frac{S_d}{\alpha_{p_b}} \right)^2 + \gamma_{SC} t_m \left( \frac{M_d}{\alpha_{M_p} \cdot \gamma_{SC}} \right)^2 \leq 1 - \frac{\Delta p_i}{\alpha_{p_b}(t_2)^2} \leq 1 \tag{5.23}
\]

where:

\[
\alpha_{c} = (1 - \beta) + \frac{\nu}{\gamma_{y}} \tag{5.15}
\]

but maximum 1.20

\[
\beta = \begin{cases} 
0.4 + q_h & \text{for } D/t_2 < 15 \\
(0.4 + q_h)(60 - D/t_2)/45 & \text{for } 15 \leq D/t_2 \leq 60 \\
0 & \text{for } D/t_2 > 60 
\end{cases} 
\]

\[
q_h = \begin{cases} 
\frac{(p_{ld} - p_e)}{p_{b}(t_2)^{\frac{3}{2}}} & \text{for } p_{ld} > p_e \\
p_{b}(t_2) & \text{for } p_{ld} \leq p_e 
\end{cases} 
\]

\(\alpha_{c}\) is not to be taken larger than 1.20.
Guidance note:

\( \varepsilon_c \) versus D/t ratio and pressure ratio \( q_{ih} \) for \( f_u/f_y = 1.15 \)

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

506 Pipe members subjected to bending moment, effective axial force and external overpressure shall be designed to satisfy the following equation:

\[
\left( \gamma_S \gamma_m \left( \frac{M_d}{\sigma_c M_p} \right) + \gamma_S \gamma_m \left( \frac{S_d}{\sigma_c S_p} \right)^2 \right) + \left( \gamma_S \gamma_m \left( \frac{p_e}{\sigma_c p} \right)^2 \right) \leq 1 \quad (5.24)
\]

\[
D/t \leq 45, \quad p_i \geq p_e
\]

Combined loading criteria - Displacement controlled condition

507 Pipe members subjected to longitudinal compressive strain (bending moment and axial force) and internal over pressure shall be designed to satisfy the following condition at all cross sections:

\[
\varepsilon_d \leq \frac{\varepsilon_c}{\gamma_c} \quad D/t \leq 45, \quad p_i \geq p_e \quad (5.25)
\]

where:

\( \varepsilon_d \) = Design compressive strain, Eq. (5.12)

\( \varepsilon_c \) = 0.78 \left( \frac{D}{D} - 0.01 \right) \left( 1 + \frac{\sigma_d}{\sigma_y} \right) \alpha_h^{-1.5} \alpha_{gw}

\( \alpha_h \) = Maximum allowed yield to tensile ratio

\( \alpha_{gw} \) = Girth weld factor

\( \gamma_c \) = Resistance strain factor, see Table 5-8

\[
\alpha_h = \Delta p_d \left( \frac{D - D}{2t_2} \right)
\]

Guidance note:
The maximum yield to ultimate stress ration, \( \alpha_h \), is found in Table 6-3 and Table 6-6. The increase of this factor with 0.02 in accordance with footnote 5 and 3 in these tables respectively does not apply since it is already included in the factor 0.78.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

508 Pipe members subjected to longitudinal compressive strain (bending moment and axial force) and external over pressure shall be designed to satisfy the following condition at all cross sections:

\[
\left( \frac{\varepsilon_d}{\varepsilon_c} \right)^{0.8} + \frac{p_e}{p_c} \leq 1 \quad D/t \leq 45, \quad p_i \geq p_e \quad (5.26)
\]

where:

\( \varepsilon_d \) = Design compressive strain, Eq. (5.12)

\( \varepsilon_c \) = 0.78 \left( \frac{D}{D} - 0.01 \right) \alpha_h^{-1.5} \alpha_{gw}

Guidance note:

For D/t < 20, the utilisation may be increased provided that full scale testing, observation, or former experience indicate sufficient safety margin in compliance with this standard. Any increased utilisation shall be supported by analytical design methods.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

509 A higher probability of failure corresponding to a serviceability limit state may be allowed during the installation phase provided that:

--- aids to detect buckle are provided;
--- repair of potential damage is feasible and may be performed during laying; and
--- buckle arrestors are installed if the external pressure exceeds the initiation propagating pressure.

Relevant resistance factors may then be calibrated according to the SLS requirements in Section 2.

Propagation buckling

510 Propagation buckling cannot be initiated unless local buckling has occurred. In case the external pressure exceeds the criteria given below, buckle arrestors should be installed and spaced determined based on consequences of failure. The propagating buckle criterion reads:

\[
p_{pr} = 35f_y \alpha_{fab} \left( \frac{L_2}{D} \right)^{2.5}
\]

Guidance note:

Collapse pressure, \( p_c \), is the pressure required to buckle a pipeline.

Initiation pressure, \( p_{init} \), is the pressure required to start a propagating buckle from a given buckle. This pressure will depend on the size of the initial buckle.

Propagating pressure, \( p_{pr} \), is the pressure required to continue a propagating buckle. A propagating buckle will stop when the pressure is less than the propagating pressure.

The relationship between the different pressures are:

\[
p_c > p_{init} > p_{pr}
\]

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

511 Table 5-8 Resistance strain factors, \( \gamma_c \)

<table>
<thead>
<tr>
<th>NDT Level</th>
<th>Supplementary Requirements</th>
<th>Safety class</th>
</tr>
</thead>
<tbody>
<tr>
<td>I U</td>
<td>Low 2.0 Normal 2.5 High 3.3</td>
<td></td>
</tr>
<tr>
<td>I -</td>
<td>Low 2.1 Normal 2.6 High 3.5</td>
<td></td>
</tr>
<tr>
<td>II N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

D 600 Global buckling

601 Global buckling implies buckling of the pipe as a bar in compression. The pipeline may buckle globally, either downwards (in a free span), horizontally (“snaking” on the seabed), or vertically (as upheaval buckling or on a free-span shoulder).

602 The effect of internal and external pressures may be taken into account using the concept of an effective axial force, see C.209 above. The procedure is as for “ordinary” compression members in air.

603 A negative effective force may cause a pipeline or a riser to buckle as a bar in compression. Distinction shall be made between load-controlled and displacement-controlled buckling.

Load-controlled buckling involves total failure, and is not allowed.
604 The following global buckling initiators shall be considered:
- trawl board impact, pullover and hooking, and
- out of straightness.

605 For global buckling resistance for load-controlled condition, reference is made to DNV Offshore Standard OS-C101, "Design of Steel Structures" (not yet issued; until issue, refer to DNV Rules for Classification of Fixed Offshore Installations, Pt. 3, Ch. 1, Structural Design, General).

606 Displacement-controlled buckling may be allowed, provided it does not result in other failure modes as listed under Displacements, and to the possibility of having low-cycle high strain fatigue. The requirements regarding accumulated plastic strain (D 1000 below) shall also be satisfied.

Guidance note:
A condition that can give rise to excessive strain is when a short length of an otherwise fully restrained pipeline is less restrained or unconstrained. A typical example is upheaval buckling of a buried pipeline.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

D 700 Fatigue

701 Reference is made to the following Rules, Classification Notes (CN) and guidelines:
- Rules for Classification Of Fixed Offshore Installations
- CN 30.2 Fatigue Strength Analysis for Mobile Offshore Units
- CN 30.5 Environmental Conditions and Environmental Loads.
- Guideline 14 - Free Spanning Pipelines

702 The pipeline systems shall have adequate safety against fatigue failures within the design life of the system.

703 All stress fluctuations imposed on the pipeline system during the entire design life, including the construction phase, which have magnitude and corresponding number of cycles large enough to cause fatigue effects shall be taken into account when determining the long-term distribution of stress ranges. The fatigue check shall include both low-cycle fatigue and high-cycle fatigue. The requirements regarding accumulated plastic strain (D 1000 below) shall also be satisfied.

Guidance note:
Typical causes of stress fluctuations in a pipeline system are:
- direct wave action;
- vibrations of the pipeline system, e.g. due to vortex shedding (current, waves, wind, towing) or fluid flow;
- supporting structure movements; and
- fluctuations in operating pressure and temperature.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

704 Special consideration shall be given to the fatigue assessment of construction details likely to cause stress concentrations, and to the possibility of having low-cycle high strain fatigue. The specific design criterion to be used depends upon the analysis method, which may be categorised into:
- methods based upon fracture mechanics (see 705)
- methods based upon fatigue tests (see 706).

705 Where appropriate, a calculation procedure based upon fracture mechanics may be used. The specific criterion to be used shall be determined on a case-by-case basis, and shall reflect the target safety levels in Section 2C 600.

706 When using calculation methods based upon fatigue tests, the following shall be considered:
- determination of long-term distribution of stress range, see 707;
- selection of appropriate S-N curve (characteristic resistance), see 708;
- determination of Stress Concentration Factor (SCF) not included in the SN-curve; and
- determination of accumulated damage, see 709.

707 As most of the loads which contribute to fatigue are of a random nature, statistical consideration is normally required in determining the long-term distribution of fatigue loading effects. Where appropriate, deterministic or spectral analysis may be used.

708 The characteristic resistance is normally given as S-N curves or e-N curves, i.e. stress amplitudes (or strain amplitudes for the case of low-cycle fatigue), versus number of cycles to failure, N. The S-N curve shall be applicable for the material, construction detail, and state of stress considered, as well as to the surrounding environment. The S-N curve should be based on the mean curve of log(N) with the subtraction of two standard deviations in log(N).

709 In the general case where stress fluctuations occur with varying amplitude of random order, the linear damage hypothesis (Miner's Rule) may be used. The application of Miner's Rule implies that the long-term distribution of stress range is replaced by a stress histogram, consisting of a number of constant amplitude stress or strain range blocks, (sri) or (eri), and the corresponding number of repetitions, ni. Thus, the fatigue criterion is given by:

\[ D_{\text{fat}} = \sum_{i=1}^{k} \frac{n_i}{N_i} \leq \alpha_{\text{fat}} \]  \hspace{1cm} (5.28)

Where:
- \( D_{\text{fat}} \) = Miner's sum
- \( k \) = number of stress blocks
- \( n_i \) = number of stress cycles in stress block i
- \( N_i \) = number of cycles to failure at constant stress range of magnitude \( (s_i) \) or strain range \( (e_i) \),
- \( \alpha_{\text{fat}} \) = allowable damage ratio, see Table 5-9

710 For detailed explanation regarding fatigue calculations/analysis reference is made to DNV Guideline No. 14 "Free spanning pipelines". In cases where this guideline is not applicable, allowable damage ratios are given in Table 5-9.

<table>
<thead>
<tr>
<th>Table 5-9 Allowable damage ratio for fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Class</td>
</tr>
<tr>
<td>( \alpha_{\text{fat}} )</td>
</tr>
</tbody>
</table>

D 800 Ovatisation

801 Risers and pipelines shall not be subject to excessive ovatisation and this shall be documented. The flattening due to bending, together with the out-of-roundness tolerance from fabrication of the pipe, is not to exceed 3%, defined as:

\[ f_0 = \frac{D_{\text{max}} - D_{\text{min}}}{D} \leq 0.03 \]  \hspace{1cm} (5.29)

The requirement may be relaxed if:
- a corresponding reduction in moment resistance has been included;
- geometrical restrictions are met, such as piggng requirements;
- additional cyclic stresses caused by the ovatisation have been considered; and
- tolerances in the relevant repair system are met.
802 Ovalisation shall be checked for point loads at any point along the pipeline system. Such point loads may arise at free-span shoulders, artificial supports and support settlements.

D 900 Ratcheting

901 Accumulated plastic deformation (ratcheting) caused by cyclic loads shall be considered. If the ratcheting causes accumulated ovality, special consideration shall be made of the effect on buckling resistance.

902 Under maximum operating temperature and pressure, the equivalent plastic strain in the pipelines shall not exceed 0.001 (0.1%). (Calculated based on elastic - perfectly plastic material. The calculations of the equivalent plastic strain assume that the reference state for zero strain is the as-built state (after pressure testing)).

903 Plastic deformation of the pipeline shall only occur when the pipeline is first exposed to its maximum temperature and pressure.

904 Ratcheting due to local and global bending stresses shall also be considered where this could eventually lead to loss of stability

D 1000 Accumulated plastic strain

1001 The equivalent plastic strain condition in C.405 and C.406 is not in itself a limit state. Equivalent plastic strain is a measure of plastic deformation, which is useful in the assessment of fracture mechanics and degradation of material properties. Requirements with respect to fracture mechanics are given in D 1100.

1002 Accumulation of plastic strain during installation and operation shall be considered for all pipelines.

The effects of strain ageing due to the accumulation of plastic strain shall be considered.

The effects of degradation of the material properties of the weld zones and parent pipe, and the influence on acceptance criteria for NDT, shall be accounted for.

1003 The amount of displacement controlled strain, both accumulated and maximum for each single strain cycle, shall be established considering all phases from construction to abandonment.

1004 When the accumulated plastic strain resulting from installation and operation load effects (including load factors and all strain concentration factors), \( \varepsilon_p \), is

\[ \varepsilon_p \leq 0.3\% \]

then the requirements of this standard for materials, welding procedures, workmanship and the acceptance criteria for NDT given in Appendix D Table D-4, Table D-5, are considered adequate.

1005 When the accumulated plastic strain resulting from installation and operation, including all strain concentration factors, is:

\[ \varepsilon_p > 0.3\% \]

an engineering criticality assessment (ECA), see D 1100 below, shall be performed on installation girth welds. This ECA shall determine the material fracture toughness required to tolerate the flaws allowed according to the acceptance criteria for NDT given in Appendix D Table D-4, Table D-5

Table D-5, or alternatively to establish the defect size that can be tolerated for a given fracture toughness.

1006 When the accumulated plastic strain resulting from installation and operation, including all strain concentration factors, is:

\[ \varepsilon_p > 2.0\% \]

then, in addition to the requirements of 1005, the characteristic strain resistance \( \varepsilon_{c} \), shall be verified as required in Section 9E and the material shall meet the supplementary requirement P.

D 1100 Fracture

1101 Pipeline systems shall have adequate resistance against initiation of unstable fracture. This shall be achieved by selecting materials with the transition temperature from brittle to ductile behaviour sufficiently below the minimum design temperature, see Table 6-4, and with high resistance to stable crack growth.

1102 The safety against unstable fracture is considered satisfactory if the materials, welding, workmanship and testing are in accordance with the requirements of this standard and the accumulated plastic strain is not exceeding 0.3%.

1103 Pipeline systems transporting gas or mixed gas and liquids under high pressure shall have adequate resistance to propagating fracture. This may be achieved by using:

- material with low transition temperature and adequate Charpy V-notch toughness,
- adequate DWTT shear fracture area
- lowering the stress level,
- use of mechanical crack arrestors, or
- by a combination of these methods.

Design solutions shall be validated by calculations based upon relevant experience and/or suitable tests.

1104 For linepipe required to resist propagating fractures, the additional requirements in Section 6D 200 and modifications for linepipe base material shall apply for the subsea section of the pipeline system. For depths down to 10 metres and onshore, the required Charpy V-notch impact energy shall be specially considered. Deep water pipelines will experience reductions in tensile stresses due to the external pressure. Supplementary requirements to fracture arrest properties need not be applied when the pipeline design tensile hoop stress is below 40% of \( f_y \).

1105 Material meeting the supplementary requirement for fracture arrest properties (F) (Section 6D 200) is considered to have adequate resistance to running propagating ductile fracture for applications up to 80% usage factor, 15 MPa internal pressure and 30 mm wall thickness.

1106 For pipelines subjected to an accumulated plastic strain exceeding 0.3%, an engineering criticality assessment (ECA) shall be carried out in order to confirm that unstable fracture will not occur during pipelaying, or during operation of the pipeline.

1107 Possible crack growth (ductile tearing) and high and low-cycle fatigue crack growth shall be considered in the assessment. The assessment shall confirm that the largest weld defects expected to remain after NDT will not increase during pipelaying to an extent such that unstable fracture or fatigue failure will occur during operation of the pipeline.

1108 The effect of strain ageing on fracture toughness, shall be taken into account as relevant by testing artificially strain aged material.

1109 The ECA shall be carried out in accordance with BS 7910 at Level 3, with modifications necessary for plastic design and multiple strain cycles. Some guidance for use of BS 7910 for plastic design and multiple strain cycles is given in Section 12.

1110 The maximum defect size resulting from, or used in, the ECA shall be adjusted for the probability of detection possible with NDT and the accuracy of the equipment to be used in determining length, height, location and orientation of imperfections.

1111 The uncertainty data used shall be appropriate for the applied testing equipment and procedures for the detection and assessment of flaws in the material and weld geometries in
question. The data used for quantitative estimates of ultrasonic testing uncertainty, performance and reliability, are preferably to be of the "measured response versus actual flaw size" type. The probability of detection level with the applied testing equipment and procedures used shall be based on a confidence level of 95% or better.

1112 If adequate data is not available, the following approach shall be used:

— If the purpose of the ECA is to establish the tolerable defect size for given material properties and stresses, 2 mm shall be subtracted from the calculated defect height and length, when acceptance criteria for non-destructive testing are established.

— If the purpose of the ECA is to establish the material properties and stresses required to tolerate a given defect size, the defect size used as input into the ECA shall be increased in size by adding 2 mm to the stated height and width.

D 1200 Accidental limit state

1201 The design against accidental loads may be performed by direct calculation of the effects imposed by the loads on the structure, or indirectly, by design of the structure as tolerable to accidents.

1202 The acceptance criteria for ALS relate to the overall allowable probability of severe consequences

1203 Design with respect to accidental load must ensure that the overall failure probability complies with the target values in Section 2. This probability can be expressed as the sum of the probability of occurrence of the i'th damaging event, \( P_{D_i} \), times the structural failure probability conditioned on this event, \( P_{f,T} \). The requirement is accordingly expressed as:

\[
\sum P_{D_i} \cdot P_{f,T} \leq p_{f,T} \tag{5.30}
\]

where \( p_{f,T} \) is the relevant target probability according to Section 2. The number of discretisation levels must be large enough to ensure that the resulting probability is evaluated with sufficient accuracy.

1204 The inherent uncertainty of the frequency and magnitude of the accidental loads, as well as the approximate nature of the methods for determination of accidental load effects, shall be recognised. Sound engineering judgement and pragmatic evaluations are hence required.

1205 If non-linear, dynamic finite element analysis is applied, it shall be ensured that system performance and local failure modes (e.g. strain rate, local buckling, joint overloading and joint fracture) are adequately accounted for by the models and procedures applied.

1206 A simplified design check with respect to accidental load may be performed as shown in Table 5-10 using appropriate partial safety factors. The adequacy of simplified design check must be assessed on the basis of the summation above in order to verify that the overall failure probability complies with the target values in Section 2.

<table>
<thead>
<tr>
<th>Table 5-10 Simplified Design Check versus Accidental loads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prob. of occurrence</strong></td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>&gt;10^-2</td>
</tr>
<tr>
<td>10^-3</td>
</tr>
<tr>
<td>10^-4</td>
</tr>
</tbody>
</table>

Note to table:
Standard industry practice assumes safety factors equal to 1.0 for an accidental event with a probability of occurrence equal to 10^-4, and survival of the pipeline is merely related to a conservative definition of characteristic resistance. In this standard, accidental loads and events are introduced in a more general context with a link between probability of occurrence and actual failure consequence. For combined loading the simplified design check proposes a total factor in the range 1.1-1.2, which is consistent with standard industry practice interpreted as corresponding to safety class Normal for accidental loads with a probability of occurrence equal to 10^-4.

E. Special Considerations

E 100 General

101 This subsection gives guidance on conditions that shall be evaluated separately. Both the load effects and acceptance criteria are affected.

E 200 Pipe soil interaction

201 For limit states influenced by the interaction between the pipeline and the soil, this interaction shall be determined taking due account for all relevant parameters and the uncertainties related to these.

In general pipeline soil interaction depends on the characteristics of the soil, the pipeline, and the loads, which shall all be properly accounted for in the simulation of the pipeline soil interaction.

202 The main soil characteristics governing the interaction are the shear strength and deformation properties. The non-linear stress - strain characteristics of the soil shall be accounted for. If linear springs are used to represent the interaction, the response in the springs shall be checked in order to verify that the load level is compatible with the spring stiffness used.

203 Pipeline characteristics of importance are submerged weight, diameter stiffness, and roughness of the pipeline surface, which shall all be accounted for as relevant for the limit state in question.

204 All relevant effects of load characteristics shall be considered, including any long term load history effects such as varying vertical reactions from installation laying pressures, and variations in the unit weight of the pipe. Cyclic loading effects are also to be considered.

Some soils have different resistance values for long term loading and for short term loading, related to the difference in drained and non-drained behaviour and to creep effects in drained and non-drained condition. This shall be taken into account.

205 For limit states involving or allowing for large displacements (e.g. lateral pull-in, pipeline expansion of expansion loops or when displacements are allowed for on-bottom condition) the soil will be loaded far beyond failure, involving large non-linearities, remoulding of soil, ploughing of soil etc. Such non-linear effects and the uncertainties related to these shall be considered.

206 Due to the uncertainties in governing soil parameters, load effects etc., it is difficult to define universally valid methods for simulation of pipeline soil interaction effects. The limitations of the methods used, whether theoretically or empirically based, shall be thoroughly considered in relation to the problem at hand. Extrapolation beyond documented validity of a method shall be performed with care, as shall simplifications from the problem at hand to the calculation model used. When large uncertainties exist, the use of more than one
calculation approach shall be considered.

E 300 Spanning risers/pipelines

301 Spanning risers and pipelines shall have adequate safety against excessive yielding, fatigue and ovality and these shall be documented.

302 For design of free spanning pipelines, reference is made to DNV Guideline No 14; “Free spanning pipelines”.

E 400 On bottom stability

401 The pipeline shall be supported, anchored in open trench, or buried in such a way that under extreme functional and environmental loading conditions, the pipeline will not move from its as-installed position. This does not include permissible lateral or vertical movements, thermal expansion, and a limited amount of settlement after installation.

Guidance note:
The acceptance criterion on permissible movements may vary along the pipeline route. Examples of possible limitations to pipeline movements include:
— yielding, buckling and fatigue of pipe;
— deterioration/wear of coating;
— geometrical limitations of supports; and
— distance from other pipelines, structures or obstacles.

402 Liquid or gas pipelines in the air- or gas-filled condition shall have a specific gravity which is higher than that of the surrounding sea water (negative buoyancy).

403 When the pipeline is routed in areas that may be influenced by unstable slopes, that could lead to slope failure and flow of soil that will impact the pipeline, the probability of such slope failures shall be evaluated. Any relevant slope failure triggering effect, such as wave loading, earthquake loading or man made activities (e.g. the pipe-laying itself), shall be considered. Possible flow rates and densities at the pipeline shall be evaluated for stability. If stability cannot be guaranteed by sufficient weight of the pipeline, by burial of the pipeline or by other means, re-routing of the pipeline shall be required.

404 For weight calculations of the pipe, the nominal wall thickness shall be reduced to compensate for the expected average weight reduction due to metal loss. For pipelines with minor corrosion allowance this reduction may be omitted and the nominal thickness used.

405 Buried pipelines shall have adequate safety against sinking or flotation. For both liquid and gas pipelines, sinking shall be considered assuming that the pipeline is water filled, and flotation shall be considered assuming that the pipeline is gas or air filled (if relevant).

406 If the specific submerged weight of the water-filled pipe is less than that of the soil, then no further analyses are required to document safety against sinking. If pipelines are installed in soils having a low shear strength, then the soil bearing resistance shall be documented. If the soil is, or is likely to be, liquefied, it shall be documented that the depth of sinking will be satisfactorily limited (either by the depth of liquefaction or by the build-up of vertical resistance during sinking) meeting the requirements of D above.

407 If the specific submerged weight of the gas- or air-filled pipe is less than that of the soil, it shall be documented that the shear strength of the soil is adequate to prevent flotation. Thus, in soils which are or may be liquefied, the specific weight of the buried gas- or air-filled pipeline is not to be less than that of the soil.

408 Pipelines resting directly on the sea bottom without any special supporting structures or anchoring devices other than weight coating, shall be designed against sinking as described under 405 above. Special considerations shall here be made to mechanical components such as valves and Tee’s.

409 It shall be documented that pipelines situated on the sea bottom have adequate safety against being lifted off the bottom or moved horizontally. For assessment of horizontal (transverse) stability of pipelines exposed to wave and current loads, reference is made to RP E305 “On Bottom Stability”.

410 The most unfavourable combination of simultaneously acting vertical and horizontal forces on the pipeline shall be considered. When determining this unfavourable combination, the variation in forces along the line, including directionality effects of waves and current, shall be addressed.

Guidance note:
The transverse pipeline stability may be assessed using three-dimensional dynamic or two-dimensional static analysis methods. The dynamic analysis methods allow limited pipe movements, but require accurate three-dimensional modelling. The static analysis method may be expressed by:

\[
\gamma_s (F_D - F_I) \leq \mu (W_{sub} - F_L)
\]

where

- \(\gamma_s\) = factor of safety, normally not to be taken as less than 1.1
- \(F_D\) = hydrodynamic drag force per unit length
- \(F_I\) = hydrodynamic inertia force per unit length
- \(\mu\) = hydrodynamic inertia force per unit length
- \(W_{sub}\) = submerged pipe weight per unit length
- \(F_L\) = hydrodynamic lift force per unit length

411 The coefficient of equivalent friction, \(\mu\) may vary within a wide range depending on the seabed soil, surface roughness, weight and diameter of the pipeline. When the pipeline has some penetration into the soil, the lateral resistance includes both friction type resistance and resistance due to mobilising the soil outside the contact surface. In such cases the equivalent friction coefficient may vary with the vertical load level.

412 Axial (longitudinal) stability shall be checked. The anode structural connection (when exposed to friction, e.g., pipelines without weight coating) shall be sufficient to sustain the anticipated friction force.

413 Pipeline movements due to thermal axial expansion, shall be allowed for near platforms/structures (e.g. at riser tie-in point) and where the pipeline changes direction (e.g. at offset spools). The expansion calculations shall be based upon conservative values for the axial frictional resistance.

414 In shallow water, the repeated loading effects due to wave action may lead to a reduction of the shear strength of the soil. This shall be considered in the analysis, particularly if the back fill consists of loose sand which may be susceptible to liquefaction.

415 If the stability of the pipeline depends on the stability of the seabed, the latter should be checked.

E 500 Trawling interference

501 The pipeline system shall be checked for all three loading phases due to trawl gear interaction, as outlined in Section 4F. For more detailed description, reference is made to the Guideline 13; “Interference between Trawl Gear and Pipelines”.

502 The acceptance criteria are dependent on the trawling frequency (impact) and the safety classification (pull-over and hooking) given in Section 2C 400.

503 The acceptance criteria for trawl impact refer to an ac-
ceptable dent size. The maximum accepted ratio of permanent dent depth to the pipe diameter is:

\[ \frac{H_p}{D} \leq 0.05 \eta \]  \hspace{1cm} (5.32)

where:

\[ H_p = \text{permanent plastic dent depth} \]

\[ \eta = \text{usage factor given in Table 5-11. Load effect factors equal to unity} \]

Table 5-11  Usage factor (\(\eta\)) for trawl door impact

<table>
<thead>
<tr>
<th>Impact frequency (per year per km)</th>
<th>Usage factor (\eta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;100</td>
<td>0</td>
</tr>
<tr>
<td>1-100</td>
<td>0.3</td>
</tr>
<tr>
<td>(10^{-4}-1)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

504 When allowing for permanent dents, additional failure modes such as fatigue and collapse shall be taken into account. Any beneficial effect of internal over-pressure, i.e. "pop-out" shall not normally be included. The beneficial effects of protective coating may be taken into account. The impact effectiveness of coating shall be documented.

505 Pullover loads shall be checked in combination with other relevant load effects. All relevant failure modes for lateral buckling shall be checked. Accumulation of damage due to subsequent trawling is not normally allowed.

506 Hooking loads shall be checked in combination with other relevant load effects. All relevant failures modes shall be checked.

E 600 Third party loads, dropped objects

601 The pipeline shall be designed for impact forces caused by, e.g. dropped objects, fishing gear or collisions. The design may be achieved either by design of pipe, protection or means to avoid impacts.

602 The design criteria shall be based upon the frequency/likelihood of the impact force and classified as accidental, environmental or functional correspondingly, see D 1200.

E 700 Insulation

701 When a submerged pipeline is thermally insulated, it shall be documented that the insulation is resistant to the combination of water, temperature and hydrostatic pressure.

702 Furthermore, the insulation should be resistant to oil and oil-based products, if relevant. The insulation shall also have the required mechanical strength to external loads, as applicable.

703 With respect to corrosion, see Section 8.

E 800 Pipe-in-pipe and bundles

801 For pipe-in-pipe and bundle configurations, advantage may be taken of other loading conditions, e.g. pressure containment for carrier pipe. When determining the safety class, advantage may also be taken on the reduced failure consequences compared to those of ordinary pipelines.

802 The combined effective force for a pipe-in-pipe or a bundle may be calculated using the expression in C 200 for each component and summing over all components. The external pressure for each component shall be taken as the pressure acting on its external surface, i.e. the pressure in the void for internal pipes. Release of effective axial force by end expansions, lateral and/or vertical deformations or buckling depends on how the pipes may slide relatively to each other. Therefore, analysis of cases where the effective axial force is important, such as analysis of expansion, buckling and dynamics, requires accurate modelling of axial restraints such as spacers, bulk-heads etc.

F. Pipeline Components and Accessories

F 100 General

101 Criteria for pipeline components and accessories are given in Section 7.

G. Supporting Structure

G 100 General

101 All supporting structures shall be designed according to Offshore Standard OS-C101, "Design of Steel Structures" (not yet issued; until issue, refer to DNV Rules for Classification of Fixed Offshore Installations, Pt. 3, Ch. 1, Structural Design, General).

G 200 Riser supports

201 The riser supports should be designed against the possible forms of failure with at least the same degree of safety as that of the riser they support. However, if safety considerations indicate that the overall safety is increased by a reduction of the failure load of certain supports, such considerations may govern the support design (weak link principle).

202 For bolted connections, consideration shall be given to friction factors, plate or shell element stresses, relaxation, pipe crushing, stress corrosion cracking, fatigue, brittle failure, and other factors that may be relevant.

203 For supports with doubler and/or gusset plates consideration shall be given to lamellar tearing, pull out, element stresses, effective weld length, stress concentrations and excessive rotation.

204 In clamps utilising elastomeric linings, the long-term performance of the material with regard to creep, sea water and air or sun light resistance shall be determined.

G 300 J-tubes

301 An overall conceptual evaluation shall be made in order to define the required:

— safety class,
— impact design, and
— pressure containment resistance.

302 The J-tube shall be designed against the failure modes given in D 100.

Guidance note:

301 above includes evaluation of whether the j-tube shall be designed for the full design pressure and to which safety class (i.e. hoop stress usage factors). The J-tube concept may e.g. be based on "burst disc" which will imply that a lower pressure containment resistance shall be governing.

303 The J-tube spools should be joined by welding.

G 400 Stability of gravel

401 Gravel applied for mechanical protection of pipelines and as sleepers for supporting pipelines in free spans shall have sufficient stability against hydrodynamic loads. The possibility of scour for the expected range of water particle velocity shall be taken into account.

402 Gravel sleepers are to have sufficient safety against slope failure. The shear strength of the underlying soil shall be taken into account.
H. Installation and Repair

H 100 General

101 The pipeline strength and stability shall be determined according to subsection D and E above.

Guidance note:
According to this standard, equivalent limit states are used for all phases. Hence the design criteria in this section also apply to the installation phase. Installation is usually classified as a lower safety class (safety class low) than operation, corresponding to lower partial safety factors (higher failure probability).

102 The design analysis for risers and pipelines shall include both installation and repair activities, in order to ensure that they can be installed and repaired without suffering damage or requiring hazardous installation or repair work.

103 The design shall verify adequate strength during all relevant installation phases and techniques to be used, including:
- initiation of pipe laying operation,
- normal continuous pipe laying,
- pipe lay abandonment and pipeline retrieval,
- termination of laying operation,
- tow out operations (bottom tow, off-bottom tow, controlled depth tow and surface tow),
- pipeline reeling and unreeling,
- trenching and back filling,
- riser and spool installation,
- tie-in operations and
- landfalls.

104 The configuration of pipeline sections under installation shall be determined from the laying vessel to the final position on the seabed. The configuration shall be such that the stress/strain levels are acceptable when all relevant effects are taken into account. Discontinuities due to weight coating, buckle arrestors, in-line assemblies etc. shall be considered.

105 The variation in laying parameters that affect the configuration shall be considered. An allowed range of parameter variation shall be established for the installation operation.

106 Critical values shall be determined for the installation limit condition, see Section 9 D 400.

107 Configuration considerations for risers and pipelines shall also be made for other installation and repair activities, and the allowed parameter variations and operating limit conditions shall be established.

108 If the installation and repair analyses for a proposed pipeline system show that the required parameters cannot be obtained with the equipment to be used, the pipeline system shall be modified accordingly.

109 The flattening due to a permanent bending curvature, together with the out-of-roundness tolerances from fabrication of the pipe shall meet the requirements defined in D 800.

H 200 Pipe straightness

201 The primary requirement regarding permanent deformation during construction, installation and repair is the resulting straightness of the pipeline. This shall be determined and evaluated with due considerations of effects on:
- instability;
- positioning of pipeline components e.g. valves and Tee-joints; and
- operation.

202 The possibility of instability due to out of straightness during installation (twisting) and the corresponding consequence shall be determined.

203 If Tee-joints and other equipment are to be installed as an integrated part of the pipeline assembled at the lay barge, no rotation of the pipe due to plastification effects shall be permitted. In this case the residual strain from bending at the over-bend shall satisfy the following during installation:

\[ \gamma_{rot} \varepsilon_r \leq \varepsilon_{r,\text{rot}} \]  

(5.33)

where

- \( \varepsilon_r \) = residual strain from over bend
- \( \gamma_{rot} \) = 1.3 safety factor for residual strain
- \( \varepsilon_{r,\text{rot}} \) = limit residual strain from over bend

204 The above equations only consider rotation due to residual strain from installation along a straight path. Other effects can also give rotation (curved lay route, eccentric weight, hydrodynamic loads, reduced rotational resistance during pulls due to lateral play/elasticity in tensioners/pads/tracks etc) and need to be considered.

205 Instability during operation, due to out of straightness caused by the installation method and the corresponding consequences, shall be determined. Residual stresses affecting present and future operations and modifications shall also be considered.

206 The requirement for straightness applies to the assumed most unfavourable functional and environmental load conditions during installation and repair. This requirement also applies to sections of a pipeline where the strains are completely controlled by the curvature of a rigid ramp (e.g. stinger on installation vessel), whether or not environmental loads are acting on the pipe.

Guidance note:
Rotation of the pipe within the tensioner clamps of the pipe due to elasticity of the rubber and slack shall be included in the evaluation of the rotation.

H 300 Coating

301 Concrete crushing due to excessive compressive forces for static conditions in the concrete during bending at the over-bend is not acceptable.
SECTION 6
LINEPIPE

A. General

A 100 Scope

101 This section specifies the requirements for materials, manufacture, testing and documentation of linepipe, with regard to the characteristic properties of materials which shall be obtained after heat treatment, expansion and final shaping.

102 The requirements are applicable for linepipe in:

— Carbon Manganese (C-Mn) steel,
— clad/lined steel, and
— corrosion resistant alloys (CRA) including ferritic austenitic (duplex) steel, austenitic stainless steels, martensitic stainless steels (“13% Cr”), other stainless steels and nickel-based alloys.

103 Materials, manufacturing methods and procedures that comply with recognised practices or proprietary specifications are normally acceptable provided such standards comply with the requirements of this section.

A 200 Material specification

201 A material specification referring to this section (Section 6) of the offshore standard shall be prepared stating additional requirements and/or deviations to materials, manufacture, fabrication and testing of linepipe.

202 The specification shall reflect the results of the materials selection (see Section 5B 500) and shall include specific, detailed requirements to the properties of the linepipe. The specified properties of materials and weldments shall be consistent with the specific application and operational requirements of the pipeline system. Suitable allowances shall be included for possible degradation of the mechanical properties resulting from subsequent fabrication and installation activities.

203 The specification may be a Material Data Sheet (MDS) referring to this standard. The MDS should include specific requirements subject to agreement etc.

204 Specific requirements to the manufacturing processes shall be stated in the Manufacturing Procedure Specification (MPS) (see E 300). The type and extent of testing, the applicable acceptance criteria for verifying the properties of the material, and the extent and type of documentation, records and certification shall be stated in the MPS.

A 300 Pre-qualification of materials and manufacturers

301 Pre-qualification of materials based on the media to be transported, loads, temperatures and service conditions, shall be considered in order to verify that the materials will fulfil functional requirements.

302 Requirements for the pre-qualification of manufacturers shall be considered in each case. The consideration shall take into account the complexity and criticality of the product to be supplied, and the requirements of this standard.

A 400 Process of manufacture

401 The linepipe shall be manufactured according to one of the following processes:

Submerged Arc-Welded (SAWL or SAWH) linepipe

402 Linepipe manufactured by forming from strip or plate and with one longitudinal (SAWL) or spiral (helical) (SAWH) seam formed by the submerged arc process, with at least one pass made on the inside and one pass from the outside of the pipe. An intermittent or continuous single pass tack weld may be made by the gas metal arc welding method. The forming may be followed by cold expansion to obtain the required dimensions.

Seamless (SML) linepipe

403 Linepipe manufactured by a hot forming process without welding. In order to obtain the required dimensions, the hot forming may be followed by sizing or cold finishing.

High Frequency Welded (HFW) linepipe

404 Linepipe formed from strip (skelp) and welded with one longitudinal seam, without the use of filler metal. The longitudinal seam is generated by high frequency current (minimum 100 kHz) applied by induction or conduction. The weld area shall be heat treated. The forming may be followed by cold expansion to obtain the required dimensions.

Electron Beam (EBW) and Laser Beam Welded (LBW) linepipe

405 Linepipe formed from strip (skelp) and welded with one longitudinal seam, with or without the use of filler metal. The forming may be followed by cold expansion to obtain the required dimensions.

Clad steel (C) linepipe

406 Clad steel linepipe can be manufactured by any manufacturing process which guarantees a metallurgical bond between the base metal and the cladding.

Lined steel (L) linepipe

407 Lined steel linepipe can be manufactured by any process which guarantees a mechanical bonding between the base and lining material.

408 Welding procedures, welding consumables, welding personnel, handling of welding consumables, and the execution of welding shall meet the requirements of Appendix C.

B. Linepipe Designations

B 100 Linepipe NDT levels

101 C-Mn steel linepipe and the C-Mn steel section of clad/lined steel pipes with longitudinal or helical weld seams have, in this offshore standard, been divided into two (2) NDT levels; NDT Level I and NDT Level II. NDT Level I has more stringent requirements to NDT of the pipe longitudinal or helical weld seam.

102 Linepipe with NDT Level I allows use of displacement controlled criteria (strain based design), whereas NDT Level II is restricted to load controlled conditions (see Section 5B 500 and C 100).

B 200 Supplementary requirements

201 Linepipe to this standard may be provided meeting supplementary requirements for:

— sour service, suffix S (see D 100),
— fracture arrest properties, suffix F (see D 200),
— linepipe for plastic deformation, suffix P (see D 300),
— enhanced dimensional requirements for linepipe, suffix D (see D 400), and
— high utilisation, suffix U (see D 500).
The supplementary requirements shall be addressed in the MPS and the required tests shall be included in the qualification of the MPS.

**B 300 Designations**

301 Carbon Manganese linepipe and clad/lined steel pipes, to be used to this standard, shall be designated with:

- process of manufacture (see A 400),
- SMYS,
- NDT level (see B 100 and,
- supplementary requirement suffix (see B 200).

E.g. "SML 450 I S" designates a seamless pipe with SMYS 450 MPa, NDT Level I and meeting sour environment requirements.

E.g. "SAWL 415 II L - UNS XXXXX" designates a submerged arc welded pipe, with SMYS 415 MPa, NDT level II, lined with a UNS designated material.

302 Duplex stainless steel linepipe to be used to this standard shall be designated with:

- process of manufacture (see A 400),
- grade (see C 300), and
- supplementary requirement suffix (see B 200).

E.g. "SML 22Cr D" designates a seamless 22Cr grade meeting the enhanced dimensional requirements.

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**C. Material Properties**

**C 100 General**

101 Requirements for steel making, chemical analysis, pipe manufacture, type and extent of mechanical testing and NDT are given in E below.

102 For pipe OD > 300 mm, tensile properties shall be tested in both transverse and longitudinal direction to the pipe axis, while the Charpy V-notch samples shall be tested only in the transverse direction. All mechanical and corrosion testing shall be conducted in accordance with Appendix B.

103 For pipe OD ≤ 300 mm, all mechanical testing shall be conducted in the longitudinal direction. All mechanical and corrosion testing shall be conducted in accordance with Appendix B.

104 If materials shall be used at a design temperature above 50°C, the yield stress at the T_max may be determined during the qualification of the manufacturing procedure specification. This information shall be obtained either by use of the curves in Sec.5 B600 or by testing.

105 When applicable, linepipe to this standard shall also meet the appropriate supplementary requirements.

---

If the cold forming during pipe manufacture of C-Mn and clad/lined steels exceeds 5% strain, strain ageing tests shall be performed on the actual pipe without any straightening and additional deformation. Strain ageing tests shall conform to Table 6-11. The absorbed energy shall not be less than 50% of the energy absorption obtained in the un-aged linepipe material, and the required Charpy V-notch impact properties of Table 6-3 shall be met in the aged condition. The testing shall be performed in accordance with Appendix B.

Testing of Charpy V-notch impact properties shall, in general, be performed on test specimens 10x10mm. Where test pieces with a width < 10mm are used, the measured impact energy (KV_m) and the test piece cross-section measured under the notch (A) (mm²) shall be reported. For comparison with the values in Table 6-3 the measured energy shall be converted to the impact energy (KV) in Joules using the formula:

\[ KV = \frac{8 \times 10 \times KV_m}{A} \]  

(6.1)

**C 200 Carbon Manganese (C-Mn) steel linepipe**

201 These requirements are applicable to welded or seamless linepipe in C-Mn steel with SMYS up to 555 MPa. Use of higher strength shall be subject to agreement.

**Chemical composition**

202 The chemical composition of C-Mn steel parent materials shall be within the limits given in Table 6-1 and Table 6-2 for the appropriate yield stress levels. The chemical composition of mother pipes for bends shall be within the limits given in Section 7.

**Mechanical properties**

203 Mechanical testing shall be performed after heat treatment, expansion and final shaping. The testing shall be performed in accordance with Appendix B.

204 Requirements for tensile and Charpy V-notch properties are given in Table 6-3 and Table 6-4. Welds shall meet the requirement for KVT impact properties given in Table 6-3.

205 Unless sour service is specified (see D 100), the hardness in the Base Material (BM) and weld (weld metal + HAZ) shall comply with Table 6-3.

206 Fracture toughness testing of the Base Material (BM) and the Weld Metal (WM) (welded linepipe) shall be conducted as part of the qualification (Table 6-11 and Table 6-12). The measured fracture toughness of the BM and the WM, shall as a minimum have a CTOD value of 0.20 mm when tested at the minimum design temperature. The testing shall be performed in accordance with Appendix B A 800. Testing is not required for pipes with t_nom < 13 mm.
## Table 6-1  Welded C-Mn steel linepipe, chemical composition

<table>
<thead>
<tr>
<th>SMYS</th>
<th>245</th>
<th>290</th>
<th>360</th>
<th>415</th>
<th>450</th>
<th>485</th>
<th>555</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.14</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>Mn 5)</td>
<td>1.35</td>
<td>1.65</td>
<td>1.65</td>
<td>1.65</td>
<td>1.65</td>
<td>1.75</td>
<td>1.85</td>
</tr>
<tr>
<td>Si</td>
<td>0.40</td>
<td>0.40</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>P</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>S</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>Cu</td>
<td>0.35</td>
<td>0.35</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Ni</td>
<td>0.30</td>
<td>0.30</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Mo</td>
<td>0.10</td>
<td>0.10</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Cr 6)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Al (total) 7)</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Nb 8)(9)</td>
<td>-</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>V 8)</td>
<td>-</td>
<td>0.04</td>
<td>0.05</td>
<td>0.08</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Ti 8)</td>
<td>-</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>N 7)</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>B 10)</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
<tr>
<td>CE 11)</td>
<td>0.36</td>
<td>0.34</td>
<td>0.37</td>
<td>0.38</td>
<td>0.39</td>
<td>0.41</td>
<td>0.44</td>
</tr>
<tr>
<td>$P_{cm}$ 12)</td>
<td>0.19</td>
<td>0.19</td>
<td>0.20</td>
<td>0.21</td>
<td>0.22</td>
<td>0.23</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### Notes

1) Chemical composition applies for wall thicknesses up to 35 mm and shall be subject to agreement for larger wall thicknesses.

2) When scrap material is being used in steel production, the amount of the following residual elements shall be determined and reported, and the levels shall not exceed: 0.03% As, 0.01% Sb, 0.02% Sn, 0.01% Pb, 0.01% Bi and 0.006% Ca.

3) When calcium is intentionally added, the Ca/S ratio shall be $= 1.5$ when S $> 0.0015$.

4) Except for deoxidation elements, other elements than those mentioned in this table shall not be intentionally added if not specifically agreed.

5) For each reduction of 0.01% carbon below the maximum specified value, an increase of 0.05% manganese above the specified maximum values is permitted with a maximum increase of 0.1%.

6) 0.5-1.0% Cr may be used subject to agreement.

7) Al:N $\geq$ 2:1 (not applicable for titanium killed steels).

8) $(\text{Nb} + \text{V} + \text{Ti})_{\text{max}}$: 0.12%. This value may be increased to maximum 0.15% subject to agreement.

9) For SMYS = 485 MPa and for cladded material, the Nb content may be increased to 0.10% subject to agreement.

10) Boron (max 30 ppm) may be added subject to agreement.

11) $CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$

12) $P_{cm} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + \frac{B}{5}$
### Table 6-2 Seamless C-Mn steel linepipe, chemical composition

<table>
<thead>
<tr>
<th>SMYS</th>
<th>245</th>
<th>290</th>
<th>360</th>
<th>415</th>
<th>450</th>
<th>485</th>
<th>555</th>
</tr>
</thead>
<tbody>
<tr>
<td>C  4)</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.15</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Mn 4)</td>
<td>1.35</td>
<td>1.65</td>
<td>1.65</td>
<td>1.65</td>
<td>1.75</td>
<td>1.85</td>
<td>1.85</td>
</tr>
<tr>
<td>Si</td>
<td>0.40</td>
<td>0.40</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>P</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>S</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>Cu</td>
<td>0.35</td>
<td>0.35</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Ni</td>
<td>0.30</td>
<td>0.30</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Mo</td>
<td>0.10</td>
<td>0.10</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Cr  5)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Al (total) 6)</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Nb  7)</td>
<td>-</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>V  7)</td>
<td>-</td>
<td>0.04</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Ti  7)</td>
<td>-</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>N  6)</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
<td>B  8)</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

#### Notes

1) Chemical composition applies for wall thicknesses up to 26 mm and shall be subject to agreement for larger wall thicknesses.

2) When scrap material is being used in steel production, the amount of the following residual elements shall be determined and reported, and the levels shall not exceed: 0.03% As, 0.01% Sb, 0.02% Sn, 0.01% Pb, 0.01% Bi and 0.006% Ca.

3) Except for deoxidation elements, other elements than those mentioned in this table shall not be intentionally added if not specifically agreed.

4) For each deduction of 0.01% carbon below the maximum specified value, an increase of 0.05% manganese above the specified maximum values is permitted with a maximum increase of 0.1%.

5) 0.5-1.0% Cr may be used subject to agreement.

6) Al:N ≥ 2:1 (not applicable for titanium killed steels)

7) (Nb+V+Ti)% maximum: 0.12% This value may be increased to maximum 0.15% subject to agreement.

8) Boron (max 30 ppm) may be added subject to agreement.

9) \[ CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15} \]

10) \[ P_{cm} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B \]
Table 6-3 C-Mn steel linepipe, mechanical properties $^{1,2}$

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>RISERS</th>
<th>PIPELINES</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 $\leq t &lt; 40$</td>
<td>$T_0 = T_{\text{min}} - 10$</td>
<td>$T_0 = T_{\text{min}} - 20$</td>
<td>1) Mixed gas and liquid (s) are to be regarded as gas.</td>
</tr>
<tr>
<td>$t &gt; 40$</td>
<td>$T_0 = T_{\text{min}} - 10$</td>
<td>$T_0 = T_{\text{min}} - 20$</td>
<td>2) Increasing thicknesses will require lower test temperatures. Alternatively higher absorbed energy at the same temperature shall be required.</td>
</tr>
</tbody>
</table>

Table 6-4 C-Mn steel linepipe, Charpy V-notch testing temperatures $T_0$ (ºC) as a function of $T_{\text{min}}$ (ºC) (Minimum Design Temperature)

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Nominal wall</th>
<th>RISERS</th>
<th>PIPELINES</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 $\leq t &lt; 40$</td>
<td>$T_0 = T_{\text{min}} - 10$</td>
<td>$T_0 = T_{\text{min}} - 20$</td>
<td>1) Mixed gas and liquid (s) are to be regarded as gas.</td>
<td></td>
</tr>
<tr>
<td>$t &gt; 40$</td>
<td>$T_0 = T_{\text{min}} - 10$</td>
<td>$T_0 = T_{\text{min}} - 20$</td>
<td>2) Increasing thicknesses will require lower test temperatures. Alternatively higher absorbed energy at the same temperature shall be required.</td>
<td></td>
</tr>
</tbody>
</table>

C 300 Ferritic-austenitic (duplex) steel

301 The requirements are applicable to welded and seamless linepipe in 22Cr and 25Cr Duplex stainless steel grades according to ASTM A790 (Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe), or an accepted equivalent standard.

Chemical composition

302 The chemical composition of duplex stainless steel parent materials shall be within the limits given in Table 6-5. Modifications are subject to agreement.

Metallographic examination

303 Metallographic examination of the base material and of the weld metal root, the weld metal cap, and the heat affected zone in the root area of welded pipe shall be performed and comply with requirements in 304 below.

304 Metallographic examination shall be performed after final solution heat treatment. The examination shall be conducted at 400X magnification. The material shall be essentially free from grain boundary carbides, nitrides and intermetallic phases after solution heat treatment. The ferrite content shall be measured according to ASTM E562 (Standard Practice for Determining Volume Fraction by Systematic Manual Point Count). Base material ferrite content shall be within the range 35-55%. For weld metal root, weld metal cap, and heat affected zone, the ferrite content shall be within the range 35-65%.

Mechanical properties

305 Mechanical testing shall be performed after heat treatment, expansion and final shaping. Requirements for tensile and Charpy V-notch properties are given in Table 6-6. Weldment shall meet the requirement for KVT impact properties.

306 Unless sour service requirements apply (see D 100), the hardness in the Base Material (BM) and the weld (weld metal + HAZ) shall comply with Table 6-6.

307 Fracture toughness testing of the Base Material (BM) and the Weld Metal (WM) (welded linepipe) shall be conducted as part of the qualification (Table 6-11 and Table 6-12). The measured fracture toughness of the BM and the WM shall, as a minimum, have a CTOD value of 0.20mm when tested at the minimum design temperature. The testing shall be performed in accordance with Appendix B A 800. Testing is not required for pipes with $t_{\text{nom}} < 13$mm.

Corrosion testing

308 Corrosion testing according to ASTM G 48 shall be performed in order to confirm adequate manufacturing procedures affecting the microstructure of 25 Cr Duplex stainless steel. For 25 Cr duplex with a specified PRE value of minimum 40, testing to ASTM G 48 shall be performed in accordance with Appendix B. The maximum allowable weight loss is 4.0 g/m² for solution annealed material tested 24 hours at 50°C.

309 If testing to ASTM G 48 shall be performed for duplex stainless steel with a PRE value less than 40, the testing temperature and/or acceptance criteria shall be subject to agree-
C 400 Other stainless steel and nickel based corrosion resistant alloy (CRA) linepipe

401 The requirements below are applicable to austenitic stainless steels, martensitic ("13% Cr") stainless steels and nickel based CRAs.

402 The linepipe shall be supplied in accordance with a recognised standard that defines the chemical composition, mechanical properties and all the issues listed in Section 5 B500 and as specified in the following. If a recognised standard is not available, a specification shall be prepared that defines these requirements.

403 For martensitic stainless steels ("13% Cr") the same requirements for fracture toughness as for C-Mn steels shall apply (see 206).

Corrosion testing

404 The same requirements as stated in 308 for duplex stainless steel shall apply for other stainless steel and nickel based corrosion resistant alloys with a specified PRE value of minimum 40.

Metallographic examination of welds

405 Metallographic examination at a magnification of 400X of the weld metal and the HAZ shall be performed. The material shall be essentially free from grain boundary carbides, nitrides and intermetallic phases after solution heat treatment.

C 500 Clad/lined steel linepipe

501 The requirements below are applicable to linepipe consisting of a C-Mn steel base material and a thinner internal metallic layer.

502 Linepipe is denoted "clad" if the bond between base and cladding material is metallurgical, and "lined" if the bond is mechanical.

503 The cladding and the lined material shall be compatible with the service requirements and shall be determined and agreed in each case. The cladding/lined material thickness shall not be less than 2.5 mm.

Supply condition

504 Clad/lined linepipe shall be supplied in the heat-treatment condition that is appropriate for both types of material.

Chemical composition and mechanical properties of base material

505 The chemical composition of the base material shall comply with the requirements to C-Mn steel for linepipe given in Table 6-1 and Table 6-2.

506 The mechanical properties of the base material shall meet the requirements in Table 6-3 and Table 6-4. Mechanical testing shall be performed after heat treatment, expansion and final shaping.

507 Fracture toughness testing of the Base Material (BM) and the Weld Metal (WM) (welded linepipe), shall be conduct-
ed as part of the qualification (Table 6-12 and Table 6-13). The measured fracture toughness of the BM and the WM shall, as a minimum, have a CTOD value of 0.20mm, when tested at the minimum design temperature. The testing shall be performed in accordance with Appendix B A 800. Testing is not required for pipes with \( t_{nom} < 13\text{mm} \).

508 The cladding/lining material shall be removed from the test pieces prior to testing.

**Chemical composition of cladding/lining material**

509 Cladding/lining materials shall primarily be selected on the basis of requirements to corrosion resistance, including SSC. The chemical composition of cladding materials shall be specified according to recognised standards. If a recognised standard is not available, a specification shall be prepared that defines these requirements. Applicable requirements in C 300 and C 400 shall be met.

**Chemical composition of weld metal**

510 The welding consumables shall be selected taking into consideration the reduction of alloying elements by dilution of iron from the base material.

**Metallographic examination of welds**

511 Metallographic examination of the weld metal and the HAZ in the root area of the cladding material, shall be performed at a magnification of 400X. The microstructure shall be essentially free from grain boundary carbides, nitrides and intermetallic phases.

**Properties of clad material and linepipe**

512 Two bend tests from each plate/strip shall be bent 180° around a former with a diameter three times the plate thickness. One test piece shall be bent with the cladding material in tension, the other with the cladding material in compression. After bending there shall be no sign of cracking or separation on the edges of the specimens. The bend test shall be carried out in as specified Appendix B.

513 Shear testing in accordance with Appendix B shall be performed as required in Table 6-11 and Table 6-12. The minimum shear strength shall be 140 MPa.

514 Hardness testing of welded linepipe shall be performed on a test piece comprising the full cross section of the weld. Indentations shall be made in the base material, the cladding material and the metallurgical bonding area as detailed in Appendix B.

515 The hardness of base material, cladding material, HAZ, weld metal and the metallurgical bonding area shall meet the relevant requirements of this standard (see Table 6-3 and Table 6-6).

C 600 Weldability

601 Steels shall have adequate weldability for all stages of manufacture, fabrication and installation of the pipeline, including field and contingency conditions, hyperbaric welding and anode installation.

602 Welding and repair welding procedures, welding personal, handling of welding consumables, and the execution of welding shall meet the requirements in Appendix C.

**Guidance note:**

Local brittle zones (LBZs) can be formed in the HAZ of C-Mn microalloyed steels. These areas tend to exhibit very low cleavage resistance, resulting in low CTOD values. The LBZs are associated with the sections of the HAZs that are experiencing grain coarsening during the welding operation. The microstructure in these zones consists predominantly of a bainitic structure, with a large amount of martensite/austenite (M/A) constituents (B_t-microstructure). The M/A constituents, as opposed to ferrite/carbide aggregate such as pearlite, may have a detrimental effect on the material’s toughness. This should particularly be kept in mind when selecting the chemical composition for steels with SMYS ≥ 450 MPa.

In order to improve HAZ toughness, it is essential to refine the grain size and suppress the formation of bainite with M/A constituents.

---end---of---Guidance---note---

603 The linepipe supplier shall provide information with regard to appropriate Post Weld Heat Treatment (PWHT) temperature for the respective materials.

**Pre-production weldability testing**

604 For qualification of pipeline materials and welding consumables, a weldability testing programme as specified below should be performed. The type and extent of testing, and the acceptance criteria for weldability testing shall be agreed in each case.

605 Relevant documentation may be agreed in lieu of the weldability testing.

**C-Mn steels and martensitic (‘‘13% Cr’’) stainless steels**

606 For steels with SMYS ≥ 415 MPa, the weldability testing/documentation shall, as a minimum, include bead on plate, Y-groove, and also fracture toughness tests of base material and HAZ. In addition, for steels with SMYS ≥ 450 MPa, metallographic examination should be conducted to establish the presence of LBZs. The testing program shall be in accordance with Table 6-11, Table 6-12 and Appendix C. The maximum and minimum heat inputs giving acceptable properties in the weld zones of the linepipe, with corresponding preheat temperatures and working temperatures, shall be determined for both fabrication and installation welding.

607 For materials where only limited practical experience exists, the programme may further include HAZ thermal cycling tests, continuous cooling transformation tests, delayed cracking tests and controlled thermal severity tests.

**Duplex stainless steel**

608 For duplex stainless steel, the weldability testing/documentation shall determine the effect of thermal cycles on the mechanical properties, hardness, and microstructure. The maximum and minimum heat inputs giving an acceptable ferrite/austenite ratio and a material essentially free from intermetallic phases shall be determined for both fabrication and installation welding. Allowances for repair welding shall be included.

**Other stainless steels and nickel based alloys**

609 For austenitic stainless steels and nickel based CRA’s, the weldability testing/documentation shall determine the effect of thermal cycles on the mechanical properties, hardness and microstructure. The range of heat inputs giving properties shall be determined for both fabrication and installation welding, including allowances for repair welding.

**Clad/lined steel linepipe**

610 For clad/lined linepipe, the weldability of the base material shall be tested/documentated as required in 604 and 605. For the clad/lining material, the weldability testing/documentation shall determine the dilution effects and the effect of thermal cycles on the mechanical properties, hardness and microstructure. The range of heat inputs giving acceptable properties shall be determined for both fabrication and installation welding. Allowances for repair welding shall be included.

**D. Supplementary Requirements**

D 100 Supplementary requirement, sour service (S)

101 For pipelines to be used for fluids containing hydrogen sulphide and defined as "sour service" according to NACE Standard MR0175 (Sulphide Stress Cracking Resistant Metal
lic Materials for Oil Field Equipment), all requirements to materials selection, maximum hardness, and manufacturing and fabrication procedures given in the latest edition of the said standard shall apply. This includes pipelines which are nominally dry (i.e. free from liquid water during normal operation) if other conditions for sour service according to the above standard are valid. Further, the additional requirements, modifications and clarifications defined below shall apply.

102 Use of linepipe materials not listed for sour service in NACE MR0175 (latest edition) and not covered by this section shall be qualified according to the guidelines of the said document. As an alternative, the guidelines for qualification in EFC Publications No. 16 and No.17 may be used for C-Mn and CRA linepipe respectively. The qualification shall include testing of Sulphide Stress Cracking (SSC) resistance of base materials and welds (seam welds and girth welds, as applicable).

Guidance note:
SSC-testing as specified in the referenced NACE and EFC document has a duration of 720 hours and is, as such, unsuitable for purchase release purposes.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

103 Qualification is also applicable to linepipe materials listed for sour service in NACE MR0175, in case hardness or other requirements relating to manufacturing or fabrication deviate from those in this document.

Guidance note:
It may also be considered to specify SSC testing of grades meeting all requirements for sour service in this standard, as a part of a program for pre-qualification of linepipe manufacturing or installation procedures.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

104 All welding procedures (including repair welding) shall be qualified and include hardness testing as specified in Appendix C, Paragraph E.

C-Mn steel linepipe

105 C-Mn steels with SMYS exceeding 450 MPa are not covered by NACE MR0175 (as per 1998), and shall be pre-qualified for sour service as stated in 102 unless later included in the said document.

106 The chemical composition shall be modified as given in Table 6-7 and Table 6-8. Other elements not listed in these tables shall be in accordance with Table 6-1 and Table 6-2 respectively. The notes given Table 6-1 and Table 6-2 shall apply.

Table 6-7 Chemical composition of welded C-Mn steel linepipe for supplementary requirement, sour service

<table>
<thead>
<tr>
<th>SMYS (MPa)</th>
<th>Up to 360</th>
<th>415</th>
<th>450</th>
</tr>
</thead>
<tbody>
<tr>
<td>C max.</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Mn max.</td>
<td>1.35</td>
<td>1.45</td>
<td>1.55</td>
</tr>
<tr>
<td>P max.</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>S max.</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Cu max.</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Ni max.</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Mo max.</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Cr max.</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>P cm max.</td>
<td>0.19</td>
<td>0.20</td>
<td>0.21</td>
</tr>
</tbody>
</table>

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

107 Additional requirements to steel making as given in E.403 shall apply.

108 Welded linepipe resistance to Hydrogen Pressure Induced Cracking (HPIC) shall be verified by testing (ref. Appendix B) during qualification of the MPS and linepipe manufacturing, as stated in E 800.

Guidance note:
Hydrogen Pressure Induced Cracking (HPIC) as used in this document is frequently referred to as either Hydrogen Induced Cracking (HIC) or Stepwise Cracking (SWC).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

109 During welding procedure qualification and production, hardness measurements shall be performed as given in Appendix B. The hardness in the base material, weld and HAZ shall not exceed 250 HV10 in the root area, and 275 HV10 in the cap area.

Guidance note:
It is recommended to specify a maximum hardness of 220 HV10 for the base material in order to allow for hardness increase during girth welding.

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Duplex steel linepipe

110 Linepipe grades, associated hardness criteria, and requirements to manufacturing/fabrication shall comply with NACE MR0175 (latest edition). During welding procedure qualification and production, hardness measurements shall be performed as given in Appendix B. For 22 Cr Duplex and 25Cr Duplex, the hardness in the weld shall not exceed 310 HV10 and 330 HV10 respectively.

Clad/lined steel linepipe

111 Materials selection for cladding/lining, the associated hardness criteria, and requirements to manufacturing and fabrication shall comply with NACE MR0175 (latest edition). The same applies to welding consumables for weldments exposed to the internal fluid. The selection of the C-Mn steel base material is not subject to any special sour service requirements.

112 During qualification of welding procedures and production, hardness measurements shall be performed as indicated in Appendix B. The hardness in the internal heat-affected zone and in the fused zone of the cladding/lining shall comply with relevant requirements of NACE MR0175 (latest edition).

D 200 Supplementary requirement, fracture arrest properties (F)

201 The requirements to fracture arrest properties are valid for gas pipelines carrying essentially pure methane up to 80% usage factor, up to a pressure of 15 MPa and to 30mm wall thickness. Fracture arrest properties outside these limitations, or for less severe conditions, shall be subject to agreement (see Section 5D 1100). Charpy toughness values for fracture arrest properties need to be determined at the following temperatures:

- **SMYS (MPa):**
  - Up to 360
  - 415
  - 450

- **Product analysis, maximum weight %**
  - **SMYS (MPa):**
    - Up to 360
    - 415
    - 450
  - **C max.:** 0.12
  - **Mn max.:** 1.35
  - **P max.:** 0.015
  - **S max.:** 0.003
  - **Cu max.:** 0.35
  - **Ni max.:** 0.30
  - **Mo max.:** 0.10
  - **Cr max.:** 0.30
  - **P cm max.:** 0.19

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
given in Table 6-9 are valid for full size (10 mm x 10 mm) specimens.

**C-Mn steel linepipe**

202 A Charpy V-notch transition curve shall be established for the linepipe base material. Five sets of specimens shall be tested at different temperatures, including $T_{\text{min}}$. The Charpy V-notch energy value in the transverse direction and at $T_{\text{min}}$ shall, as a minimum, meet the values given in Table 6-9. The values obtained in the longitudinal direction, when tested, shall be at least 50% higher than the values required in the transverse direction.

203 This paragraph shall apply for all linepipes to be delivered without a final heat treatment (normalising or quench and tempering) of the entire pipe. A Charpy V-notch transition curve shall be established for the linepipe base material in the strain-aged condition. The plastic deformation shall be equal to the actual deformation introduced during manufacturing (no additional straining is required). The samples shall be aged for 1 hour at 250°C. Five sets of specimens shall be tested at different temperatures, including $T_{\text{min}}$. The Charpy V-notch energy value in the transverse direction, and at $T_{\text{min}}$, shall not be less than 50% of the energy absorption obtained in the undeformed/un-aged condition (see 202), and shall as a minimum, meet the values given in Table 6-9 in the deformed and aged condition. Values obtained at other test temperatures are for information. The values obtained in the longitudinal direction, when tested, shall at least be 50% higher than the values required in the transverse direction.
Table 6-9  Charpy V-notch Impact Test Requirements for Fracture Arrest Properties tested at T_{min} (Joules; Transverse Values; Average value of three specimens) 1)

| Wall thickness | \( \leq 30 \text{ mm} \) 2)
|---------------|-----------------
| OD (mm)       |                 |
| \( \leq 610 \) | \( \leq 820 \)  | \( \leq 1120 \) |
| SMYS          |                 |
| 245           | 40              | 40              |
| 290           | 43              | 52              |
| 360           | 61              | 75              |
| 415           | 77              | 95              |
| 450           | 89              | 109             |
| 485           | 100             | 124             |
| 555           | 126             | 155             |

Notes

1) Minimum individual results to exceed 75% of these values
2) Fracture arrest properties for larger wall thicknesses and diameters shall be subject to agreement (see Section 5 D800)

204 Drop Weight Tear (DWT) testing shall only be performed on linepipe with outer diameter \( > 500 \text{ mm} \), wall thickness \( > 8 \text{ mm} \), and SMYS \( > 360 \text{ MPa} \). The DWT testing shall include testing of one set for each of the following five temperatures: -70, -50, -30, 0 and +20°C. If one of these temperatures equals the minimum design temperature, the set shall be tested 10°C below this temperature. Two additional sets shall be tested at the minimum design temperature. Each set shall consist of two specimens taken from the same test coupon. The test shall be performed in accordance with Appendix B. The specimens tested at the minimum design temperature shall as a minimum, meet an average of 85% shear area with one minimum value of 75%.

205 For linepipe material with SMYS \( \geq 450 \text{ MPa} \) and a wall thickness \( \geq 25 \text{ mm} \), the acceptance criteria stated in 204 (average and minimum shear area) may be subject to agreement when supplementary requirements for sour service (D 100) are specified concurrently with supplementary requirements for fracture arrest (D 200).

Duplex stainless steel linepipe

206 A Charpy V-notch transition curve shall be established for duplex stainless steel base material. Five sets of specimens shall be tested in the temperature range from \(-80 \degree\text{C}\) to \(+20 \degree\text{C}\). The Charpy V-notch energy value in the transverse direction, at the \( T_{\text{min}} \), shall be according to Table 6-6.

Clad/lined steel linepipe

207 For clad/lined steel linepipe, the requirements as for C-Mn steels apply to the base material.

D 300 Supplementary requirement, linepipe for plastic deformation (P)

301 Supplementary requirement (P) is only applicable for seamless linepipe material made of C-Mn and duplex stainless steels, exposed to an accumulated plastic strain from installation and operation, \( \varepsilon_p \geq 2\% \) (see Section 5D 800 and Section 9E).

302 Requirements for welded linepipe and linepipe in other materials are subject to agreement. The following additional requirements and modifications for linepipe material and dimensional tolerances shall apply.

Guidance note:

Strain hardening capacity is an essential parameter for pipes which are to be exposed to large plastic strain, ref. e.g. Section 12K 400.

The requirements of supplementary requirement P are hence often hard to meet for material grades with SMYS exceeding 415 MPa.

303 The dimensional tolerances should meet supplementary requirements for enhanced dimensional requirements for linepipe (D) in D 400.

304 The finished pipe is recommended to meet the following requirements prior to being tested according to 305:

- the measured yield stress of base material should not exceed SMYS by more than 100 MPa;
- the YS/TS ratio should not exceed 0.85, and
- the elongation should be minimum 25%.

305 Mechanical testing shall be performed on samples removed from finished pipe. The samples shall be successively deformed by uni-axial tension and compression, in steps corresponding to those of the installation process. \( \varepsilon_p \) shall be at least equal to the \( \varepsilon_e \) introduced during installation and service. The samples shall be artificially aged at 250°C for one hour before testing. The testing shall be conducted in accordance with Appendix B.

306 The testing shall include:

- tensile testing,
- hardness testing, and
- Charpy V-notch impact toughness testing. Test temperature shall be according to Table 6-4 or Table 6-6 as relevant.

307 The following requirements shall be met after straining (see 305):

- longitudinal yield stress and tensile strength shall meet the requirements of Table 6-3 or Table 6-6 as relevant, and
- the YS/TS ratio shall not exceed 0.97, and
- the elongation shall be minimum 15%, and
- Charpy V-notch impact toughness shall be according to Table 6-3 or Table 6-6 as relevant, and
- the hardness shall meet the requirements in C.205 or C.306 as relevant.

Subject to agreement, a higher yield stress may be accepted for duplex stainless steel pipes for use in umbilicals.

308 If the supplementary requirement for sour service (S) and/or fracture arrest properties (F) is required, the testing for these supplementary requirements shall be performed on samples that are removed, strained and artificially aged in accordance with 305. The relevant acceptance criteria shall be met.

D 400 Supplementary requirement, dimensions (D)

401 Supplementary requirements for enhanced dimensional requirements for linepipe (D) are given in E 1200 and Table 6-15.

402 Requirements for tolerances should be selected considering the influence of dimensions and tolerances on the subsequent fabrication/installation activities and the welding facilities to be used.
D 500  Supplementary requirement, high utilisation (U)

501  Supplementary requirements for high utilisation (U) shall be applied for linepipe material utilised in accordance with Section 5B 600, and should also, in general, be applied for linepipe material with SMYS = 450 MPa. The provided test scheme is valid for production in excess of 50 lots. Supplementary requirement U shall be conducted in addition to the requirements specified in E 800. Supplementary requirement U does only consider the SMYS in the transverse direction.

502  The test regime given in this sub-section intend to ensure that the average yield stress is at least two standard deviations above SMYS and the ultimate strength is at least three standard deviations above SMTS. The testing scheme applies to production in excess of 50 lots. Alternative ways of documenting the same based upon earlier test results in the same production is allowed.

503  The objective of the extended test program specified below is to ensure a high confidence in achieving consistent yield stress for linepipe materials subjected to high utilisation during service. The supplementary requirement U only considers the yield stress of the material. All other properties shall be tested in accordance with E 800.

Mandatory mechanical testing

504  The testing frequency shall comply with E.805.

505  If the results from the mandatory testing meet the requirement SMYS x 1.03, no further testing is required in order to accept the test unit (see E.804).

506  If the result from the mandatory testing falls below SMYS, the re-test program given in 508 shall apply.

Confirmatory mechanical testing

507  If the mandatory test result falls between SMYS x 1.03 and SMYS, then two (2) confirmatory tests taken from two (2) different pipes (a total of two tests) within the same test unit shall be performed. If the confirmatory tests meet SMYS, the test unit is acceptable. If one or both of the confirmatory tests fall below SMYS, the re-test program given in 509 shall apply.

Re-testing

508  If the result from the mandatory testing falls below SMYS, four (4) re-tests taken from four (4) different pipes (a total of 4 tests), within the same test unit, shall be tested. If the four re-tests meet SMYS, the test unit is acceptable. If one of the re-tests fall below SMYS the test unit shall be rejected.

509  If one or both of the confirmatory tests fail to meet SMYS, two (2) re-tests taken from each of two (2) different pipes within the same test unit shall be tested for each of the failed confirmatory tests (a total of 4 tests). If all re-tests meet SMYS, the test unit is acceptable. If any of the re-tests fall below SMYS the test unit shall be rejected.

510  Re-testing of failed pipes is not permitted.

511  If the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample shall be replaced by a correctly prepared sample from the same pipe, and a retest performed.

512  If a test unit has been rejected after re-testing (508, 509 above), the Manufacturer may conduct individual testing of all the remaining pipes in the test unit. If the total rejection of all the pipes within one test unit exceeds 15%, including the pipes failing the mandatory and/or confirmatory tests, the test unit shall be rejected.

513  In this situation, the Manufacturer shall investigate and report the reason for failure and shall change the manufacturing process if required. Re-qualification of the MPS is required if the agreed allowed variation of any parameter is exceeded (see E.304).

E. Manufacture

E 100  General

101  The following requirements are applicable to the manufacture of linepipe in C-Mn, duplex, and clad/tidned steel.

102  Manufacture of linepipe in other metallic materials shall be performed according to a specification that meets the requirements of A 200 and applicable requirements of this sub-section.

E 200  Quality Assurance

201  Manufacturers of linepipe shall have an implemented quality assurance system meeting the requirements of ISO 9002. Further requirements to quality assurance are given in Section 2B 500.

E 300  Manufacturing Procedure Specification and Qualification

Manufacturing Procedure Specification (MPS)

301  Before production commences, the Manufacturer shall prepare an MPS. The MPS shall demonstrate how the specified properties may be achieved and verified through the proposed manufacturing route. The MPS shall address all factors which influence the quality and reliability of production. All main manufacturing steps from control of received raw material to shipment of finished pipe, including all examination and check points, shall be covered in detail. References to the procedures established for the execution of all steps shall be included.

302  The MPS shall as a minimum contain the following information:

- plan(s) and process flow description/diagram;
- project specific quality plan;
- manufacturing process (see A 400);
- manufacturer and manufacturing location of raw material and/or plate for welded pipes;
- raw material scrap content including allowable variation;
- steelmaking process, casting process, alloying practice, rolling or working condition and heat treatment, including target values and proposed allowable variation in process parameters;
- target values for chemical composition, including a critical combination of intended elements and proposed allowable variation from target values;
- pipe forming process;
- alignment and joint design for welding and production WPS (see Appendix C);
- final heat treatment condition;
- method for cold expansion/sizing/finishing, target and maximum sizing ratio;
- NDT procedures;
- pressure test procedures;
- list of specified mechanical and corrosion testing;
- dimensional control procedures;
- pipe number allocation;
- pipe tracking procedure;
- marking, coating and protection procedures;
- handling, loading and shipping procedures, and
- reference to applicable supplementary requirements (see B 200).

303  The MPS shall be subject to agreement.

Manufacturing Procedure Qualification Test (MPQT)
304 The MPS shall be qualified for each pipe size. Each MPQT shall include full qualification of two pipes from two different lots (see 809). The minimum type and extent of chemical, mechanical, and non-destructive testing are given in Table 6-11, Table 6-12 and Table 6-13, and the acceptance criteria for qualification of the MPS are given in this section. Testing shall be performed as described in Appendix B and Appendix D.

305 Qualification of welding procedures shall be performed in accordance with Appendix C.

306 For C-Mn steels with SMYS ≥ 450 MPa, duplex stainless steels and clad/lined steels the qualification of the MPS should be completed prior to start of production. Qualification during first day of production is performed at Manufacturer's own risk.

307 Additional testing may be required (e.g. weldability testing, analysis for trace elements for steel made from scrap, etc.) as part of the qualification of the MPS.

308 The validity of the qualification of the MPS shall be limited to the steelmaking, rolling, and manufacturing/fabrication facilities where the qualification was performed.

309 If one or more tests in the qualification of the MPS fail to meet the requirements, the MPS shall be reviewed and modified as necessary, and a complete re-qualification performed.

310 For C-Mn steels with SMYS < 450 MPa that are not intended for sour service, relevant documentation may be agreed in lieu of qualification testing.

E 400 Steel making

401 All steel making shall be performed using the raw materials stated in the qualified MPS, follow the same activity sequence, and stay within the agreed allowable variations. The manufacturing practice and instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be described in the MPS.

402 All steels shall be made by an electric or one of the basic oxygen processes. C-Mn steel shall be fully killed and made to a fine grain practice. Details and follow-up of limiting macro, as well as micro, segregation shall be given in the MPS. Duplex stainless steel shall be refined by argon oxygen or vacuum oxygen decarburisation before casting.

403 For steel to be used for linepipe meeting the supplementary requirement for sour service (see D 100), special attention to impurities and inclusion shape control shall be required. Details of the inclusion shape control treatment shall be given in the MPS.

404 Before undergoing plate/strip/pipe forming, the slabs/ingots shall be inspected and fulfill the surface finish requirements specified in the MPS.

E 500 Manufacture of plate and strip

Manufacturing

501 All manufacturing of plate and strip shall be performed following the sequence of activities and within the agreed allowable variations of the qualified MPS. The manufacturing practice and the instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be described in the MPS.

502 The following requirements shall apply for the manufacturing:

— the mill shall have proper control of start and finish rolling temperature, rolling reduction and post-rolling cooling rate (i.e. accelerated cooling);
— plate and strip thickness shall be controlled by continuously operating devices;
— heat treatment shall be controlled by temperature measuring devices;
— plate and strip edges shall be cut back sufficiently after rolling, to ensure freedom from defects; and
— strip end welds shall not be permitted unless specifically agreed.

Non-destructive testing

503 The following NDT shall be performed either at the plate/strip mill, or at the pipe mill:

— full ultrasonic testing of plate and strip, or pipe body, for laminar imperfections;
— full ultrasonic testing of clad plate, or clad pipe body, for laminar imperfections and lack of bonding;
— full ultrasonic testing of the edges of plate/strip covering at least a 50 mm wide band on the inside of future weld preparations.

The ultrasonic testing shall meet the requirements of Appendix D. All NDT shall be performed after final heat treatment of the plate or strip.

Workmanship, visual examination and repair of defects

504 Plates and strip shall be subject to 100% visual examination on both sides. The inspection shall be performed in a sufficiently illuminated area (approximately 500 lx) by trained personnel with sufficient visual acuity (e.g. Jaeger J-w eyesight test at 300 mm within the last 12 months). The surface finish produced by the manufacturing process, shall ensure that surface imperfections can be detected by visual inspection.

505 The surface finish produced by the manufacturing process, shall ensure that surface imperfections can be detected by visual inspection. Cracks, notches and gouges are not acceptable. Other imperfections such as scabs, seams, laps, tears, slivers, impressed mill scale etc. shall only be acceptable if not exceeding 2% of the nominal wall thickness, with a maximum of 0.5 mm. The actual remaining wall thickness shall be above the minimum allowable wall thickness (Table 6-14, Table 6-15 as applicable). Surface defects shall not appear over large areas.

506 Surface defects in the plate or strip may be removed by local manual grinding provided that:

— the wall thickness is not in any position reduced to a value below the minimum allowed, and never more than 3 mm; and
— the sum of all ground areas does not exceed 10% of the total surface area of each plate or strip.

507 Grinding by the use of automatic equipment may be performed subject to agreement.

508 Grinding may introduce cold working and hardnesses incompatible with the service requirements for plate and strip intended to meet the supplementary requirements for sour service (see D 100). In such cases hardness testing may be required in order to permit grinding.

509 Repair of plate and strip by welding is not permitted.

Mechanical testing of clad steel plate and strip

510 Clad steel plate and strip shall be tested according to, and meet the requirements given in, C 500.

E 600 Linepipe manufacture

601 Manufacturing of linepipe shall be performed using the starting materials specified, following the sequence of activities, and within the agreed allowable variations and the essential variables of the qualified WPS (see Appendix C). Joiners should not be permitted.

Processes of manufacture

602 Manufacture of linepipe shall be in accordance with one of the processes given in A 400.
Starting material and supply conditions

603 Linepipe in C-Mn steel for $T_{\text{min}} \leq +5^\circ \text{C}$ shall be manufactured using the starting materials and corresponding forming methods and final heat treatment as given in Table 6-10.

604 Duplex stainless steel pipe shall be delivered in solution-annaled and water-quenched condition.

605 Clad/lined steel linepipe shall be supplied in the heat treatment condition which is appropriate for both types of material. The heat treatment shall be in line with the steel Manufacturer’s recommendations.

Cold expansion and cold sizing

606 The extent of cold sizing and cold forming expressed as the sizing ratio $s_r$, shall be calculated according to the following formula:

$$s_r = \left( \frac{D_a - D_b}{D_a} \right) \times 100\%$$

where

$D_a$ is the outside diameter after sizing
$D_b$ is the outside diameter before sizing

The extent of cold sizing and cold forming shall be calculated according to the following formula:

$$s_r = \left( \frac{D_a - D_b}{D_a} \right) \times 100\%$$

where

$D_a$ is the outside diameter after sizing
$D_b$ is the outside diameter before sizing

Traceability

607 A system for traceability of the heat number, heat treatment batch, lot number and test unit number of the starting material and the records from all required tests to each individual pipe shall be established and described in the MPS. Care shall be exercised during storage and handling to preserve the identification of materials.

Manufacture of seamless pipe

608 The manufacturing practice and the instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be described in the MPS:

— wall thickness shall be controlled by continuously operating devices;
— pipe ends shall be cut back sufficiently after rolling to ensure freedom from defects; and
— pipes may be sized to their final dimensions by expansion or reduction. This shall not produce excessive permanent strain. In cases of cold sizing, where no further heat treatment is performed, the sizing ratio, $s_r$ shall not exceed 0.015.

<table>
<thead>
<tr>
<th>Type of pipe</th>
<th>Starting Material</th>
<th>Pipe forming</th>
<th>Final heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seamless pipe (SML)</td>
<td>Ingot and continuously cast</td>
<td>Hot rolling</td>
<td>Normalised or normalising formed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hot rolling and cold finishing</td>
<td>Quenched and tempered</td>
</tr>
<tr>
<td>High frequency welded pipe (HFW)</td>
<td>Normalising rolled strip</td>
<td>Cold forming</td>
<td>Normalised weld area</td>
</tr>
<tr>
<td></td>
<td>Thermo-mechanically rolled strip</td>
<td></td>
<td>Heat treated weld area</td>
</tr>
<tr>
<td></td>
<td>Hot rolled or normalising rolled strip</td>
<td></td>
<td>Entire pipe normalised</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cold forming and hot stretch under controlled temperature, resulting in a normalised condition</td>
<td>Entire pipe quenched and tempered</td>
</tr>
<tr>
<td>Submerged arc welded pipe</td>
<td>Normalised or normalising rolled plate or strip</td>
<td>Cold forming</td>
<td>None, unless required due to degree of cold forming</td>
</tr>
<tr>
<td>— longitudinal seam (SAWL)</td>
<td>Thermo-mechanically rolled plate or strip</td>
<td></td>
<td>Quenching and tempering</td>
</tr>
<tr>
<td>— helical seam (SAWH)</td>
<td>Quenched and tempered plate or strip</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Soft annealed plate or strip</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>As-rolled plate or strip</td>
<td>Normalising forming</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Normalised or normalising rolled plate or strip</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Manufacture of welded pipe

609 Welding procedures, welding personnel, handling of welding consumables and the execution and quality assurance of welding, shall meet the requirements of Appendix C.

610 The manufacturing practice including forming, welding and heat treatment, and the methods used to control manufacturing process variables and their tolerances, shall be described in the MPS. The following requirements apply:

— plate and strip shall be cut to the required width and the weld bevel prepared by milling or other agreed methods before forming;
— cold forming (i.e. below 250°C) of C-Mn steel shall not introduce a plastic deformation exceeding 5% for clad and C-Mn steels, unless heat treatment is performed or strain ageing tests show acceptable results (see C.106);
— normalised forming of materials and weldments shall be performed as recommended by the Manufacturers of the plate/strip and welding consumables;
— run-on and run-off tabs shall be of sufficient length such that the welding arcs are stabilised before the welding pool enters the pipe material, and the entire welding pool has left the pipe material before stop of welding;
— high-frequency welded pipes should not contain strip end welds;
— spiral welded pipes should not contain strip weld connections;
— the strip width for spiral welded pipes, should not be less than 0.8 and not more than 3.0 times the pipe diameter;
— arc stops during welding shall be repaired according to a qualified welding repair procedure;
— cold expansion for SAWL pipe should be within the range $0.003 < s_r < 0.015$. Expansion shall not introduce high local deformations;
— HFW and SAWH pipes may be sized to their final dimensions by expansion or reduction. This shall not produce excessive permanent strain. In cases of cold sizing, where no further heat treatment or only heat treatment of the weld area is performed, the sizing ratio, $s_r$ shall not exceed 0.015;
— welded clad steel linepipe shall be formed, welded and heat treated as recommended by the starting material Manufacturer;
— heat treatment shall be performed as recommended by the material Manufacturer with regard to heating and cooling rates, soaking time, and soaking temperature;
— the outside and/or internal weld bead shall be ground flush to an agreed length at both pipe ends.
Further, one pipe from every heat following the initially failed of these three tests fail, then all the ten heats shall be tested.

If any of the tests during the subsequent testing fail (one pipe from each lot) or once per 100 pipes, whatever gives the highest test frequency.

Methods and procedures for chemical analysis shall be according to recognised industry standards, and be referred to in the MPS.

All elements listed in Table 6-1, Table 6-2 or Table 6-5 as relevant shall be determined and reported. Other elements added for controlling the material properties may be added, subject to agreement. When scrap material is being used for production of C-Mn steel, the content of the elements As, Sb, Sn, Pb, Bi and Ca shall be checked once during MPS/MPQ and reported, and meet the requirements given in Table 6-1 and Table 6-2. Limitations on amount of scrap metal shall then be stated in the MPS.

If the value of any elements, or combination of elements fails to meet the requirements, a re-test consisting of two specimens shall be made. The re-test specimens shall be sampled from two additional pipes from the same heat. If one or both re-tests still fail to meet the requirements, the heat should be rejected.

Requirements for methods and procedures for mechanical and corrosion testing are given in Appendix B.

Sampling for mechanical and corrosion testing shall be performed after heat treatment, expansion and final shaping. Location of the samples shall be as shown in Appendix B. The samples shall not be flame cut or prepared in a manner that may influence their mechanical properties.

Samples intended for strain age testing shall be taken from pipes that have been subjected to the maximum expansion allowed.

The mechanical and corrosion testing shall include the testing shown in Table 6-11 and Table 6-12 as applicable. The tests required for qualification of the MPS are denoted "Q", and the tests required for production testing are denoted "P". Testing of other materials than those listed in Table 6-11 and Table 6-12 shall be subject to agreement, however, the testing should, as a minimum incorporate the testing stated in these tables.

Mechanical and corrosion testing

Mechanical testing during manufacturing shall be performed on one randomly selected pipe from each lot, (see 809) or once per 50 pipes, whatever gives the highest testing frequency. This number of pipes is denoted "test unit".

HPIC testing during manufacturing shall be performed on one randomly selected pipe from each of the three (3) first heats, or until three consecutive heats have shown acceptable test results.

After three consecutive heats have shown acceptable test results, the testing frequency for the subsequent production may be reduced to one per casting sequence. The Ca/S ratio shall be greater than 1.5 (see Table 6-1).

If any of the tests during the subsequent testing fail (one test per casting sequence), three pipes from three different heats of the last ten heats, selecting the heats with the lowest Ca/S ratio, shall be tested. Providing these three tests show acceptable results, the ten heats are acceptable. However, if any of these three tests fail, then all the ten heats shall be tested. Further, one pipe from every heat following the initially failed heat shall be tested until the test results from three consecutive heats have been found acceptable. After three consecutive heats have shown acceptable test results, the testing frequency may again be reduced to one test per casting sequence.

In order to accept or reject a particular heat, re-testing shall be conducted in accordance with 811 to 815.

A 'lot' is defined as pipes from:

- the same heat,
- the same heat treatment batch (if applicable), and
- the same diameter and wall thickness.

For linepipe material subjected to a high utilisation (see Section 5), supplementary requirements for high utilisation (U) shall apply (D 500), in addition to the requirements given in E 800.

Re-testing

If one of the tests fails to meet the requirements, two additional re-tests shall be performed on samples taken from two different pipes within the same test unit. Both re-tests shall meet the specified requirements. The test unit shall be rejected if one or both of the re-tests do not meet the requirements.

If a test unit has been rejected, the Manufacturer may conduct individual testing of all the remaining pipes in the test unit. If the total rejection of all the pipes within one test unit exceeds 25%, the test unit shall be rejected. In this situation the Manufacturer shall investigate and report the reason for failure and shall change the manufacturing process if required. Re-qualification of the MPS is required if the agreed allowed variation of any parameter is exceeded (see 304).

Re-testing of failed pipes shall not be permitted. If a pipe fails due to low CVN values in the fusion line (HAZ), testing of samples from the same pipe may be performed subject to agreement.

The reason for the failure of any test shall be established and appropriate corrective action performed to avoid re-occurrence of test failures.

If the test results are influenced by improper sampling, machining, preparation, treatment or testing, the test sample shall be replaced by a correctly prepared sample from the same pipe and a retest performed.

Non-destructive testing

General

Linepipe shall be subjected to non-destructive testing (NDT). Requirements for personnel, methods, equipment, procedures and acceptance criteria for NDT are given in Appendix D.

When automated NDT equipment is used, a short area at both pipe ends may not be tested. The untreated ends may either be cut off or the ends subjected to NDT, as detailed in Appendix E. The extent of untreated ends and description of the technique, sensitivity and parameters used for testing of the pipe ends shall be included in the MPS.

NDT of linepipe shall be performed after completion of all cold straightening, forming, heat treatment and expansion.

Type and extent of non-destructive testing

NDT for qualification of the MPS and during production shall be carried out according to Table 6-13.

If deviations from the requirements are found, the extent of testing shall be increased as agreed until a consistent com-
Table 6.11 Welded linepipe - mechanical and corrosion testing 1)

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Location</th>
<th>Pipe material</th>
<th>C-Mn Steel</th>
<th>Duplex Steel</th>
<th>Clad/lined Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile test</td>
<td>Pipe body</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Charpy V-notch test</td>
<td>Weldment</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Bend test</td>
<td>Weldment</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
<tr>
<td>Hardness test 3)</td>
<td>Pipe body</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
</tbody>
</table>

Table 6.12 Seamless linepipe - mechanical and corrosion testing (S) (see D 100)

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Location</th>
<th>Pipe material</th>
<th>C-Mn steel</th>
<th>Duplex Steel</th>
<th>Clad/lined Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile tests</td>
<td></td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Charpy V-notch test</td>
<td></td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Weldability tests 3)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
<tr>
<td>Hardness test 4)</td>
<td></td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
<tr>
<td>Metallographic examination</td>
<td></td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
<tr>
<td>Fracture toughness test</td>
<td></td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Strain ageing test 4)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Weldability testing 3)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
</tr>
<tr>
<td>Pitting corrosion test 5)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Shear strength and bend tests 6)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
</tbody>
</table>

Additional testing for supplementary requirement, sour service (S) (see D 100)

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Location</th>
<th>Pipe material</th>
<th>C-Mn steel</th>
<th>Duplex Steel</th>
<th>Clad/lined Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSC test 8)</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
</tbody>
</table>

Additional testing for supplementary requirement, fracture arrest properties (F) (see D 200)

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Location</th>
<th>Pipe material</th>
<th>C-Mn steel</th>
<th>Duplex Steel</th>
<th>Clad/lined Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charpy V-notch transition curve test</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Strain aging transition curve test</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
<tr>
<td>Drop weight tear test</td>
<td></td>
<td>Q</td>
<td>Q &amp; P</td>
<td>Q &amp; P</td>
<td>Q &amp; P (2)</td>
</tr>
</tbody>
</table>

Notes

1) All testing shall be performed in accordance with the requirements of Appendix B
2) Test of base material only.
3) Test shall be performed unless otherwise agreed (see C 600).
4) Acceptance criteria are different for sour and ordinary service.
6) See C.512 and C.513.
7) Not applicable for materials meeting all Supplementary Requirements for sour service in D 100.
8) HFW, EBW and LBW pipes, only.
E 1000 Visual inspection, workmanship and correction of defects

Visual inspection

1001 Each linepipe shall be subject to 100% visual inspection of the outside of the pipe body.

1002 For pipe with an internal diameter (ID) ≥ 610 mm, the interior of the pipe shall be 100% visually inspected. For pipe with an ID < 610 mm, the interior shall be inspected from both ends as far as access permits. Boroscopes or similar devices should be used to extend the access. The interior of duplex stainless steel and clad/lined material should be 100% visually inspected.

1003 The inspection shall be performed after heat treatment, expansion and final shaping, and in a sufficiently illuminated area (approximately 500 lx) by trained personnel with sufficient visual acuity (e.g. Jaeger J-w eyesight test at 300 mm within the last 12 months).

Workmanship

1004 The surface finish produced by the manufacturing process shall ensure that surface imperfections can be detected by visual inspection. Cracks, notches and gouges are not acceptable. Other imperfections such as scabs, seams, laps, tears, slivers, impressed mill scale etc. shall only be acceptable if not exceeding 2% of the nominal wall thickness, and with a maximum of 0.5 mm. The acceptance limit for surface imperfections on seamless pipes is 5% of the nominal wall thickness. The actual remaining wall thickness shall be above the minimum allowable wall thickness (Table 6-14, Table 6-15 as applicable). Surface defects shall not appear over large areas.

1005 The pipe surface of cold-formed welded linepipe shall have an even curvature without "flats" along the longitudinal/spiral weld seam, local thinning, steps and wavy edges. Dents, offset at plate edges, and out-of-line weld bead shall not exceed the limits given in Appendix D.

1006 Irregularities in the pipe curvature of cold-formed welded linepipe that may be caused by uneven hardness distribution shall be investigated to determine the hardness and dimensions of the area. Any hard spot exceeding 50 mm in any direction shall not have a hardness exceeding values given in Table 6-3, Table 6-6 as relevant.

For linepipe intended to meet the supplementary requirements for sour service, there shall be no hard spots with hardness exceeding:

- 250 HV10 internally and 275 HV10 externally, for C-Mn steel; and
- for other steels, maximum allowable hardness according to NACE MR0175 latest edition.

Regardless of their size, no hard spots outside the hardness re-
requirements for the applicable material are allowed within 100 mm of the pipe ends.

**1007** The weld seam of welded linepipe shall meet the acceptance criteria for visual examination given in Appendix D.

**Correction of defects**

**1008** Surface defects in the pipe body and weld seam (welded pipes) may be removed by local manual grinding provided that:

- the wall thickness is not in any position reduced to a value below the minimum allowed, and never more than 3 mm; and
- the sum of all ground areas does not exceed 10% of the total internal and external surface area of each pipe.

**1009** More extensive grinding may be performed by the use of automatic equipment.

**1010** Weld repair of pipe body is not permitted.

**1011** Repair welding of the weld seam is allowed for SAWL and SAWH pipes only and shall be performed in accordance with qualified welding repair procedures. Requirements for welding repair procedures are given in Appendix C. Repair welding may only be performed subject the following limitations:

- repair welding within a distance of 150 mm of the pipe ends shall not be allowed,
- repair welding of cracks shall not be allowed,
- total repair length in any weld shall not exceed 10% of the weld length,
- repair welding of previously repaired areas shall not be allowed,
- repair by welding after cold expansion shall not be allowed,
- the distance between two weld repair areas shall not be less than 150 mm,
- repair by welding after final heat treatment shall not be allowed,
- through thickness repair shall not be allowed, and
- hydrostatic testing and subsequent NDT shall be performed or repeated after weld repair.

**E 1100 Mill pressure test**

**1101** Each length of linepipe shall be hydrostatically tested, unless the alternative approach described in 1108 is used.

**1102** For pipes with reduced utilisation of the wall thickness, the test pressure \( p_h \) may be reduced as permitted in Section 5D 400.

**1103** The test pressure \( p_h \) for all other pipes shall, in situations where the seal is made on the inside or the outside of the linepipe surface, be conducted at the lowest value obtained by utilising the following formulæ:

\[
p_h = \frac{2 \cdot t_{\text{min}}}{D - t_{\text{min}}} \cdot \min[SMYS \cdot 0.96; SMTS \cdot 0.84] \tag{6.2}
\]

**1104** In situations where the seal is made against the end face of the linepipe by means of a ram or by welded on end caps, and the linepipe is exposed to axial stresses, the test pressure shall be calculated such that the maximum combined stress equals:

\[
s_{\text{c}} = \min[SMYS \cdot 0.96; SMTS \cdot 0.84] \tag{6.3}
\]

based on the minimum pipe wall thickness \( t_{\text{min}} \).

**Guidance note:**

The von Mises Equivalent stress shall be calculated as:

\[
\sigma_{\text{cc}} = \sqrt[4]{\frac{1}{N} \left( \sigma_h^2 + \sigma_l^2 - \sigma_h \cdot \sigma_l \right)}
\]

where

\[
\sigma_h = \frac{p_h \cdot (D - t_{\text{min}})}{2 \cdot t_{\text{min}}}
\]

\[
\sigma_l = \frac{N}{A_i}
\]

\[
N = \text{True pipe wall force which depend on the test set up end restraints.}
\]

\[
(t_{\text{min}} \text{ is equivalent to } t_1 \text{ in Section 5})
\]

**1105** In cases where the specified corrosion allowance restricts the test pressure due to mill testing capacity, the test pressure shall be \( p_h = 1.5 \cdot p_{ld} \), where \( p_{ld} \) is the local design pressure.

**1106** The test configuration shall permit bleeding of trapped air prior to pressurisation of the pipe. The pressure test equipment shall be equipped with a calibrated recording gauge. The applied pressure and the duration of each hydrostatic test shall be recorded together with the identification of the pipe tested. The equipment shall be capable of registering a pressure drop of minimum 2% of the applied pressure. The holding time at test pressure shall be minimum 10 seconds. Calibration records for the equipment shall be available.

**1107** Each pipe shall withstand the test pressure without any sign of leakage, sweats or permanent deformation. Linepipe that fails the hydrostatic test shall be rejected.

**1108** Subject to agreement, the hydrostatic testing may be omitted for expanded pipes manufactured by the UOE process. It shall in such situations be documented that the expansion process and subsequent pipe inspection will:

- ensure that the pipe material stress-strain curve is linear up to a stress corresponding to 1103,
- identify defects with the potential for through-thickness propagation under pressure loading, and
- identify pipes subject to excessive permanent deformation under pressure loading to a degree equivalent to that provided by hydrostatic testing.

Workmanship and inspection shall be at the same level as for hydrostatically tested pipe.

The expansion process parameters and inspection results shall be recorded for each pipe.

**E 1200 Dimensions, weight and lengths**

**1201** The extent of dimensional testing and dimensional tolerances are given in Table 6-14 and Table 6-15. If deviations from the requirements are found, the extent of testing shall be increased as agreed until a consistent compliance to the given requirements is re-established.

**1202** All test equipment shall be calibrated. The methods to be used for monitoring dimensions, shall be in accordance with the requirements given in 1204 to 1213.

**1203** All specified tests shall be recorded as acceptable or not acceptable. Wall thickness measurements shall be recorded for 10% of the specified tests. All other results shall be recorded for 100% of the specified tests.

**Diameter of pipe ends and pipe body**

**1204** The actual diameter of pipe ends and body shall be calculated based on circumferential measurements taken within 100 mm from each pipe end and for the pipe body, at the locations given in Table 6-14 or Table 6-15 as relevant. Unless oth-
erwise agreed, the diameter tolerance shall relate to the inside diameter for pipe ends and outside diameter for pipe body. A circumferential tape or calliper gauge can be used. External measurements shall be corrected by using the actual wall thickness.

Out-of-roundness for pipe ends and pipe body

1205 The out-of-roundness for pipe ends shall be calculated by the following formula:

\[ O = D_{\text{max}} - D_{\text{min}} \]  \hspace{1cm} (6.4)

where

\[ O \] = out-of-roundness in mm
\[ D_{\text{max}} \] = the largest measured inside or outside diameter
\[ D_{\text{min}} \] = the smallest measured inside or outside diameter

Unless otherwise agreed, out-of-roundness values shall relate to the inside diameter for pipe ends, and to outside diameter for pipe body.

1206 The largest and smallest inside diameters shall be measured at a minimum of four equally spaced positions around the circumference. Pipe end measurements shall be taken in the same cross-sectional plane, within 100 mm from the pipe end. Body measurements shall be taken in the same cross-sectional plan, approximately in the middle of the pipe length.

Local out-of-roundness.

1207 Local out-of-roundness, dents and peaking, shall be measured internally (when access permits) and externally, using a gauge with the correct curvature according to the specified nominal diameter. The distance between pipe body and the correct curvature shall be measured. Dial type gauges may be used subject to agreement.

Wall thickness at pipe end and pipe body

1208 The wall thickness shall be measured with a mechanical calliper or calibrated non-destructive testing device. Measurements for seamless pipe shall be taken in the same positions as specified in 1206. For welded pipe three measurements shall be taken; on both sides of the weld immediately adjacent to the weld, and directly opposite to the weld.

Straightness

1209 Straightness measurements shall be taken using a taut string or wire from end to end along the pipe measuring the greatest deviation or by other equivalent methods.

Preparation of pipe ends and end squareness.

1210 Pipe ends shall be cut square and shall be free from burrs. The out of squareness shall be measured. End preparations shall meet the specified dimensions and tolerances.

Radial offset (High-Low)

1211 The radial offset shall be measured at regular intervals along the length of the pipe. If radial offset is equal to or exceeds the acceptance criterion, the entire length of the pipe shall be accurately measured.

Weight

1212 Each pipe/pipe bundle shall be weighed separately and the weight recorded.

Length

1213 The length of each pipe shall be measured and recorded. The individual length and the average length of the delivered pipes shall meet the specified dimensions and tolerances, as given in the purchase order.
### Table 6-14 Standard dimensional requirements for linepipe

<table>
<thead>
<tr>
<th>Characteristic to be tested</th>
<th>Extent of testing</th>
<th>Welded pipe</th>
<th>Seamless pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter pipe ends (D^{1}) ≤ 610 mm</td>
<td>R (^{2,3})</td>
<td>±0.5 mm or ±0.5% (D^{1}) (whichever is greater), but max. ±1.6 mm</td>
<td>(</td>
</tr>
<tr>
<td>Diameter pipe ends (D^{1}) &gt; 610 mm</td>
<td>R (^{2})</td>
<td>±1.6 mm</td>
<td>±2.0 mm</td>
</tr>
<tr>
<td>Greatest difference in pipe diameter between pipe ends (each pipe measured)</td>
<td>R (^{2})</td>
<td>12.5% (t)</td>
<td></td>
</tr>
<tr>
<td>Diameter pipe body, (D^{1}) ≤ 610 mm</td>
<td>R (^{2,4})</td>
<td>±0.5 mm or ±0.75% (D^{1}) (whichever is greater), but max. ±3.0 mm</td>
<td>(</td>
</tr>
<tr>
<td>Out-of-roundness, pipe ends (Dh^{3}) ≤ 75</td>
<td>R (^{2})</td>
<td>10% (D^{1}), but max. 7.5 mm</td>
<td>1.5% (D^{1}), but max. 7.5 mm</td>
</tr>
<tr>
<td>Out-of-roundness, pipe ends, (Dh^{3}) &gt; 75</td>
<td>R (^{2})</td>
<td>1.5% (D^{1}), but max. 15.0 mm</td>
<td></td>
</tr>
<tr>
<td>Out-of-roundness, pipe body, (Dh^{3}) ≤ 75</td>
<td>R (^{2,4})</td>
<td>2.0% (D^{1}), but max. 15.0 mm</td>
<td></td>
</tr>
<tr>
<td>Out-of-roundness, pipe body, (Dh^{3}) &gt; 75</td>
<td>R (^{2,4})</td>
<td>(</td>
<td>± 0.5% (D^{1}) (whichever is greater)), but max. ±3.0 mm</td>
</tr>
<tr>
<td>Local out-of-roundness (5^{5})</td>
<td>R (^{2})</td>
<td>(&lt; 0.5% (D^{1}), but max. 2.5 mm</td>
<td>-</td>
</tr>
<tr>
<td>Wall thickness, (t^{3}) ≤ 15 mm</td>
<td>100% (^{6})</td>
<td>(</td>
<td>± 0.75\text{ mm}</td>
</tr>
<tr>
<td>Wall thickness, 15 &lt; (t^{3}) &lt; 20 mm</td>
<td>100% (^{6})</td>
<td>(</td>
<td>± 1.0\text{ mm}</td>
</tr>
<tr>
<td>Wall thickness, (t^{3}) ≥ 20 mm</td>
<td>100% (^{6})</td>
<td>(+ 1.5\text{ mm} / -1.0\text{ mm}</td>
<td>±10% (t^{3}), but max. ±3 mm</td>
</tr>
<tr>
<td>Straightness</td>
<td>R (^{2})</td>
<td>(</td>
<td>≤ 0.15% L</td>
</tr>
<tr>
<td>End squareness</td>
<td>R (^{2})</td>
<td>(</td>
<td>≤ 1.6\text{ mm from true }90^\circ</td>
</tr>
<tr>
<td>Radial offset (HFW, EBW, LBW pipes)</td>
<td>R (^{2})</td>
<td>(m_{\text{min}}\text{ at weld }\geq t_{\text{min}}^{8})</td>
<td>-</td>
</tr>
<tr>
<td>Radial offset (SAW pipes)</td>
<td>R (^{2})</td>
<td>(≤ 0.1; t^{3}), but max. 2.0 mm</td>
<td>-</td>
</tr>
<tr>
<td>Length of pipe</td>
<td>100%</td>
<td>see E1213</td>
<td></td>
</tr>
<tr>
<td>Weight of each single pipe/pipe bundle</td>
<td>100%</td>
<td>(-3.5% / +10% of nominal weight</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES**

1) \(D\) = specified outside or inside diameter (see 1204 and 1205)
2) R means random testing of 5% of the pipes per shift with a minimum of 3 pipes per shift.
3) \(t\) = specified nominal wall thickness.
4) Dimensions of pipe body to be measured approximately in the middle of the pipe length.
5) To be measured as a distance from a template with the same OD as the pipe and with a length of OD/4, max. 200mm
6) 100% means testing of every pipe.
7) \(m_{\text{min}}\) = actual measured minimum wall thickness of each measured pipe.
8) \(t_{\text{min}}\) = specified minimum wall thickness.

### Table 6-15 Supplementary requirements, enhanced dimensional requirements for linepipe, suffix \(1^{1}\)

<table>
<thead>
<tr>
<th>Characteristic to be tested</th>
<th>Extent of testing</th>
<th>Welded pipe</th>
<th>Seamless pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter pipe ends (D^{1}) ≤ 610 mm</td>
<td>100%</td>
<td>(</td>
<td>± 0.5\text{ mm or }± 0.3% (D^{1}) (whichever is greater)</td>
</tr>
<tr>
<td>Diameter pipe ends 310 &lt; (D^{1}) &lt; 610 mm</td>
<td>100%</td>
<td>(</td>
<td>± 1.6\text{ mm}</td>
</tr>
<tr>
<td>Diameter pipe ends (D^{1}) ≥ 610 mm</td>
<td>100%</td>
<td>(</td>
<td>± 2.0\text{ mm}</td>
</tr>
<tr>
<td>Greatest difference in pipe diameter between pipe ends (each pipe measured)</td>
<td>10%</td>
<td>10% (t), but max. 3 mm</td>
<td></td>
</tr>
<tr>
<td>Diameter pipe body (D^{1}) ≤ 610 mm</td>
<td>10%</td>
<td>(</td>
<td>± 0.5% (D^{1}), but max. ±1.25 mm</td>
</tr>
<tr>
<td>Diameter pipe body 310 &lt; (D^{1}) &lt; 610 mm</td>
<td>10%</td>
<td>(</td>
<td>± 0.75% (D^{1}), but max. ±3.0 mm</td>
</tr>
<tr>
<td>Diameter pipe body (D^{1}) ≥ 610 mm</td>
<td>10%</td>
<td>(</td>
<td>± 0.5% (D^{1}), but max. ±4.0 mm</td>
</tr>
<tr>
<td>Out-of-roundness, pipe ends (Dh^{3}) ≤ 75</td>
<td>100%</td>
<td>1.0% (D^{1}), but max. 5.0 mm</td>
<td></td>
</tr>
<tr>
<td>Out-of-roundness, pipe ends, (Dh^{3}) &gt; 75</td>
<td>100%</td>
<td>1.5% (D^{1}), but max. 5.0 mm</td>
<td></td>
</tr>
<tr>
<td>Out-of-roundness, pipe body, (Dh^{3}) ≤ 75</td>
<td>10% (^{4})</td>
<td>1.5% (D^{1}), but max. 10.0 mm</td>
<td></td>
</tr>
<tr>
<td>Out-of-roundness, pipe body, (Dh^{3}) &gt; 75</td>
<td>10% (^{4})</td>
<td>2.0% (D^{1}), but max. 10.0 mm</td>
<td></td>
</tr>
<tr>
<td>Local out-of-roundness (5^{5})</td>
<td>10%</td>
<td>(&lt; 0.5% (D^{1}), but max. 2.0 mm</td>
<td>-</td>
</tr>
<tr>
<td>Wall thickness, (t^{3}) ≤ 15 mm</td>
<td>100% (^{6})</td>
<td>(</td>
<td>± 0.5\text{ mm}</td>
</tr>
<tr>
<td>Wall thickness, 15 &lt; (t^{3}) &lt; 20 mm</td>
<td>100% (^{6})</td>
<td>(</td>
<td>± 0.75\text{ mm}</td>
</tr>
<tr>
<td>Wall thickness, (t^{3}) ≥ 20 mm</td>
<td>100% (^{6})</td>
<td>(</td>
<td>± 1.0\text{ mm}</td>
</tr>
<tr>
<td>Straightness</td>
<td>10%</td>
<td>(</td>
<td>≤ 0.15% L</td>
</tr>
<tr>
<td>End squareness</td>
<td>10%</td>
<td>(</td>
<td>1.6\text{ mm from true }90^\circ</td>
</tr>
<tr>
<td>Radial offset (HFW, EBW, LBW pipes)</td>
<td>10%</td>
<td>(m_{\text{min}}\text{ at weld }\geq t_{\text{min}}^{8})</td>
<td>-</td>
</tr>
</tbody>
</table>
### F. Marking and Protection

**F 100 General**

101 All marking shall be easily identifiable and in such a condition that it is readable during the subsequent activities.

102 The type of marking shall be subject to agreement.

103 Each linepipe shall be marked with a unique number. The marking shall reflect the correlation between the product and the respective inspection document.

104 On customer's request, each linepipe shall be protected until taken into use, including bevel protectors on bevelled pipes.

### G. Documentation, Records and Certification

**G 100 General**

101 Linepipe shall be delivered with Inspection Certificate 3.1.B according to European Standard EN 10204 (Metallic Products - Types of Inspection Documents) or an accepted equivalent.

102 The Inspection Certificate shall identify the products represented by the certificate, with reference to product number, heat number and heat treatment batch. The certificate shall include or refer to the results of all specified inspection, testing and measurements. The supply condition and the final heat treatment shall be stated in the certificate.

103 Records from the qualification of the MPS and other documentation shall be in accordance with the requirements in Section 3.
SECTION 7
COMPONENTS AND ASSEMBLIES

A. General

A 100 Scope

101 This section specifies requirements to the design, manufacture, fabrication, testing and documentation of pipeline components and structural items, and to the fabrication and testing of risers, expansion loops, pipe strings for reeling and towing.

A 200 Quality assurance

201 Requirements for quality assurance are given in Section 2B 500. Corresponding requirements for the material processing and the manufacture of components shall be specified.

B. General requirements for Design of Pipeline Components

B 100 General

101 All pressure-containing pipeline components shall generally represent the same safety level as the connecting riser/pipeline section.

102 Design of pipeline components shall be according to recognised standards. The strength shall, as a minimum be:

--- equivalent to the connecting pipeline, or
--- sufficient to accommodate any environmental load and the maximum forces that will be transferred to the component from the connecting pipeline under installation and operation.

Guidance note:
It should be noted that the definitions of yield stress used in other design and material standards may be different to those used for pipelines.

---end---of---G-u-i-d-a-n-c-e---n-o-t-e---

103 If the code or standard used for design of a component does not take into account forces other than the internal pressure, then additional calculations are required in order to address the maximum forces that can be transferred to the component from the connecting pipeline sections under installation and operation.

104 If the code or standard used for design of a component does not take into account the possibility for internal leakage due to forces transferred to the component from the connecting pipeline sections, then additional calculations or qualification tests shall be performed.

105 Design by finite element analysis should comply with ASME VIII, Division 2, Appendix 4 or an equivalent recognised standard.

106 External hydrostatic pressure shall be considered in the design with respect to both strength and leakage.

107 The following factors shall apply for the design of components unless the requirements of the selected code or standard are more stringent:

<table>
<thead>
<tr>
<th>Table 7-1 Design Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal pressure load factor (not hydrostatic test pressure)</td>
</tr>
<tr>
<td>External loads load factor</td>
</tr>
<tr>
<td>Usage factor</td>
</tr>
</tbody>
</table>

108 Sufficient strength and fitness for purpose shall be demonstrated in at least one of the following ways:
--- engineering calculations,
--- documented prototype testing,
--- documented history of successful use of the component, produced according to the same design, compatible materials, manufacturing and testing procedures and used under equivalent operating conditions,
--- strength test to failure, or
--- experimental stress analyses.

109 For piggable components the internal diameter of the component shall be equal to that of the connecting pipeline sections, and shall meet the same tolerance requirements.

110 The transition between a component and other items (e.g. connecting linepipe) where the material thickness or yield stress is unequal shall be according to ASME B31.8 Appendix I or equally recognised codes.

111 If the chemical composition and the delivery condition of components require qualification of a specific welding procedure for welding of the joint between the component and the connecting linepipe, then the component should be fitted with pup pieces of the linepipe material in order to avoid field welding of these components.

Alternatively, rings of the component material should be provided for welding procedure qualification of the field weld.

B 200 Material selection

201 The mechanical properties, chemical composition, weldability and corrosion resistance of materials used in components shall be compatible with the part of the pipeline system where they are located. Low internal temperatures due to system depressurisation shall be considered during the material selection.

202 The material in pipeline components and structural items shall be selected taking into account the considerations given in Section 5B 500. In addition, the suitability of a material for a particular application shall include consideration of the following aspects:
--- external and internal corrosion;
--- galvanic corrosion between dissimilar metals;
--- accumulation of seawater and other corrosive substances, and areas where chemical inhibition or cathodic protection may be ineffective;
--- suitability for use with the fluid to be transported, including any additives; and
--- resistance to abrasion or mechanical damage likely to occur during installation and operation.

203 A component should be forged rather than cast whenever a favourable grain flow pattern, a maximum degree of homogeneity, and the absence of internal flaws are of importance.

204 Particular consideration shall be given to the suitability of elastomers and polymers for use in the specific application and service conditions.

205 The need for pre-qualification of materials for the service condition shall be considered, based on the media to be transported, loads, temperatures and the material selected.

206 Where pre-qualification of materials is required, the extent of testing and investigations to be performed for a complete qualification shall be specified.

207 Requirements for the pre-qualification of processes,
tests, and manufacturers shall be considered in each case. The consideration shall take into account the complexity and criticality of the product to be supplied, and the requirements of this standard.

**B 300  Flanged and mechanical connections**

301 Flanges shall meet the requirements of ISO 7005-1 or another recognised code.

302 The flange bore should match the internal diameter of adjoining pipe.

303 Flanges of proprietary design, including swivel joint flanges and hub type pipeline joints, shall be designed according to relevant sections of pressure vessel codes such as ASME VIII or BS5500. Additional calculations may be required to demonstrate that the requirements of 102, 103 and 104 are met.

304 The sealing faces of flanges shall have a surface finish, hardness and roughness suitable for the gaskets to be applied.

305 Gaskets shall be capable of withstanding the maximum pressure to which they could be subjected, as well as installation forces if flanges are laid in-line with the pipeline. Gaskets for flanges shall be made from metallic materials that are resistant to the fluid to be transported in the pipeline system. Galvanic corrosion shall be avoided. Mechanical properties shall be maintained at the anticipated in service pressures and temperatures.

306 Seals shall be designed to allow testing without pressurising the pipeline.

307 For guidance for design of couplings (sleeve type couplings) reference is made to DNV RP-F104, "Submarine Pipeline Couplings". The principles of this RP may also be applied to clamps.

308 Specifications for the tools required to install and make-up the components shall be established.

**B 400  Bolting**

401 Bolts and nuts for subsea use shall be in accordance with Table 7-2. Equivalent standards may be used subject to agreement.

<table>
<thead>
<tr>
<th>Table 7-2 Bolts and nuts for subsea use</th>
<th>Bolt</th>
<th>Nut</th>
<th>Size range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A320, Grade L7</td>
<td>ASTM A194, Grade 4/S3 (Low-temperature requirement for Grade 4 and Grade 7 nuts)</td>
<td>&lt; 50 mm</td>
<td></td>
</tr>
<tr>
<td>ASTM A320, Grade L4</td>
<td>ASTM A194, Grade 7</td>
<td>&lt; 100 mm</td>
<td></td>
</tr>
</tbody>
</table>

402 Bolts and nuts for use in above water and onshore components shall be in accordance with Table 7-3. Equivalent standards may be used, subject to agreement.

<table>
<thead>
<tr>
<th>Table 7-3 Bolts and nuts for use above water/onshore</th>
<th>Bolt</th>
<th>Nut</th>
<th>Size range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A193, Grade B7</td>
<td>ASTM A194, Grade 2H</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>ASTM A193, Grade B6</td>
<td>ASTM A194, Grade 7</td>
<td>All</td>
<td></td>
</tr>
</tbody>
</table>

403 Bolts and nuts for bolts with diameter 25mm and above shall be impact tested to the same requirements as for the steel to be bolted.

404 The hardness of bolts in carbon steel and/or low alloy material shall be less than 350HV10.

405 Carbon steel and/or low alloy bolting material shall be hot dip galvanised or have similar corrosion protection. For submerged applications or when bolting torque is specified, electrolytic galvanising or phosphating shall be used. Hot dip and electrolytic galvanising shall be followed by post-baking. For subsea use, polytetrafluoroethylene (PTFE) based coatings may be used provided electrical continuity is verified by measurements.

Cadmium plating shall not be used.

406 If other bolting materials are required for corrosion resistance or other reasons, the material shall be selected in accordance with the material selection requirements of the standard. For subsea applications, Inconel 625 (UNS N06625) shall be used when corrosion resistant bolts and nuts are required at ambient temperature, i.e. when bolts are exposed to aerated seawater and cathodic protection cannot be ensured. It shall be verified that the materials have acceptable mechanical properties at the minimum and maximum design temperature.

407 Proprietary bolting materials may be used for CRA pipelines. It shall be verified that the materials have acceptable mechanical properties at the minimum and maximum design temperature, and are tested for compatibility with cathodic protection systems.

**B 500  Valves**

501 Valves shall meet the requirements of ISO 14313, API 6D or equivalent codes or standards. Additional calculations may be required to demonstrate that the requirements of 102, 103 and 104 are met.

502 The design shall ensure that internal gaskets are able to seal, and shall include a documented safety margin which is valid during all relevant pipeline operating conditions. Sealing will be sensitive to internal deflections, enlargement of gaps and changes in their support conditions. Valve operation will be sensitive to friction and clearances.

503 Consideration should be given to requirements for durability when exposed to abrasive material (e.g. weld scale, sand etc.) or to fire loads.

504 Valves with requirements for fire durability shall be qualified by applicable fire tests. Reference may be made to API 6FA and BS 6755 Part 2 for test procedures.

505 Valve control systems and actuators shall be designed and manufactured in accordance with recognised standards. The valve actuator specification should define torque requirements for valve operation, with a suitable safety margin to accommodate deterioration and friction increase during service.

**B 600  Pressure vessels**

601 Pressure vessels such as pig traps and slug catchers shall be designed in accordance with ASME VIII, BS 5500 or equivalent standard.

602 The design of closures and items such as nozzle reinforcements, saddle supports, vent- kick and drain branches shall comply with the applied design standard.

603 Closures shall be designed such that the closure cannot be opened while the pig trap is pressurised. An interlock arrangement with the main pipeline valve should be provided.

**B 700  Components fabricated by welding**

701 The design of components fabricated by welding of plate shall be in accordance with industry recognised engineering practices. Where such components cannot be designed in accordance with this standard, the design shall be in accordance with ASME VIII, BS 5500 or equivalent standards. Additional calculations may be required to demonstrate that the requirements of 102, 103 and 104 are met.

**B 800  Insulating joints**

801 Prefabricated insulating joints shall be designed in accordance with ASME VIII, BS 5500 or equivalent standards. Additional calculations may be required to demonstrate that the requirements of B102, B103 and B104 are met.

802 The insulating and spacing materials shall be resistant to the fluid transported in the pipeline system. Mechanical prop-
properties shall be maintained at the anticipated in service pressures and temperatures.

803 Insulating joints shall be pressure tested at a constant temperature as follows:
- hydrostatic test to 1.50 x design pressure with a holding time of minimum 2 hours; and
- hydraulic fatigue test consisting of 40 consecutive cycles with the pressure changed from about 10bar to 85% of the hydrostatic test pressure. At the completion of the test cycles the pressure shall be increased to the hydrostatic test pressure and maintained for 30 minutes.

804 No pressure drops are allowed during hydrostatic testing, and no leaks are allowed during the tests.

805 After having passed the pressure tests, the joint shall be dried with hot air and tested to confirm electrical discontinuity with the joint in the vertical position as follows:
- electrical resistance test, and
- dielectric strength test

806 The electrical resistance test shall give a resistance of at least 5 Mohms at 1000 V of applied continuous current. If the joint shows electrical resistance below the required value it shall be dried again and re-tested. One re-test only shall be allowed.

807 The dielectric strength test shall be performed by applying an AC sinusoidal current with a frequency of 50 - 60 Hz to the joint. The current shall be applied gradually, starting from an initial value not exceeding 1.2kV increasing to 2.5kV in a time not longer than 10 seconds and shall be maintained at peak value for 60 seconds. The test is acceptable if no breakdown of the insulation or surface arcing occurs during the test.

B 900 Pipeline fittings

901 Tees shall be of the extruded outlet, integral reinforcement type. The design shall be according to ASME B31.4, B31.8 or equivalent. Additional calculations may be required to demonstrate that the requirements of 102 and 103 are met.

902 Bars of barred tees should not be welded directly to the high stress areas around the extrusion neck. It is recommended that the bars transverse to the flow direction are welded to a pup piece, and that the bars parallel to the flow direction are welded to the transverse bars only. If this is impracticable, alternative designs should be considered in order to avoid peak stresses at the ends.

903 Y-pieces and tees where the axis of the outlet is not perpendicular to the axis of the run (lateral tees) shall not be designed to ASME B31.4 or B31.8, as these items require special consideration, i.e. design by finite element analysis. Additional calculations may be required to demonstrate that the requirements of 102 and 103 are met.

904 The design of hot taps shall ensure that the use of and the design of the component will result in compliance with API Recommended Practice 2201, "Procedure for Welding and Hot Tapping on Equipment in Service".

905 Standard butt welding fittings complying with ANSI B16.9, MSS SP-75 or equivalent standards may be used provided that:
- the actual bursting strength of the fitting is demonstrated to exceed that of the adjoining pipe; and
- the fitting is demonstrated to be able to accommodate the maximum forces that can occur in the pipeline, both under installation and operation and the requirements of 102 and 103.

906 End caps for permanent use shall be designed according to ASME VIII, BS 5500 or equivalent standards.

907 Steel socket welding fittings shall not be used.

B 1000 Anchor flanges

1001 Anchor flanges shall be designed for pressure containment according to ASME VIII, BS 5500 or equivalent standards.

1002 Additional calculations may be required to demonstrate that the requirements of 102 and 103 are met.

B 1100 Other components

1101 System components which are not specifically covered in this subsection shall be demonstrated as fit for purpose as stated in B 100.

B 1200 Structural items

1201 Structural items such as support and protective structures that are not welded onto pressurised parts are considered as structural elements. See Section 5G.

1202 Structural items acting as a pressure containing part of the pipeline system shall meet the requirements for the section of the pipeline system where they shall be located.

1203 Structural items shall not be welded directly to pressure containing parts or linepipe. Supports, attachments etc. shall be welded to a doubler plate or ring.

1204 Girth welds shall not be inaccessible under doubler rings, clamps or other parts of supports.

1205 Permanent doubler plates and rings shall be made from a material satisfying the requirements of the pressure containing parts. Doubler rings shall be made as fully encircling sleeves with the longitudinal welds made with backing strips, and avoiding penetration into the pressure containing material. Other welds shall be continuous, as small as possible, and made in a manner to minimise the risk of root cracking and lamellar tearing.

C. Material and Manufacturing Specifications for Components

C 100 Material and manufacturing specifications

101 All material, manufacture and testing requirements applicable for a particular component shall be stated in a specification.

102 The specification shall be based on this standard and other recognised codes/standards as applicable for the component. Where a suitable code/standard is not available, the specification shall define the requirements.

103 The specification shall reflect the results of the material selection and shall include specific, detailed requirements for the:
- mechanical properties of the materials; and
- how such properties will be achieved through requirements for manufacturing processes, verification through tests and supporting documentation.

Mechanical Properties

104 The materials shall be specified and tested such that acceptable weldability under field and contingency conditions is ensured and verified.

105 The specified mechanical properties of materials and weldments shall be suitable for the specific application and operational requirements of the pipeline system.

106 Suitable allowances for possible degradation of the mechanical properties of a material, e.g. as a result of subsequent fabrication activities, should be included in the specification.
**D. Material for Hot Formed, Forged and Cast Components**

**D 100 General**

101 The materials should comply with internationally recognised standards, provided that such standards have acceptable equivalence to the requirements given in Section 6 and this section. Modification of the chemical composition given in such standards may be necessary to obtain sufficient weldability, hardenability, strength, ductility, toughness and corrosion resistance.

**Sour Service**

102 For components in pipeline systems to be used for fluids containing hydrogen sulphide and defined as “sour service” according to NACE Standard MR0175 (Sulphide Stress Cracking Resistant Metallic Materials for Oil Field Equipment), all requirements to materials selection, maximum hardness, and manufacturing and fabrication procedures given in the latest edition of the above standard shall apply. This includes pipelines that are nominally dry (i.e. free from liquid water during normal operation) if other conditions for sour service according to the above standard are valid. Further, the additional requirements, modifications and clarifications defined below shall apply.

103 Use of materials not listed for sour service in NACE MR0175 (latest edition) shall be qualified according to the guidelines of this document. As an alternative, the guidelines for qualification in EFC publications No. 16 and 17 may be used. The qualification shall include the testing of Sulphide Stress Cracking (SSC) of base materials and welds as applicable. The qualification is only valid for a specific production line and/or manufacturer/fabricator.

104 The chemical composition of low alloy steel materials in Table 7-4 shall not exceed the values given in Table 7-4. The maximum Carbon Equivalent (CE) shall not exceed 0.52, when calculated in accordance with:

\[
CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{15} + \frac{Cu + Ni}{15}
\]

105 The final chemical composition for sour service is subject to agreement.

106 The hardness in base materials, welds and HAZ shall be in accordance with NACE MR0175 (latest edition).

**Guidance note:**

It is recommended that the hardness in the base material, weld metal and HAZ be kept considerably lower than the NACE requirement in order to allow for hardness increase during girth welding.

107 Components made from rolled plate material shall be tested for resistance to Hydrogen Induced Pressure Cracking (HIPC).

108 Plate material shall be manufactured in a manner minimizing macro and micro segregation, and shall be Ca or rare earth inclusion shape treated.

109 Requirements for SSC and HIPC testing are given in Appendix B.

110 Plate material shall be 100% ultrasonic tested in accordance with Appendix D, subsection F.

111 Requirements for material properties shall be fulfilled in the final condition, i.e. in the finished components. Materials for auxiliary items such as guide bars etc. shall be made from a material satisfying the requirements to chemical composition, mechanical properties and documentation of pressure containing parts.

**D 200 Components made of low alloy C-Mn steel**

201 These requirements are applicable to forged, hot formed and cast components made of low alloyed C-Mn steel with SMYS up to 555 MPa. Use of higher strength materials shall be subject to agreement.

202 The steel shall be fully killed and made to a fine grain melting practice. The material shall be produced by using the:

- basic oxygen furnace,
- electric arc furnace,
- vacuum arc re-melting furnace (VAR), or
- an electroslag re-melting furnace (ESR) followed by vacuum degassing.

**Chemical composition**

203 The chemical composition, taken from the product analysis, of material for hot-formed components, castings and forgings, shall not exceed the values given in Table 7-4. The notes given in Table 7-5 shall apply, except Note 9 and Note 10.

204 The maximum Carbon Equivalent (CE) shall not exceed 0.52, when calculated in accordance with:

\[
CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{15} + \frac{Cu + Ni}{15}
\]

### Table 7-4 Chemical composition of materials for hot-formed, cast and forged components

<table>
<thead>
<tr>
<th>Element</th>
<th>Product analysis, maximum weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.16</td>
</tr>
<tr>
<td>Mn</td>
<td>1.60</td>
</tr>
<tr>
<td>P</td>
<td>0.015</td>
</tr>
<tr>
<td>S</td>
<td>0.010</td>
</tr>
<tr>
<td>Si</td>
<td>0.40</td>
</tr>
<tr>
<td>Ni</td>
<td>2.00</td>
</tr>
<tr>
<td>Cr</td>
<td>2.50</td>
</tr>
<tr>
<td>Mo</td>
<td>1.10</td>
</tr>
<tr>
<td>Cu</td>
<td>0.50</td>
</tr>
<tr>
<td>Nb</td>
<td>0.060</td>
</tr>
<tr>
<td>V</td>
<td>0.10</td>
</tr>
<tr>
<td>Ti</td>
<td>0.040</td>
</tr>
<tr>
<td>Al</td>
<td>0.060</td>
</tr>
<tr>
<td>N</td>
<td>0.012</td>
</tr>
</tbody>
</table>

205 For material to be quenched and tempered, the content of hardening elements Cr, Mo, Cu and Ni shall be sufficient to obtain the desired microstructure in the centre of the component. The selected chemical composition shall have adequate hardenability to ensure through thickness hardening of the respective component.

206 The chemical composition shall ensure the intended heat treatment response, and that the required mechanical properties are obtained.

---

End of Guidance note
The chemical composition shall be agreed prior to start of production.

**Mechanical properties**

- **207** Tensile, hardness and Charpy V-notch properties shall meet the requirements given in Table 6-3 and Table 6-4.
- **208** Mechanical testing shall be performed after heat treatment. The testing shall be performed in accordance with Appendix B and F 700.
- **209** For materials with a thickness > 40 mm the impact test temperature and the energy absorption requirements shall be specially considered. Increasing thickness will require lower test temperatures. Alternatively, higher energy absorption at the same test temperature should be required. The energy absorption shall not in any case be lower than required in Table 6-3, nor shall impact testing be performed at temperatures higher than the minimum design temperature.
- **211** Requirements for fracture toughness testing of the base material and weld metal shall be considered for material thickness > 50 mm. The measured fracture toughness should, as a minimum, be a CTOD value of 0.15 mm at the minimum design temperature.
- **212** Ductility, also in the thickness direction, shall be adequate for the part in question, taking manufacturing and service conditions into consideration. Through thickness tensile testing may be required.
- **213** For design temperatures above 50°C, the actual yield stress at the maximum design temperature shall comply with the requirements stated in Section 5B 600.

**D 300 Components made of ferritic-austenitic (duplex) steel, other stainless steel and nickel based corrosion resistant alloy (CRA)**

- **301** All requirements with regard to chemical composition, mechanical properties and supplementary requirements (when applicable) for 22Cr and 25Cr duplex stainless steel, austenitic and martensitic stainless steel and other CRAs shall be in accordance with Section 6.
- **302** For components made of duplex stainless steel, other stainless steels or nickel based corrosion resistant alloys (CRA) intended for seawater service, corrosion testing shall be conducted in accordance with Section 6C.308 and Section 6C.404 as relevant.

**D 400 Delivery condition**

- **401** Forgings and hot formed components in low alloy steel shall be delivered in the normalised or in the quenched and tempered condition.
- **402** Castings in low alloy steel shall be delivered in the homogenised, normalised and stress relieved or in the homogenised, quenched and tempered condition.
- **403** Duplex steel components shall be delivered in the solution annealed and water quenched condition.
- **404** For component material delivered in the quenched and tempered condition the tempering temperature shall be sufficiently high to allow effective post weld heat treatment during later manufacture / installation.

**E. Hot Forming, Forging, Casting and Heat Treatment**

**E 100 Hot forming**

- **101** Hot forming shall be performed to the agreed procedure according to the guidance given in G 500
- **102** Hot forming, including extrusion of branches in low alloy steel, shall be done within a temperature range of 800 - 1000°C. Adequate temperature control shall be performed and the component shall be allowed to cool in still air.
- **103** For duplex stainless steel material, the hot forming shall be conducted within the temperature range 1000 -1150°C.

**E 200 Forging**

- **201** Forging shall be performed in general compliance with ASTM A694. Each forged product shall be hot worked as far as practicable, to the final size and shape with a minimum reduction ratio of 4:1.
- **202** Weld repair of forgings shall not be permitted.

**E 300 Casting**

- **301** Casting shall be performed in general compliance with ASTM A352.
- **302** A casting shall be made from a single heat and as a single unit.
- **303** Castings may be repaired by grinding to a depth of maximum 10% of the actual wall thickness, provided that the wall thickness in no place is below the minimum designed wall thickness. The ground areas shall merge smoothly with the surrounding material.
- **304** Defects deeper than those allowed by 303 may be repaired by welding. The maximum extent of repair welding should not exceed 20% of the total surface area. Excavations for welding shall be ground smooth and uniform and shall be suitably shaped to allow good access for welding.
- **305** All repair welding shall be performed by qualified welders and according to qualified welding procedures.

**E 400 Heat treatment**

- **401** Heat treatment procedures shall be prepared and agreed prior to start of heat treatment.
- **402** Heat treatment procedures shall as a minimum contain the following information:
  - heating facilities;
  - furnace (if applicable);
  - insulation (if applicable);
  - measuring and recording equipment, both for furnace control and recording of component temperature;
  - calibration intervals;
  - fixtures and loading conditions;
  - heating and cooling rates;
  - temperature gradients;
  - soaking temperature range and time;
  - maximum time required for moving the component from the furnace to the quench tank (if applicable);
  - cooling rates (conditions);
  - type of quenchant (if applicable); and
  - start and end maximum temperature of the quenchant (if applicable).
- **403** Components should be rough machined to near final dimensions prior to heat treatment.
- **404** The furnace temperature shall be controlled to within ± 10°C and thermocouples shall be attached to each component during the entire heat treatment cycle.
- **405** For components which are to be water quenched, the time from removal of components from the oven until they are immersed in the quenchant shall not exceed 90 seconds for C-Mn and low alloy steel, and 60 seconds for duplex stainless steels.
- **406** The water shall be heavily agitated, preferably by cross flow to ensure rapid, adequate quenching. The start and end temperature of the quenching water shall be recorded and shall not exceed 40°C.
- **407** The heat treatment equipment shall be calibrated at least
once a year in order to ensure acceptable temperature stability and uniformity.

**F. Manufacturing of Components, Equipment and Structural Items**

**F 100 General**

101 These requirements are applicable for the manufacture of components, equipment and structural items for use in submarine pipelines.

102 If there are conflicting requirements between this standard and the referenced code or standard used for manufacture of components and equipment, the requirements of this standard shall have precedence.

103 Requirements for mechanical and corrosion testing are given in Appendix B and this section.

104 Requirements for NDT personnel, NDT equipment, methods, procedures and acceptance criteria are given in Appendix D.

105 Welding procedures, welding personnel, handling of welding consumables shall meet the requirements in Appendix C.

106 Welding shall be performed in accordance with applicable requirements of H 600.

107 The Contractor shall be capable of producing welded joints meeting the required quality. This may include welding of girth welds, overlay welding and post weld heat treatment of the components. Relevant documentation of the Contractor's capabilities shall be available if requested.

108 Production tests required during the production shall be performed in a manner which, as far as possible, reproduces the actual welding and covers the welding of a sufficient large test piece in the relevant position. Production welds cut out due to NDT failure may be used.

109 When production testing is required, the number of tests as specified in Appendix C should be made.

110 Components and equipment intended for welded connections to linepipe shall have dimensional tolerances on diameter and thickness equal to the linepipe, in order to ensure acceptable alignment for welding. Where welded joints in quenched and tempered steel are to be post weld heat treated (PWHT), the PWHT temperature shall be a minimum of 25°C below the tempering temperature for the base material.

111 The Manufacturer shall develop a Manufacturing Procedure Specification (MPS).

**Manufacturing Procedure Specification (MPS)**

112 Before production commences the Manufacturer shall prepare a MPS. The MPS shall demonstrate how the specified properties may be achieved and verified through the proposed manufacturing route. The MPS shall address all factors which influence the quality and reliability of production. All main manufacturing steps from control of received material to shipment of the finished product(s), including all examination and check points, shall be covered in detail. References to the procedures and acceptance criteria established for the execution of all steps shall be included.

113 The MPS shall as a minimum contain the following information:

- plan(s) and process flow description/diagram;
- project specific quality plan;
- manufacturing processes used;
- supply of material; manufacturer and manufacturing location of material;
- production process control procedures;
- welding procedures;
- heat treatment procedures;
- NDT procedures;
- pressure test procedures;
- list of specified mechanical and corrosion testing;
- dimensional control procedures;
- marking, coating and protection procedures; and
- handling, loading and shipping procedures.

114 The MPS shall be subject to agreement.

**F 200 Manufacture of flanges**

201 Flanges shall be manufactured, inspected, tested, and documented in accordance with:

- recognised practices,
- the referenced design standard, and
- the material and manufacturing specification.

The specified starting material and the methods and procedures agreed and qualified for the manufacture shall be used.

202 Flanges shall be forged close to the final shape. Machining of up to 10% of the local wall thickness at the outside of the flange is allowed. Contact faces of flanges shall have a machined finish with a surface roughness compatible with the gaskets to be used.

203 Mechanical testing shall be as given in F 700.

204 Corrosion testing shall be performed as specified in D 100 and D 300 as relevant.

205 Non-destructive testing and acceptance criteria shall be in accordance with Appendix D.

206 The extent of non-destructive testing shall be:

- 100% magnetic particle or dye penetrant testing; and
- 100% ultrasonic testing of the first 10 flanges of each size and type ordered. If no defects are found, the extent of ultrasonic testing may be reduced to 10% of each size and type. If defects are found in the first 5 flanges or during testing 10% of the flanges, all flanges of this size and similar type are to 100% tested.

**F 300 Manufacture of valves**

301 Valves shall be manufactured, inspected, tested, and documented in accordance with:

- recognised practices,
- the requirements of the referenced design standard, and
- the material and manufacturing specification.

The specified starting materials and the methods and procedures agreed and qualified for the manufacture shall be used.

302 The extent of mechanical (see F 700), non-destructive and corrosion testing, where required, shall be performed as specified in this section (see D). The types of test and the acceptance criteria shall be consistent with the requirements for the pipeline or pipeline sections where the valve(s) will be used.

303 Hydrostatic testing shall be performed as required in the applied design code, except that the holding time shall be minimum 2 hours if a shorter time is allowed by the code.

304 Valves with requirements for leak tightness shall be leak tested as required in the applied design code (e.g. riser valves, maintenance valves and pig trap isolation valves). Consideration shall be given to valve performance at both high and low differential pressures across the valve.

305 All testing shall be performed to agreed procedures.
F 400  Manufacture of pressure-containing equipment and components fabricated by welding

401 Pressure-containing equipment such as pig traps, slug catchers, and components fabricated by welding of plates shall be manufactured, inspected, tested and documented in accordance with:

— recognised practices,
— the requirements of this standard,
— the requirements the referenced design standard, and
— the material and manufacturing specification.

The specified starting materials and the methods and procedures agreed and qualified for the manufacture shall be used.

402 Hydrostatic testing shall be performed as required in the referenced design standard, except that the holding time shall be minimum 2 hours if a shorter time is specified by the referenced design standard.

F 500  Manufacture of other equipment and components

501 Other components and equipment, such as insulating joints, mechanical connectors, tees and Y-pieces and other fittings and components fabricated by hot forming of plate, shall be manufactured inspected, tested and documented in accordance with:

— recognised practices,
— the requirements of this standard,
— the requirements the referenced design standard, and
— the material and manufacturing specification.

The specified starting materials and the methods and procedures agreed and qualified for the manufacture, shall be used.

502 Pressure containing components shall be subject to hydrostatic testing unless such testing is impracticable. The test pressure shall be 1.50 times the design pressure, and the holding time shall be 2 hours. If the applied design code requires higher pressures or a longer holding time, then the more stringent requirements shall apply.

503 The hydrostatic test pressure shall be recorded during the test using equipment with calibration certificates not older than one year. No pressure drops or leaks are allowed during hydrostatic testing.

504 Insulating joints shall be tested as detailed in B 800.

505 Qualification testing of sleeve type couplings and clamps for the particular pipeline dimensions, dimensional tolerances and surface finish shall be performed according to agreed procedures.

F 600  Fabrication of structural items

601 Structural items shall be fabricated, inspected, tested and documented in accordance with:

— recognised practices,
— the requirements of this standard,
— the requirements the referenced design standard, and
— the material and manufacturing specification.

The specified materials and the methods and procedures agreed and qualified for the fabrication shall be used.

F 700  Mechanical testing of hot formed, cast and forged components

701 Testing of the mechanical properties of components after hot forming, casting or forging shall be performed on a test material taken from:

— a prolongation of the component;
— an integrated test coupons, that is removed from the component after final heat treatment; or
— by random selection of components of the same type and form, from the same heat and heat treatment batch.

All mechanical testing shall be conducted after final heat treatment.

702 The material thickness and forging reduction for integrated test coupons shall be representative of the actual component.

703 Separate test coupons should not be used but may be allowed subject to agreement, provided that they are heat treated simultaneously with the material they represent, and the material thickness, forging reduction, and mass are representative of the actual component.

704 A simulated heat treatment of the test piece shall be performed if welds between the component and other items such as linepipe are to be post weld heat treated at a later stage or if any other heat treatment is intended.

705 One component from each lot (i.e. components of the same size, type and form from each heat or heat treatment batch, whichever occurs more frequently) shall be tested as follows:

— two tensile specimens taken from the base material in the transverse direction at 1/3 thickness;
— two sets of Charpy V-notch specimens taken in the transverse direction at each location 2 mm below the inner and outer surface, and two sets of specimens from the same location as the tensile specimens. The notch shall be perpendicular to the component’s surface;
— metallographic samples taken from the same location as the Charpy V-notch specimens and at 1/3T, 1/2T and 2/3T. A minimum of 3 hardness measurements shall be taken on each sample. The 1/3T and 2/3T specimens shall include the nearest surface “as is” after the heat treatment (not machined).

706 The distance from the edge of the test piece to the nearest edge of any specimen shall not be less that 1/3 of the thickness. For welded components, the testing shall also include testing of the welds in accordance with Appendix C.

707 Samples for corrosion testing shall be taken such that the surface exposed to the corrosive medium will be tested.

708 The mechanical properties shall meet the specified requirements. The reduction of area shall be at least 35%. For heavy wall components with SMYS > 420 MPa, a higher ductility level should be required.

709 The hardness of the accessible surfaces of the component shall be tested. The testing shall be sufficient to establish the efficiency of the heat treatment. The hardness for components intended for non-sour service shall not exceed the requirements given in Table 6-3 for C-Mn and low alloy steel and Table 6-6 for duplex steels.

For components intended for sour service the hardness shall be in accordance with Section 6D 100.

G. Manufacture of Bends

G 100  General

101 The Manufacturer shall develop a Manufacturing Procedure Specification.

Manufacturing Procedure Specification (MPS)

102 Before production commences the Manufacturer shall prepare an MPS. The MPS shall demonstrate how the specified properties may be achieved and verified through the proposed manufacturing route. The MPS shall address all factors which influence the quality and reliability of production. All main manufacturing steps from control of received material to ship-
ment of the finished product(s), including all examination and check points, shall be covered in detail. References to the procedures and acceptance criteria established for the execution of all steps shall be included.

103 The MPS shall as a minimum contain the following information:
- plan(s) and process flow description/diagram;
- project specific quality plan;
- bending process used
- supply of material; manufacturer and manufacturing location of material;
- bending process control procedures;
- heat treatment procedures;
- NDT procedures;
- list of specified mechanical and corrosion testing;
- dimensional control procedures;
- marking, coating and protection procedures; and
- handling, loading and shipping procedures.

104 Materials for use in factory-made bends shall be selected taking into account the chemical composition and the influence of the manufacturing method upon mechanical properties, dimensions and wall thickness.

105 Induction bending is the preferred method for manufacture of bends.

106 Bends may be made from dedicated straight lengths of pipe without girth welds (mother pipe), that are hot, cold or induction bent, or from forgings. Mitre or wrinkle bends are not permitted.

107 Mother pipe in C-Mn steels shall be delivered in the normalised, quenched and tempered or TMCP condition.

108 Bends may be made from spare sections of normal line-pipe. It should be noted that “normal” linepipe, particularly pipe manufactured from TMCP plate, may not have adequate hardenability to achieve the required mechanical properties after hot or induction bending and subsequent post bending heat treatment.

109 Hot expanded mother pipe may experience dimensional instability after post bending heat treatment.

110 Mother pipe and other pipe for use in bend shall meet all applicable requirements given in Section 6. Waiving of the mill pressure test according to Section 6E.1108 is not applicable.

Mechanical properties of mother pipe

111 Mother pipe made of C-Mn steels and duplex stainless steels shall, as a minimum, comply with the requirements for linepipe and the Supplementary Requirements (as applicable) given in Section 6.

112 Hardness requirements for C-Mn steels and duplex stainless steels shall be in accordance with Section 6C.205 and 306 respectively.

113 Chemical composition of mother pipe

114 The chemical composition of C-Mn steel mother pipe shall be in accordance with Table 7-5. The chemical composition for duplex steel mother pipe shall be in accordance with Table 6-5 in Section 6.

Metallographic examination of mother pipe in duplex steel

115 Metallographic examination of dedicated mother pipe in duplex stainless steels shall be performed in accordance with Section 6C.304 and 305, and Appendix B.

<table>
<thead>
<tr>
<th>Element</th>
<th>SMYS 245</th>
<th>SMYS 290</th>
<th>SMYS 360</th>
<th>SMYS 415</th>
<th>SMYS 450</th>
<th>SMYS 485</th>
<th>SMYS 555</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.14</td>
<td>0.14</td>
<td>0.16</td>
<td>0.16</td>
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<td>1.85</td>
</tr>
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<td>Si</td>
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<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>P</td>
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<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>S</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
</tr>
<tr>
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<td>0.50</td>
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<td>0.50</td>
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<td>Mo</td>
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<td>0.50</td>
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</tr>
<tr>
<td>Cr</td>
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<td>0.30</td>
<td>0.50</td>
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<tr>
<td>Nb</td>
<td>-</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>V</td>
<td>-</td>
<td>0.04</td>
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<td>0.10</td>
</tr>
<tr>
<td>Ti</td>
<td>-</td>
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<td>0.04</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>
treated after hot forming and induction bending, according to the steel Manufacturer's recommendation. 

504 Bends made of clad/lined material shall be heat treated after hot forming and induction bending, according to the steel Manufacturer's recommendation. 

505 Bends manufactured by cold bending shall be stress relieved when the total deformation exceeds 3%. For wall thicknesses less than 25 mm, the total cold deformation may be increased without requiring subsequent stress relieving subject to agreement. The total deformation percentage shall be calculated in percentage by using the following equation:

\[
\% \text{Deformation} = \left( \frac{t_{\text{max}}}{2r + t_{\text{max}}} \right) \times 100
\]

\[ t_{\text{max}} = \text{Maximum pipe wall thickness} \]
\[ r = \text{Deformation radius} \]

G 600 Bending procedure qualification

601 A bending procedure shall be established and qualified. Essential variables for the allowable variation of bending parameters shall be established.

Guidance note:

Cold forming procedures may contain information concerning:
- description and sequence of operations;
- equipment to be used;
- material designation;
- pipe diameter, wall thickness and bend radius;
- initial/ successive degrees of deformation;
- position of the longitudinal seam;
- methods for avoiding local thinning, wrinkling and ovality;
- post bending heat treatment;
- hydrostatic testing procedure;
- non-destructive testing procedures; and
- dimensional control procedures.

Hot forming procedures may include information concerning:
- sequence of operations;
- sequence of operations;
- heating equipment;
- material designation;
- pipe diameter, wall thickness and bend radius;
- heating/cooling rates;
- max/min. temperature during forming operation;
- temperature maintenance/ control;
- recording equipment;
- position of the longitudinal seam;
- methods for avoiding local thinning, wrinkling and ovality;
- post bending heat treatment (duplex: full solution annealing);
- hydrostatic testing procedure;
- non-destructive testing procedures; and
- dimensional control procedures.

---

Table 7-5 C-Mn steel for bends, chemical composition\(^1\)**3)**

<table>
<thead>
<tr>
<th>N 6)</th>
<th>0.010</th>
<th>0.010</th>
<th>0.010</th>
<th>0.010</th>
<th>0.012</th>
<th>0.012</th>
<th>0.012</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 5)</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
<tr>
<td>CE 9)</td>
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<td>0.38</td>
<td>0.43</td>
<td>0.44</td>
<td>0.45</td>
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<td>0.47</td>
</tr>
<tr>
<td>P(_{cm}) 10)</td>
<td>0.23</td>
<td>0.24</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1) Chemical composition applies for wall thicknesses up to 45 mm and shall be subject to agreement for larger wall thicknesses.

2) When scrap material is being used in steel production, the amount of the following residual elements shall be determined and reported, and the levels shall not exceed: 0.03% As, 0.01% Sb, 0.02% Sn, 0.01% Pb, 0.01% Bi and 0.005% Ca.

3) Except for deoxidation elements, other elements than those mentioned in this table shall not be intentionally added if not specifically agreed.

4) For each reduction of 0.01% carbon below the maximum specified value, an increase of 0.05% manganese above the specified maximum values is permitted with a maximum increase of 0.1%.

5) 0.5-1.0% Cr may be used subject to agreement.

6) Al/N ≥ 2:1 (not applicable for titanium killed steels)

7) (Nb+V+Ti)/%\(_{\text{max}}\); 0.12% This value may be increased to maximum 0.15% subject to agreement.

8) Boron (max 30 ppm) may be added subject to agreement.

9) \[ CE = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Cu+Ni}{15} \]

10) \[ P_{cm} = C + \frac{Si}{30} + \frac{Mn+Cu+Cr+V}{20} + \frac{Ni}{60} + \frac{Mo+V}{15} + \frac{5B}{10} \]
Induction bending procedures may contain information concerning:

- the sequence of operations;
- equipment to be used;
- material designation;
- pipe diameter, wall thickness and bend radius;
- position of weld seam;
- induction bending temperature;
- bending speed;
- cooling technique (medium, pressure, location and number of nozzles etc.);
- post bending heat treatment;
- hydrostatic testing procedure;
- non-destructive testing procedures; and
- dimensional control procedures.

---end--of--Guidance---Note---

602 The bending procedure shall be qualified by mechanical and non-destructive testing, visual inspection and dimensional control. If agreed the qualification of the bending procedure may be attempted without post bending heat treatment for C-Mn steels, duplex stainless steels, other stainless steels (except martensitic) and nickel based corrosion resistant alloys.

603 Testing for qualification of the bending procedure shall include the testing as required in 604 to 610.

**Bends from seamless pipe**

604 For bends manufactured from seamless pipes the extent of tensile and Charpy V-notch impact testing shall be as follows:

**Tensile testing:**
- base material in the arc inner radius longitudinal and transverse (total 2 specimens),
- base material in the arc outer radius longitudinal and transverse (total 2 specimens),
- base material in the start transition area inner radius longitudinal and transverse (total 2 specimens),
- base material in the start transition area outer radius longitudinal and transverse (total 2 specimens), and
- base material tangent length.

**Charpy V-notch impact testing:**
- base material in the arc inner radius longitudinal and transverse (total 2 sets),
- base material in the arc outer radius longitudinal and transverse (total 2 sets),
- base material in the start transition area inner radius longitudinal and transverse (total 2 sets),
- base material in the start transition area outer radius longitudinal and transverse (total 2 sets), and
- base material tangent length.

For bends made from pipe with outside diameter less than 300 mm testing is required in the longitudinal direction only.

**Macro, micro and hardness testing:**
- One full wall macro section, taken parallel to the longitudinal axis of the bend, shall be removed from the inner and outer radii and from the stop and start transition areas and from the base material tangent length (total 5 samples);
- For duplex steel, other stainless steels and nickel based corrosion resistant alloys the specified macro sections shall be substituted by micro section in order to conduct full metallographic examination;
- Hardness testing shall be performed on the macro and micro sections according to Appendix B;
- Hardness testing shall be performed on the external surface of the completed bend. The testing shall be performed with a minimum of 8 measurements around the bend circumference in the tangent lengths, start and stop transition areas and in the middle of the arc section.

**Bends from welded pipe**

605 For bends manufactured from welded pipes the following testing shall be performed in addition to the testing specified in 604:

**Tensile testing:**
Cross weld tensile testing shall be performed in the arc area, stop and start transition areas and in the tangent length.

**Charpy V-notch impact testing:**
- Weld metal, FL, FL + 2 mm and FL + 5 mm in the arc (4 sets),
- Weld metal in the start transition area (1 set),
- Weld metal in the stop transition area (1 set).

**Macro, micro and hardness testing:**
- Two full wall macro sections of the weld, taken parallel to the longitudinal axis of the bend, shall be removed from the stop and start transition areas (total 2 samples); For duplex steel, other stainless steels and nickel based corrosion resistant alloys the specified macro sections shall be substituted by micro section of the weld in order to conduct full metallographic examination.

**Applicable to all bends**

606 Tensile test specimens shall be taken from the middle of the material thickness. Charpy V-notch impact test specimens shall be taken 2 mm below the inner surface and macro/micro specimens shall represent the full material thickness.

607 For bends where the stop and start transition zones and the tangent length are not retained in the delivered bend, mechanical testing in these areas is not required.

608 The requirements for tensile Charpy V-notch and hardness testing shall be in accordance with Section 6 Table 6-3 and Table 6-4 for C-Mn steels, and Table 6-6 for duplex steels. For duplex steel, other stainless steels and nickel based corrosion resistant alloys the metallography shall meet the requirements given in Section 6C.3.105.

609 For supplementary requirement S, the required testing shall be performed in accordance with Section 6.

610 If the test results do not meet the specified requirements to mother pipe, the bending procedure shall be re-qualified including a full post bending heat treatment.

**G 700 Bending and post bend heat treatment**

701 Before bending the wall thickness shall be measured on each length of pipe.

702 If the bending operation is interrupted during hot or induction bending, the bend subject to interruption shall be rejected.

703 The longitudinal weld of welded pipe shall be in the neutral axis during bending.

704 Bending shall be performed in accordance with qualified procedures and established essential variables. The temperature during induction and hot bending shall be controlled within ±15°C using an optical pyrometer. The temperature data shall be recorded for each bend. The bending equipment shall be calibrated at least once a year in order to ensure acceptable temperature stability and uniformity.

705 Post bend heat treatment shall be performed according to E 400.

706 A minimum of one thermocouple shall be attached to a minimum of one bend per heat treatment batch. For components to be quenched and tempered (Q/T), the temperature of the quenching medium shall be recorded during the quenching
operation.

**G 800 Non-destructive testing and visual inspection**

801 Requirements for NDT personnel, NDT equipment, methods, procedures and acceptance criteria are given in Appendix D.

802 Bends shall be blast cleaned to ISO 8501, SA21/2 to remove scale from the bend area prior to visual inspection and non-destructive testing.

803 Provided that the material has been 100% ultrasonic tested for laminar imperfections as plate or pipe, the following testing shall be performed on each bend:

804 100% visual examination of external and accessible parts of internal surfaces. The bends shall be free from gouges, dents, grooves, wrinkles, bulges, kinks and surface spalling. Cracks are not permitted.

805 Minor buckles in the bend inside radius profile will be acceptable if the height and depth of the buckle does not exceed 1% of the nominal internal diameter and the length to depth ratio is greater than 12:1. The distance between acceptable minor buckles in the bend inside radius profile shall be greater than one nominal internal diameter.

806 100% radiographic or ultrasonic testing of the weld in the arc and transition zones + the end 250 mm of the tangent if not tested on the mother pipe prior to bending.

807 100% magnetic particle testing over an arc of 90° both sides of the extrados for ferromagnetic pipe, or 100% testing with liquid penetrant + 100% ultrasonic testing over the same area for non-ferromagnetic pipe, in order to verify freedom from transverse defects.

808 Ultrasonic wall thickness measurements taken around the circumference at the inside and outside radius of the bend and at both neutral axes at a spacing of 150 mm along the entire length of the bend. The wall thickness shall not be below the specified minimum at any of these locations.

809 The hardness of the exterior surface of the bend shall be tested at the locations given in 808. The hardness of the interior surface shall be tested at the inside and outside radius of the bend and at both neutral axis as far as access permits. The hardness for bends intended for non-sour service shall not exceed the requirements given in Section 6 Table 6-3 for C-Mn and low alloy steel and Table 6-6 for duplex steels.

810 After end preparation the complete end preparation and 100mm of the weld seam with magnetic particles for ferromagnetic pipe or with liquid penetrant for non-ferromagnetic pipe.

811 Final NDT, including dimensional check, shall be performed after post bending heat treatment.

**G 900 Production testing of bends**

901 During production, one bend of the heaviest wall thickness for each diameter produced within each lot shall be subject to mechanical testing.

902 Testing of induction bent bends may be performed at the random parts of the pipe that have been subject to the same temperature cycle(s) as the bent areas of pipe.

903 Testing of the start transition areas are not required for bends that have been given a full heat treatment restoring the microstructure.

904 For bends made from pipe with outside diameter less than 300 mm testing is required in the longitudinal direction only.

**Bends from seamless pipe**

905 For bends manufactured from seamless pipes the extent of mechanical testing shall be as follows:

**Tensile testing:**
- Base material in the arc outer radius longitudinal and transverse (total 2 specimens)
- Base material in the start transition area outer radius longitudinal and transverse (total 2 specimens) unless 903 is applicable.

**Charpy V-notch impact testing:**
- Base material in the arc outer radius longitudinal and transverse (total 2 sets)
- Base material in the start transition area outer radius longitudinal and transverse (total 2 sets) unless 903 is applicable.

**Macro, micro and hardness testing:**
- One full wall macro section, taken parallel to the longitudinal axis of the bend, shall be removed from the inner and outer radii and from start transition area (unless 603 is applicable)
- For duplex steel, other stainless steels and nickel based corrosion resistant alloys the specified macro sections shall be substituted by micro section in order to conduct full metallographic examination.
- Hardness testing shall be performed on the macro and micro sections according to Appendix B.

**Bends from welded pipe**

906 For bends manufactured from welded pipes the following testing shall be performed in addition to the testing specified in 905:

**Tensile testing:**
- Cross weld tensile testing in the arc area (one specimen)
- Cross weld tensile testing in the start transition area (one specimen) unless 903 is applicable

**Charpy V-notch impact testing:**
- Weld metal, FL + 2 mm and FL + 5 mm in the arc (4 sets)
- Weld metal in the start transition area (1 set) unless 903 is applicable.

**Macro, micro and hardness testing:**
- One full wall transverse macro section of the weld, shall be removed from the bend area and one from the start transition area (unless 903 is applicable)
- For duplex steel, other stainless steels and nickel based corrosion resistant alloys the specified macro sections shall be substituted by micro section of the weld in order to conduct full metallographic examination.

**Applicable to all bends**

907 Tensile test specimens shall be taken from the middle of the material thickness. Charpy V-notch impact test specimens shall be 2 mm below the inner surface and macro specimens shall represent the full material thickness.

908 For bends where the transition zones and the tangent length are not retained in the delivered bend, mechanical testing in these areas is not required.

909 The requirements for tensile, Charpy V-notch and hardness testing shall be in accordance with Section 6 Table 6-3 for C-Mn steels, and Table 6-4 for duplex steels. For duplex steel, other stainless steels and nickel based corrosion resistant alloys the metallography shall meet the requirements given in Section 6C.304.

**G 1000 Dimensions, tolerances and marking**

1001 Dimensions and tolerances at bend ends shall be com-
pattible with the adjoining pipe. Use of straight tangent lengths equal to one diameter is recommended. Ovality of cross sections shall be kept within the specified tolerances, and the bend radius shall be large enough (e.g. 5 x outer diameter) to allow passage of inspection vehicles when relevant.

1002 Dimensional control shall include:
- ID at bend ends;
- OD for bend body at inner and outer radii and both neutral axis;
- passing of gauge consisting of two aluminium plates of diameter 96% of nominal ID and fixed rigidly at a distance of 1.5 x ID;
- out-of-roundness of bend ends: maximum 1.5% and of body maximum 3%;
- outer bend radius, measured as the deviation from the specified radius to (the bend centre line + 1/2 OD) ± 1%, max 25 mm;
- the radius of bend curvature within ± 1% max ± 12.7 mm;
- the included angle between the centrelines if the straight portions of the bend within ± 0.75°;
- linear/plane straightness: the specified bend angle divided by 90° x 10 mm, max 10 mm;
- location of weld seam; and
- end squareness angle within ± 0.5°, maximum 3 mm.

1003 Bends shall be marked as required in Section 6F 100.

G 1100 Repair
1101 Welding repair of the bend base material is not permitted.
1102 Any welding repair of longitudinal weld seams shall be performed before final heat treatment and in accordance to a qualified welding procedure and shall be subject to the NDT required in Section 6.
1103 Repair of surface notches, gouges and similar by grinding shall be subject to agreement. The grinding shall not reduce the wall thickness below the specified minimum.

H. Fabrication of Risers, Expansion Loops, Pipe Strings for Reeling and Towing

H 100 General
101 The following requirements are applicable for the fabrication of risers, expansion loops, pipe strings etc. in C-Mn, duplex stainless, and clad/lined steel.
102 The fabrication shall be performed according to a specification giving the requirements for fabrication methods, procedures, the extent of testing, acceptance criteria and required documentation. The specification shall be subject to agreement prior to start of production.

H 200 Quality Assurance
201 Requirements to Quality Assurance given in Section 2B 500 shall be applied.

H 300 Materials for risers, expansion loops, pipe strings for reeling and towing

Pipe material
301 Pipe made of C-Mn steels and duplex stainless steels shall, as a minimum, comply with the requirements for line-pipe, including supplementary requirements (as applicable) given in Section 6.
302 In addition, pipe used in pipe strings for reeling shall, as a minimum, comply with supplementary requirement P given in Section 6.
303 Use of higher strength material shall be subject to agreement.

Guidance note:
For steel with SMYS > 485 MPa, it may be necessary to conduct Post Weld Heat Treatment (PWHT) of the weld zone in order to achieve the required hardness level and mechanical properties.

Forged and cast material
304 Forged and cast material shall as a minimum meet the requirements given in D of this section.

H 400 Fabrication procedures and planning
401 Before production commences, the fabricator shall prepare a Manufacturing Procedure Specification.
Manufacturing Procedure Specification (MPS)
402 The MPS shall demonstrate how the fabrication will be performed and verified through the proposed Fabrication steps. The MPS shall address all factors which influence the quality and reliability of production. All main fabrication steps from control of received material to shipment of the finished product(s), including all examination and check points, shall be covered in detail. References to the procedures and acceptance criteria established for the execution of all steps shall be included.
403 The MPS shall contain the following information:
- plan(s) and process flow description/diagram;
- project specific quality plan;
- fabrication processes used;
- supply of material, i.e. manufacturer and manufacturing location of material;
- fabrication process control procedures; welding procedures;
- heat treatment procedures;
- NDT procedures;
- pressure test procedures;
- list of specified mechanical and corrosion testing;
- dimensional control procedures;
- marking, coating and protection procedures; and
- handling, loading and shipping procedures.
404 The MPS shall be subject to agreement.
405 Due consideration shall be given to the access and time required for adequate inspection and testing as fabrication proceeds.
406 During fabrication of pipe strings for reeling and towing, the sequence of pipes included in the pipe string should be controlled such that variations in stiffness on both sides of welds are minimised. This may be achieved by matching as closely as possible the wall thickness / diameter of the pipes on both sides of the weld.
407 Due consideration during fabrication shall be given to the control of weight and buoyancy distribution of pipe strings for towing.
408 The procedures prepared by the fabricator shall be subject to agreement.

H 500 Material receipt, identification and tracking
501 All material shall be inspected for damage upon arrival. Quantities and identification of the material shall be verified. Damaged items shall be clearly marked, segregated and disposed of properly.
502 Pipes shall be inspected for loose material, debris, and other contamination, and shall be cleaned internally before being added to the assembly. The cleaning method shall not cause damage to any internal coating.
503 A system for ensuring correct installation of materials and their traceability to the material certificates shall be estab-
lished. The identification of material shall be preserved during handling, storage and all fabrication activities.

504 A pipe tracking system shall be used to maintain records of weld numbers, NDT, pipe numbers, pipe lengths, bends, cumulative length, anode installation, in-line assemblies and repair numbers. The system shall be capable of detecting duplicate records.

505 The individual pipes of pipe strings shall be marked in accordance with the established pipe tracking system using a suitable marine paint. The location, size and colour of the marking shall be suitable for reading by ROV during installation. It may be required to mark a band on top of the pipe string to verify if any rotation has occurred during installation.

506 If damaged pipes or other items are replaced, the sequential marking shall be maintained.

H 600 Cutting, forming, assembly, welding and heat treatment

601 The Contractor shall be capable of producing welded joints of the required quality. This may include welding of girth welds, other welds, overlay welding and post weld heat treatment. Relevant documentation of the Contractor’s capabilities shall be available if requested by the Purchaser.

602 Attention shall be paid to local effects on material properties and carbon contamination by thermal cutting. Preheating of the area to be cut may be required. Carbon contamination shall be removed by grinding off the affected material.

603 Forming of material shall be according to agreed procedures specifying the successive steps.

604 The fabrication and welding sequence shall be such that the amount of shrinkage, distortion and residual stress is minimised.

605 Members to be welded shall be brought into correct alignment and held in position by clamps, other suitable devices, or tack welds, until welding has progressed to a stage where the holding devices or tack welds can be removed without danger of distortion, shrinkage or cracking. Suitable allowances shall be made for distortion and shrinkage where appropriate.

606 Welding procedures shall be qualified and welding procedures, welding consumables, welding personnel, handling of welding consumables and fabrication shall meet the requirements of Appendix C.

H 700 Hydrostatic testing

701 Hydrostatic testing shall be performed if specified.

702 The extent of the section to be tested shall be shown on drawings or sketches. The limits of the test, temporary blind flanges, end closures and the location and elevation of test instruments and equipment shall be shown. The elevation of the test instruments shall serve as a reference for the test pressure.

703 End closures and other temporary testing equipment shall be designed, fabricated, and tested to withstand the maximum test pressure, and in accordance with a recognised code.

704 Testing should not be performed against in-line valves, unless possible leakage and damage to the valve is considered, and the valve is designed and tested for the pressure test condition. Blocking off or removal of small-bore branches and instrument tappings should be considered in order to avoid possible contamination. Considerations shall be given to pre-filling valve body cavities with an inert liquid unless the valves have provisions for pressure equalisation across the valve seats. All valves shall be fully open during filling.

705 Welds shall not be coated, painted or covered. Thin primer coatings may be used where agreed.

706 Instruments and test equipment used for measurement of pressure, volume, and temperature shall be calibrated for accuracy, repeatability, and sensitivity. All instruments and test equipment shall possess valid calibration certificates with traceability to reference standards within the 6 months preceding the test. If the instruments and test equipment have been in frequent use, they should be calibrated specifically for the test.

707 Gauges and recorders shall be checked for correct function immediately before each test. All test equipment shall be located in a safe position outside the test boundary area.

708 The following requirements apply for instruments and test equipment:

— Testers shall have a range of minimum 1.25 times the specified test pressure, with an accuracy better than ± 0.1 bar and a sensitivity better than 0.05 bar.
— Temperature-measuring instruments and recorders shall have an accuracy better than ± 1.0°C.
— Pressure and temperature recorders are to be used to provide a graphical record of the pressure test for the total duration of the test.

709 Calculations showing the effect of temperature changes on the test pressure shall be developed and accepted prior to starting the test. Temperature measuring devices, if used, shall be positioned close to the pipeline and the distance between the devices shall be based on temperature gradients along the pipeline route.

710 The test medium should be fresh water or inhibited sea water.

711 During pressurisation the pressure shall be increased at a steady rate up to 95% of the test pressure. The last 5% up to the test pressure shall be raised by a linear diminishing rate down to 0.5 bar per minute. Time shall be allowed for confirmation of temperature and pressure stabilisation before the test hold period begins.

712 The test pressure requirement for system pressure tests is given in Section 5D.204.

713 The holding time at test pressure shall be 6 hours.

714 The pressure shall be recorded during pressurisation, stabilisation and hold periods. Temperatures and pressure shall be recorded at least every 10 minutes during the hold period.

715 During testing, all welds, flanges, mechanical connectors etc. under pressure shall be visually inspected for leaks.

716 The pressure test shall be acceptable if there are no observed leaks or pressure drop. A pressure variation up to ± 1.0% of the test pressure is normally acceptable provided that the total variation can be demonstrated as caused by temperature fluctuations, or otherwise accounted for. If greater pressure variations are observed, the holding period shall be extended until a hold period with acceptable pressure variations has occurred.

717 Documentation produced in connection with the pressure testing of the pipeline system shall include:

— Test drawings or sketches,
— pressure and temperature recorder charts,
— log of pressure and temperatures,
— calibration certificates for instruments and test equipment, and
— calculation of pressure and temperature relationship and justification for acceptance.

H 800 Non-destructive testing and visual examination

801 All welds shall be subject to:

— 100% visual inspection; and
— 100% radiographic or ultrasonic testing, (automated ultrasonic testing should be preferred for girth welds).

802 Guidance on applicable and preferred NDT methods is given in Appendix D, A 400.
803 Requirements to automated ultrasonic testing of girth welds are given in Appendix E.

804 If allowable defect sizes are based on an ECA, ultrasonic testing, preferably automated ultrasonic testing is required.

805 All NDT shall be performed after completion of all cold forming, heat treatment and hydrostatic testing.

806 Requirements for personnel, methods, equipment, procedures, and acceptance criteria, for NDT are given in Appendix D.

H 900 Dimensional verification

901 Dimensional verification should be performed in order to establish conformance with the required dimensions and tolerances.

902 Dimensional verification of pipe strings for towing shall include weight, and the distribution of weight and buoyancy.

H 1000 Corrosion protection

Application of coatings and installation of anodes shall meet the requirements of Section 8.

I. Documentation, Records, Certification and Marking

I 100 Documentation, records, certification and marking

101 All base material, fittings and, flanges, etc. shall be delivered with Inspection Certificate 3.1.B according to European Standard EN 10204 or accepted equivalent.

102 The inspection certificate shall include:

— identification the products covered by the certificate with reference to heat number, heat treatment batch etc.;
— dimensions and weights of products;
— the results (or reference to the results) of all specified inspections and tests; and
— the supply condition and the temperature of the final heat treatment.

103 Each equipment or component item shall be adequately and uniquely marked for identification. The marking shall, as a minimum, provide correlation of the product with the related inspection documentation.

104 The marking shall be such that it easily will be identified, and retained during the subsequent activities.

105 Other markings required for identification may be required.

106 Equipment and components shall be adequately protected from harmful deterioration from the time of manufacture until taken into use.
SECTION 8
CORROSION PROTECTION AND WEIGHT COATING

A. General

A 100 Objective

101 This section aims to give general guidance on:

— conceptual and detailed design of corrosion protective systems,
— design and manufacturing of concrete weight coatings, and on
— quality control during manufacturing/fabrication of systems for corrosion protection.

102 For quantitative design parameters and functional requirements, reference is made to relevant standards and guidelines, including DNV RP B401 for cathodic protection, and DNV RP-F106 for factory applied linepipe coatings.

A 200 Application

201 This section covers external and internal corrosion protection of pipelines and risers. Concrete coatings for anti-buoyancy are also addressed. Onshore sections at any landfall of pipelines are, however, not included.

202 Linepipe materials selection associated with corrosion control is covered in Section 5. Requirements and guidance on inspection and monitoring associated with corrosion control are found in Section 10.

A 300 Definitions

301 The term corrosion control as used in this section includes all relevant measures for corrosion protection, as well as the inspection and monitoring of corrosion (see Section 10). Corrosion protection includes use of corrosion resistant materials, corrosion allowance (see Section 5B 700) and various techniques for corrosion mitigation.

302 Linepipe (external) coating refers to factory applied coating systems (mostly multiple-layer, with a total thickness of some millimetres) with a corrosion protection function, either alone or in combination with a thermal insulation function. Some coating systems may further include an outer layer for mechanical protection, primarily during laying and any rock dumping or trenching operations. Concrete coating for anti-buoyancy (weight coating) is, however, not covered by the term linepipe coating.

303 Field joint coatings refers to single or multiple layers of coating applied to protect girth welds, irrespective of whether such coating is actually applied in the field or in a factory (e.g. pipelines for reel laying and prefabricated risers).

304 For definition of corrosion zones, including splash zone, atmospheric zone and submerged zone, see D 100.

B. General Principles for Corrosion Control During Design

B 100 General

101 All components of a pipeline system shall have adequate corrosion protection to avoid failures caused or initiated by corrosion, both externally and internally.

Guidance note:
Any corrosion damage may take the form of a more or less uniform reduction of pipe wall thickness, but scattered pitting and grooving corrosion oriented longitudinally or transversally to the pipe axis is more typical. Stress corrosion cracking is another form of damage. Uniform corrosion and corrosion grooving may interact with internal pressure or external operational loads, causing rupture by plastic collapse or brittle fracture. Discrete pitting attacks are more likely to cause a pinhole leakage once the full pipe wall has been penetrated.
C. Pipeline External Coatings

C 100 General

101 The pipeline (external) coating system shall be selected based on consideration of the following major items:

- corrosion-protective (i.e. insulating) properties dictated by permeability for water, dissolved gases and salts, adhesion, freedom from pores, etc;
- resistance to physical, chemical and biological degradation, primarily in service but also during storage prior to installation (operating temperature range and design life are decisive parameters);
- requirements for mechanical properties during installation and operation;
- compatibility with fabrication and installation procedures, including field joint coating (see E 100) and field repairs;
- compatibility with concrete weight coating (see F 100), if applicable;
- compatibility with cathodic protection, and capability of reducing current demand for cathodic protection (see G 100), if applicable;
- requirement for thermal insulation properties, if applicable; and
- environmental compatibility and health hazards during coating application, fabrication/installation and operation.

102 Pipeline components shall have external coatings preferably matching the properties of those to be used for linepipe. If this is not practical, cathodic protection design may compensate for inferior properties. However, risks associated with hydrogen induced cracking by cathodic protection shall be duly considered (see Section 5B.507).

103 Coating properties (functional requirements) which apply for the coated pipes shall be defined in a purchase specification. The following properties may be specified as applicable:

- maximum and minimum thickness,
- density,
- adhesion,
- tensile properties,
- impact resistance,
- cathodic disbondment resistance,
- flexibility,
- thermal resistance or conductivity,
- abrasion resistance
- electrical resistance, and
- resistance to hydrostatic pressure
- cutbacks.

Project specific requirements to quality control shall be described.

104 DNV RP-F106 gives detailed requirements and recommendations to manufacturing of linepipe coatings, including inspection and testing associated with quality control.

C 200 Coating materials, surface preparation and application

201 The coating Manufacturer shall be capable of documenting their ability to produce coatings meeting specified properties. A coating manufacturing qualification should be executed and accepted by Purchaser before starting the coating work, especially for novel products where there is limited experience from manufacturing.

202 All coating work shall be carried out according to a qualified manufacturing procedure specification. The following items shall be described in the coating manufacturing procedure specification:

- coating materials,
- surface preparation,
109 Mechanical and physical coating properties listed in C.103 are also relevant for riser coatings, dependent on the particular corrosion protection zone. The applicable requirements to properties for each coating system and for quality control shall be defined in a purchase specification.

110 External cladding with certain Cu-base alloys may be used for combined corrosion protection and anti-fouling, primarily in the transition of the splash zone and the submerged zone (see B.103). However, metallic materials with anti-fouling properties must be electrically insulated from the cathodic protection system to be effective. Multiple-layer paint coatings and thermally sprayed aluminium coatings are applicable to the atmospheric and submerged zones, and in the splash zone if functional requirements and local conditions permit (see 106).

D 200 Coating materials, surface preparation and application

201 Riser coatings may be applied after fabrication welding, and in the atmospheric zone, after installation.

202 All coating work shall be carried out according to a qualified procedure. The coating manufacturing procedure specification shall give requirements for handling, storage, marking and inspection of coating materials.

203 Regarding requirements for qualification of coating manufacturing, coating manufacturing procedure specification and quality plan, see C 200.

204 For certain types of riser coatings, the requirements and recommendations in DNV RP-F106 are applicable.

E. Field Joint Coatings

E 100 General

101 For pipes with a weight coating or thermally insulated coating, the field joint coating is typically made up of an inner corrosion protective coating and an in-fill. The objective of the in-fill is to provide a smooth transition to the pipeline coating and mechanical protection to the inner coating. For thermally insulated pipelines and risers, the in-fill shall also have adequate insulating properties.

102 For the selection of field joint coating, the same considerations as for pipeline and riser coatings in C.101, D.105 and D.106 apply. In addition, sufficient time for application and hardening or curing is crucial during barge laying of pipelines.

103 Riser field joint coatings shall preferably have properties matching the selected pipe coating. In the splash zone, field joint coatings should be avoided unless it can be demonstrated that their corrosion protection properties are closely equivalent to those of the adjacent coating.

104 Relevant coating properties are to be defined in a project specification. The same properties as for pipelines and risers in C.103 and D.109, respectively should be considered when preparing the specification.

E 200 Coating materials, surface preparation and application

201 The Contractor shall be capable of documenting their ability to produce coatings meeting specified properties. A qualification program, including destructive testing of coatings, shall be performed prior to start of work unless relevant results from previous testing are available. For novel systems to be applied at sea, the qualification program should include installation at sea with subsequent destructive testing.

202 All coating work shall be carried out according to a qualified procedure. The following items shall be described in the field joint coating manufacturing procedure specification:

F. Concrete Weight Coating

F 100 General

101 The objectives of a concrete weight coating are to provide negative buoyancy to the pipeline, and to provide mechanical protection of the corrosion coating during installation and throughout the pipeline's operational life.

102 Requirements to raw materials (cement, aggregates, water, additives, reinforcement), and coating properties (functional requirements) shall be defined in a purchase specification. The following coating properties may be specified as applicable:

- submerged weight/negative buoyancy,
- thickness,
- concrete density,
- compressive strength,
- water absorption,
- impact resistance (e.g. over-trawling capability),
- flexibility (bending resistance), and
- cutbacks.

Recommended minimum requirements to some of the above properties are given in 203 below. Some general requirements to steel reinforcement are recommended in 204 and 205. Project specific requirements to quality control (including pipe tracking and documentation) shall also be described in the purchase documentation.

F 200 Concrete materials and coating manufacturing

201 Before starting coating production, the coating Manufacturer shall document that the materials, procedures and equipment to be used are capable of producing a coating of specified properties. A pre-production test should be performed for documentation of certain properties such as impact resistance and flexibility (bending strength).

202 All coating work shall be carried out according to a qualified manufacturing procedure specification. The following items shall be described:

- coating materials,
- reinforcement design and installation,
- coating application and curing,
- inspection and testing,
- coating repairs (see 210), and
- handling and storage of coated pipes

203 The concrete constituents and manufacturing method should be selected to provide the following recommended minimum requirements to as-applied coating properties:

- minimum thickness: 40 mm;
- minimum compressive strength (i.e. average of 3 core specimens per pipe): 40 MPa (ASTM C 39);
maximum water absorption: 8% (by volume), (testing of coated pipe according to agreed method); and
— minimum density: 1900 kg/m³ (ASTM C 642).

204 The concrete coating shall be reinforced by steel bars welded to cages or by wire mesh steel. The following recommendations apply: For welded cages, the spacing between circumferential bars should be maximum 120 mm. Steel bars should have a diameter of 6 mm minimum. The average cross sectional area of steel reinforcement in the circumferential direction should be minimum 0.5% of the longitudinal concrete cross section. The corresponding cross sectional area of steel reinforcement in the longitudinal direction should be minimum 0.08% of the transverse concrete cross section.

205 When a single layer of reinforcement is used, it shall be located within the middle third of the concrete coating. The recommended minimum distance from the corrosion protective coating is 15 mm, whilst the recommended minimum coverage is 15 mm and 20 mm for coatings with specified minimum thickness ≤ 50 mm and > 50 mm respectively. Overlap for wire mesh reinforcement should be 25 mm minimum. Electrical contact with anodes for cathodic protection shall be avoided.

206 The concrete may be applied according to one of the following methods:
— impingement application,
— compression coating,
— slipforming.

207 Rebound or recycled concrete may be used provided it is documented that specified properties are met.

208 The curing method shall take into account any adverse climatic conditions. The curing process should ensure no significant moisture loss for 7 days or a minimum compressive strength of 15 MPa.

209 Detailed criteria for repairs and recoating shall be defined. As a minimum, all areas with exposed reinforcement shall be repaired. Areas with deficient coating exceeding 10% of the total coating surface shall be recoated.

210 Procedures for repair of uncured and cored coatings shall be subject to agreement.

F 300 Inspection and testing

301 A quality plan shall be prepared and submitted to Purchaser for acceptance. The quality plan shall define the methods and frequency of inspection, testing and calibrations, acceptance criteria and requirements to documentation. Reference shall be made to applicable specifications and procedures for inspection, testing and calibration. Handling of non-conforming materials and products shall be described.

G. Cathodic Protection Design

G 100 General

101 Pipelines and risers in the submerged zone shall be furnished with a cathodic protection system to provide adequate corrosion protection for any defects occurring during coating application (including field joints), and also for subsequent damage to the coating during installation and operation.

Guidance note:
Cathodic protection may be achieved using either sacrificial ("galvanic") anodes, or impressed current from a rectifier. Sacrificial anodes are normally preferred.

102 The cathodic protection systems shall be capable of suppressing the pipe-to-seawater (or pipe-to-sediment) electrochemical potential into the range -0.80 to -1.1 V rel. Ag/AgCl/seawater. Potentials more negative than -1.1 V rel. Ag/AgCl/seawater can be achieved using impressed current. Such potentials may cause detrimental secondary effects, including coating disbondment and hydrogen-induced (stress) cracking (or "hydrogen embrittlement") of linepipe materials and welds.

Guidance note:
Pipeline system components in C-Mn steel and ferritic, martensitic or ferritic austenitic stainless steel subject to severe plastic straining during operation can suffer hydrogen induced cracking (hydrogen embrittlement) by cathodic protection, also within the potential range given above. Such damage is primarily to be avoided by restricting severe straining by design measures. In addition, special emphasis shall be laid on ensuring adequate coating of components that may be subject to localised straining.

103 Sacrificial anode cathodic protection systems are normally designed to provide corrosion protection throughout the design life of the protected object.

Guidance note:
As retrofitting of sacrificial anodes is generally costly (if practical at all), the likelihood of the initial pipeline design life being extended should be duly considered.

104 Pipeline systems connected to other offshore installations shall have compatible cathodic protection systems unless an electrically insulating joint is to be installed. At any landfall of an offshore pipeline with sacrificial anodes and impressed current cathodic protection of the onshore section, the needs for an insulating joint shall be evaluated.

Guidance note:
Without insulating joints, some interaction with the cathodic protection system of electrically connected offshore structures cannot be avoided. As the design parameters for subsea pipelines are typically more conservative than that of other structures, some current drain from riser and from pipeline anodes adjacent to the pipeline cannot be avoided, sometimes leading to premature consumption. When the structure has a correctly designed cathodic protection system such current drain is not critical as the net current drain will decrease with time and ultimately cease; i.e. unless the second structure has insufficient cathodic protection.

G 200 Design parameters and calculations

201 A detailed procedure for design calculations and recommendations for design parameters associated with sacrificial anode cathodic protection systems is given in DNV Recommended Practice RP B401 "Cathodic Protection Design".

202 The detailed anode design is dependent on the type of linepipe coating. For pipelines with weight coating, the anodes are normally designed with thickness equal to the coating. For pipelines and risers with thermally insulating coatings, the overall design should restrict heating of the anode in order to improve its electrochemical efficiency (e.g. by mounting anodes on outside of coating).

Anode cores, supports and fastening devices shall be designed to provide the required utilisation factor, to ensure electrical continuity, and to support the anode during all phases of fabrication, installation and operation.

203 The anode surface facing the pipe shall have a painting of minimum 100 m (epoxy-based or equivalent).

204 To avoid slippage during pipe installation and operation, anodes to be mounted on top of the coating may have to be designed for direct welding of anode core to doubler plates on the pipeline. The detailed design shall address the likelihood of loss of anodes during installation and its consequences for the overall system capacity. Contingency measures shall be identified as required. It is recommended that the distance between...
successive anodes does not exceed 150 m. (Larger distances should be evaluated taking into account electric resistance in pipeline, likelihood of damage to anodes and any contingency measures).

205 For anodes clamped to the pipeline or riser, each anode segment shall have an electrical cable for electrical continuity to the pipe.

206 Outline anode drawings, including fastening devices, shall be prepared for each anode type/size. Connection cables shall be detailed where applicable. Net anode weights and dimensional tolerances shall be specified on drawings.

207 The detailed engineering documentation shall contain the following:
- design premises, including design life and reference to relevant project specifications, codes, standards, etc.; and
- surface area and current demand calculations.

In addition, design documentation for sacrificial anode systems shall contain the following:
- anode mass calculations,
- anode resistance calculations,
- anode number calculations, and
- anode detailed drawings (including fastening devices and connector cables if applicable).

208 Reference is made to DNV RP B401 for design documentation of impressed current systems.

H. Manufacturing and Installation of Sacrificial Anodes

H 100 Anode manufacturing

101 Requirements to anode manufacturing, including dimensions and weight, requirements to quality control (defect tolerances, electrochemical performance during testing, etc.), marking and documentation shall be detailed in a purchase specification.

102 For each anode type/size, the Manufacturer shall prepare a detailed drawing showing location and dimensions of anode inserts, anode gross weight and other details as specified in purchase documentation (see G.206).

103 Manufacturing of anodes shall be carried out according to a manufacturing procedure specification. General requirements for anode manufacturing are given in DNV-RP B401.

104 A procedure for electrochemical testing of anode material performance during anode manufacturing is given in Appendix A of RP B401.

105 Inserts to be welded to the pipe shall be made of steel with adequate weldability. For stainless steel linepipe, such inserts shall always be welded on to doubler plates of the same material as, or otherwise compatible with, the linepipe. For C-Mn steel inserts, the carbon equivalent or Pcm value for any doubler plates shall not exceed that specified for the pipe material.

106 Detailed requirements for weight and dimensional tolerances are given in e.g. NACE RP 0492-92.

107 All anodes shall be visually examined for cracks and other significant defects. Requirements are given in e.g. NACE RP 0492-92.

108 A quality plan shall be prepared and submitted to Purchaser for acceptance. The quality plan shall define methods, frequency of inspection and testing, and acceptance criteria. Reference shall be made to applicable procedures for inspection, testing and calibrations.

109 Marking of anodes shall ensure traceability to heat number. Anodes should be delivered according to EN 10204, Inspection Certificate 3.1.B or an equivalent standard.

H 200 Anode installation

201 Anode installation may be carried out onshore e.g. for pipeline barge welding and for tow-out installation. For reel laying, pipeline anodes are typically attached offshore.

202 Anodes shall be installed according to a procedure describing handling of anodes, installation and subsequent inspection.

203 All welding or brazing of anode fastening devices and connector cables shall be carried out according to a qualified procedure (see Appendix C).

204 For linepipe that is to be concrete weight coated, electrical contact between concrete reinforcement and the anodes shall be avoided. The gaps between the anode half shells may be filled with asphalt mastic or similar. Any spillage of filling compound on the external anode surfaces shall be removed.

I. Design and Manufacturing/Fabrication of Internal Corrosion Protection

I 100 General

101 Most fluids for transportation in pipeline systems are potentially corrosive to ordinary C-Mn steel linepipe material.

102 The selection of a system for internal corrosion protection of pipelines and risers has a major effect on detailed design and must therefore be evaluated during conceptual design (see B 200 and Section 5B 500). The following options for corrosion control may be considered:

a) processing of fluid for removal of liquid water and/or corrosive agents;

b) use of linepipe or internal (metallic) lining/cladding with intrinsic corrosion resistance;

c) use of organic corrosion protective coatings or linings (normally in combination with a) or d)); and

d) chemical treatment, i.e. addition of chemicals with corrosion mitigating function.

In addition, the benefits of a corrosion allowance (see B 200 and 0) shall be duly considered.

103 The need for temporary corrosion protection of internal surfaces during storage, transportation and flooding should be considered. Optional techniques include end caps, rust protective oil/wax, and for flooding, chemical treatment (biocide and/or oxygen scavenger).

Guidance note:
The use of a biocide for treatment of water for flooding is most essential (even with short duration) as incipient bacterial growth established during flooding may proceed during operation and cause corrosion damage. For uncoated C-Mn steel pipelines, an oxygen scavenger may be omitted since oxygen dissolved in seawater will become rapidly consumed by uniform corrosion without causing significant loss of wall thickness. Film forming or “passivating” corrosion inhibitors are not actually required and may even be harmful.

---end---of---Guidance---note---

I 200 Internal corrosion protection by fluid processing

201 Corrosion control by fluid processing may involve removal of water from gas/oil (dehydration), or of oxygen from seawater for injection (deoxygenation), for example. Consequences of operational upsets on material degradation shall be evaluated. The necessity for corrosion allowance and redund-
dant systems for fluid processing should be considered. Online monitoring of fluid corrosion properties downstream of processing unit is normally required. For oil export pipelines carrying residual amounts of water, a biocide treatment should be considered as a back up (see I 500).

I 300 Internal corrosion protection by use of linepipe in Corrosion Resistant Alloys (CRAs)

301 The selection of corrosion resistant materials has normally been preceded by an evaluation of a C-Mn steel option, where the material was concluded to provide inadequate safety and/or cost effectiveness in terms of operational reliability (see B 200).

302 For the subsequent selection of corrosion resistant materials, the following major parameters shall be considered:

- mechanical properties;
- ease of fabrication, particularly weldability; and
- internal and external corrosion resistance, in particular with respect to environmentally induced cracking.

Guidance note:
Procurement conditions such as availability, lead times and costs should also be considered.

---end-of-Guidance-note---

303 The need for pre-qualification of candidate suppliers of linepipe and pipeline components in CRAs shall be duly considered.

I 400 Internal corrosion protection by organic coatings or linings

401 If internal coatings or linings are to be evaluated as an option for corrosion control, the following main parameters shall be considered:

- chemical compatibility with all fluids to be conveyed or contacted during installation, commissioning and operation, including the effects of any additives (see I 500);
- resistance to erosion by fluid and mechanical damage by pigging operations;
- resistance to rapid decompression;
- reliability of quality control during coating application;
- reliability of (internal) field joint coating systems, if applicable; and
- consequences of failure and redundant techniques for corrosion mitigation.

Guidance note:
Internal coating of pipelines (e.g. by thin film fusion bonded epoxy) has primarily been applied for the purpose of friction reduction in dry gas pipelines ("flow coatings"). Although internal coatings can not be expected to be fully efficient in preventing corrosion attack if corrosive fluids are conveyed, any coating with adequate properties may still be efficient in reducing forms of attack affecting membrane stresses and hence, the pressure retaining capacity of the pipeline.

---end-of-Guidance-note---

I 500 Internal corrosion protection by chemical treatment

501 Chemical treatment of fluids for corrosion control may include:

- corrosion inhibitors (e.g. "film forming");
- pH-buffering chemicals;
- biocides (for mitigation of bacterial corrosion);
- glycol or methanol (added at high concentrations for hydrate inhibition, diluting the water phase);
- dispersants (for emulsification of water in oil); and
- scavengers (for removal of corrosive constituents at low concentrations).

Guidance note:
For pipelines carrying untreated well fluid or other fluids with high corrosivity and with high requirements to safety and reliability, there is a need to verify the efficiency of chemical treatment by integrity monitoring using a tool allowing wall thickness measurements along the full length of the pipeline (see Section 10).

---end-of-Guidance-note---
SECTION 9
INSTALLATION

A. General

A 100 Objective

101 The objective of this section is to provide requirements as to which analyses, studies and documentation shall be prepared and agreed for the installation, and further to provide requirements for the installation and testing of the complete pipeline system which are not covered elsewhere in the standard.

A 200 Application

201 This section is applicable to installation and testing of pipelines and rigid risers designed and manufactured according to this standard.

A 300 Failure Mode Effect Analysis (FMEA) and Hazard and Operability (HAZOP) studies

301 Systematic analyses of equipment and installation operations shall be performed in order to identify possible critical items or activities which could cause or aggravate a hazardous condition, and to ensure that effective remedial measures are taken. The extent of analysis shall reflect the criticality of the operations and the extent of experience available from previous similar operations.

302 Special attention shall be given to sections of the pipeline route close to other installations or shore approaches where there is greater risk of interference from shipping, anchoring etc. For critical operations, procedural HAZOP studies shall be performed.

Guidance note:

Guidance in performing Failure Mode Effect Analysis is given in DNV Rules for Classification of High Speed and Light Craft, Pt.0 Ch.4 Sec.2.

---end---of---Guidance---note---

A 400 Installation and testing specifications and drawings

401 Specifications and drawings shall be prepared covering installation and testing of pipeline systems, risers, protective structures etc.

402 The specifications and drawings shall describe, in sufficient detail, requirements to installation methods and the processes to be employed and to the final result of the operations.

403 The requirements shall reflect the basis for, and the results of, the design activities. The type and extent of verification, testing, acceptance criteria and associated documentation required to verify that the properties and integrity of the pipeline system meet the requirements of this standard, as well as the extent and type of documentation, records and certification required, shall be stated.

404 Requirements to the installation manual and the extent of tests, investigations and acceptance criteria required for qualification of the installation manual shall be included.

A 500 Installation Manuals

501 Installation manuals shall be prepared by the various Contractors.

502 The installation manual is a collection of the manuals and procedures relevant to the specific work to be performed. It is prepared in order to demonstrate that the methods and equipment used by the Contractor will meet the specified requirements, and that the results can be verified. The installation manual shall include all factors that influence the quality and reliability of the installation work, including normal and contingency situations, and shall address all installation steps, including examinations and check points. The manual shall reflect the results of the FMEA analysis or HAZOP studies, and shall state requirements for the parameters to be controlled and the allowable range of parameter variation during the installation.

The following shall, as a minimum, be covered:

— quality system manual,
— mobilisation manual,
— construction manual,
— health, safety and environment manual, and
— emergency preparedness manual.

The manuals should include:

— purpose and scope of the activity;
— responsibilities;
— materials, equipment and documents to be used;
— how the activity is performed in order to meet specified requirements; and
— how the activity is controlled and documented.

504 The installation manual shall be updated/revised as needed as installation proceeds.

505 The installation manuals are subject to agreement through:

— review of methods, procedures and calculations,
— review and qualification of procedures,
— qualification of vessels and equipment, and
— review of personnel qualifications

506 Requirements to the installation manual and acceptance are given in the various subsections. The results of the FMEA analysis or HAZOP studies (see A 300) shall also be used in determining the extent and depth of verification of equipment and procedures.

507 In cases where variations in manner of performance of an activity may give undesirable results, the essential variables and their acceptable limits shall be established.

A 600 Quality Assurance

601 The installation Contractor shall as a minimum have an implemented quality assurance system meeting the requirements of ISO 9001/ISO9002 or equivalent. Further requirements for quality assurance are given in Section 2B 500.

A 700 Welding

701 Requirements for welding processes, welding procedure qualification, execution of welding and welding personnel are
given in Appendix C.

702 Requirements for mechanical and corrosion testing for qualification of welding procedures are given in Appendix B.

703 The mechanical properties and corrosion resistance of weldments shall at least meet the requirements given in the installation and testing specifications.

704 For weld repair at weld repair stations where the pipeline section under repair is subjected to tensile and bending stresses, a weld repair analysis shall be performed. The analysis shall determine the maximum excavation length and depth combinations that may be performed, taking into account all stresses acting at the area of the repair. The analysis shall be performed in accordance with the requirements to Engineering Criticality Assessment (ECA) given in Section 5D.

The analysis shall consider the reduction of yield and tensile strength in the material due to the heat input from defect excavation, preheating, and welding and also dynamic amplification due to weather conditions and reduced stiffness effect at field joints. The stresses in the remaining section shall not be above 80% of SMYS.

705 The weld repair analysis shall be subject to agreement.

706 The root and the first filler pass shall, as a minimum, be completed at the first welding station before moving the pipe. Moving the pipe at an earlier stage may be permitted if an analysis is performed showing that this can be performed without any risk of introducing damage to the deposited weld material. This analysis shall consider the maximum misalignment allowed, the height of the deposited weld metal, the possible presence of flaws, support conditions for the pipe and any dynamic effects.

A 800 Non-destructive testing and visual examination

801 Requirements for methods, equipment, procedures, acceptance criteria and the qualification and certification of personnel for visual examination and non-destructive testing (NDT) are given in Appendix D.

802 Requirements to automated ultrasonic testing (AUT) are given in Appendix E.

803 The extent of NDT for installation girth welds shall be 100% ultrasonic or radiographic testing. It is recommended that radiographic testing is supplemented with ultrasonic testing in order to enhance the probability of detection and/or characterisation/sizing of defects.

804 For wall thickness > 25mm, automated ultrasonic testing should be used.

805 Ultrasonic testing (UT) shall be used in the following cases:

- UT or automated ultrasonic testing (AUT) shall be performed whenever sizing of flaw height and/or determination of the flaw depth is required;
- 100% testing of the first 10 welds for welding processes with high potential for non-fusion type defects, when starting installation or when resuming production after suspension of welding and when radiographic testing is the primary NDT method. For wall thickness above 25mm additional random local spot checks during installation are recommended;
- testing to supplement radiographic testing for wall thickness above 25 mm, to aid in characterising and sizing of ambiguous indications;
- testing to supplement radiographic testing for unfavourable groove configurations, to aid in detection of defects;
- 100% lamination checks of a 50 mm wide band at ends of cut pipe.

806 If ultrasonic testing reveals unacceptable defects not discovered by radiography, the extent of ultrasonic testing shall be 100% for the next 10 welds. If the results of this extended testing are unsatisfactory, the welding shall be suspended until the causes of the defects have been established and rectified.

807 For “Golden Welds” (critical welds e.g. tie-in welds that will not be subject to pressure testing, etc.) 100% ultrasonic testing, 100% radiographic testing, and 100% magnetic particle testing or 100% liquid penetrant testing of non-ferromagnetic materials shall be performed. If the ultrasonic testing is performed as automated ultrasonic testing, see Appendix E, the radiographic and magnetic particle/liquid penetrant testing may be omitted subject to agreement.

808 Magnetic particle testing or liquid penetrant testing of non-ferromagnetic materials shall be performed to verify complete removal of defects before commencing weld repairs, and for 100% lamination checks at re-bevelled ends of cut pipe.

809 Visual Examination shall include:

- 100% examination of completed welds for surface flaws, shape and dimensions;
- 100% examination of the visible pipe surface, prior to field joint coating; and
- 100% examination of completed field joint coating.

A 900 Production tests

901 One production test is required for each Welding Procedure Specification (WPS) used for welding of the pipeline girth welds.

902 Production tests should not be required for welding procedures qualified specifically for tie-in welds, flange welds, Tee-piece welds etc.

903 Production tests may, subject to agreement, be omitted in cases where fracture toughness testing during welding procedure qualification is not required by this standard, or for C-Mn steel linepipe with SMYS < 450MPa.

904 The extent of production tests shall be expanded if:

- the Contractor has limited previous experience with the welding equipment and welding methods used,
- the welding inspection performed is found to be inadequate,
- severe defects occur repeatedly
- any other incident indicates inadequate welding performance, and
- the installed pipeline is not subjected to system pressure testing, see Section 5B.203.

905 The extent of production testing shall be consistent with the inspection and test regime and philosophy of the pipeline project.

906 Production tests shall be subject to the non-destructive, mechanical and corrosion testing as required in Appendix C.

907 If production tests show unacceptable results, appropriate corrective and preventative actions shall be initiated and the extent of production testing shall be increased.

B. Pipeline Route, Survey and Preparation

B 100 Pre-installation route survey

101 A pre-installation survey of the pipeline route may be required in addition to the route survey required for design purposes by Section 3 if:

- the time elapsed since the original survey is significant,
- a change in seabed conditions is likely to have occurred,
- the route is in areas with heavy marine activity, and
- new installations are present in the area.

102 The pre-installation survey, if required, shall determine:
C. Marine Operations

C 100 General

101 These requirements are applicable for vessels performing pipeline and riser installation and supporting operations. The requirements are applicable for the marine operations during installation work only. Specific requirements for installation equipment onboard vessels performing installation operations are given in the relevant subsections.

102 The organisation of key personnel with defined responsibilities and lines of communication shall be established prior to start of the operations. Interfaces with other parties shall be defined.

103 All personnel shall be qualified for their assigned work. Key personnel shall have sufficient verbal communication skills in the common language used during operations.

104 Manning level should comply with IMO's "Principles of Safe Manning". Non-propelled vessels shall have similar manning and organisation as required for propelled units of same type and size.

C 200 Vessels

201 All vessels shall have valid class with a recognised classification society. The valid class shall cover all systems of importance for the safety of the operation. Further requirements to vessels shall be given in a specification stating requirements for:

- anchors, anchor lines and anchor winches;
- anchoring systems;
- positioning and survey equipment;
- dynamic positioning equipment and reference system;
- alarm systems, including remote alarms when required;
- general seaworthiness of the vessel for the region;
- cranes and lifting appliances;
- pipeline installation equipment (see D); and
- any other requirement due to the nature of the operations.

202 Vessels shall have a documented maintenance programme covering all systems vital for the safety and operational performance of the vessel, related to the operation to be performed. The maintenance programme shall be presented in a maintenance manual or similar document.

203 Status reports for any recommendations or requirements given by National Authorities and/or classification societies, and status of all maintenance completed in relation to the maintenance planned for a relevant period, shall be available for review.

204 An inspection or survey shall be performed prior to mobilisation of the vessels to confirm that the vessels and their principal equipment meet the specified requirements and are suitable for the intended work.

C 300 Anchoring systems, anchor patterns and anchor positioning

301 Anchoring systems for vessels kept in position by anchors (with or without thruster assistance) while performing marine operations shall meet the following requirements:

- instruments for reading anchor line tension and length of anchor lines shall be fitted in the operations control room or on the bridge, and also at the winch station; and
- remotely operated winches shall be monitored from the control room or bridge, by means of cameras or equivalent.

302 Anchor patterns shall be predetermined for each vessel using anchors to maintain position. Different configurations for anchor patterns may be required for various sections of the pipeline, especially in the vicinity of fixed installations and

B 200 Seabed preparation

201 Seabed preparation may be required to:

- remove obstacles and potential hazards interfering with the installation operations;
- prevent loads or strains that occur as a result of seabed conditions such as unstable slopes, sand waves, deep valleys and possible erosion and scour from exceeding the design criteria;
- prepare for pipeline and cable crossings;
- infill depressions and remove high-spots to prevent unacceptable free spans; and
- carry out any other preparation due to the nature of the succeeding operations.

202 Where trench excavation is required before pipelaying, the trench cross-section shall be specified and the trench shall be excavated to a sufficiently smooth profile to minimise the possibility of damages to the pipeline, coating and anodes.

203 The extent of, and the requirements for, seabed preparation shall be specified. The laying tolerances shall be considered when the extent of seabed preparation is determined.

B 300 Pipeline and cable crossings

301 Preparations for crossing of pipelines and cables shall be carried out according to a specification detailing the measures adopted to avoid damage to both installations. The operations should be monitored by ROV to confirm proper placement and configuration of the supports. Support and profile over the existing installation shall be in accordance with the accepted design.

302 The specification shall state requirements concerning:

- minimum separation between existing installation and the pipeline,
- co-ordinates of crossing,
- marking of existing installation,
- confirmation of position and orientation of existing installations on both sides of the crossing,
- lay-out and profile of crossing,
- vessel anchoring,
- installation of supporting structures or gravel beds,
- methods to prevent scour and erosion around supports,
- monitoring and inspection methods,
- tolerance requirements, and
- any other requirements.

B 400 Preparations for shore approach

401 The location of any other pipelines, cables or outfalls in the area of the shore approach shall be identified and clearly marked.

402 Obstructions such as debris, rocks and boulders that might interfere with or restrict the installation operations shall be removed. The seabed and shore area shall be prepared to the state assumed in the design such that over-stressing in the pipeline during the installation and damage to coating or anodes is avoided.
other subsea installations or other pipelines or cables.

303 Anchor patterns shall be according to the results of a mooring analysis, using an agreed computer program, and shall be verified to have the required capacity for the proposed location, time of year and duration of operation. Distance to other installations and the possibility to leave the site in an emergency situation shall be considered.

304 Station-keeping systems based on anchoring shall have adequate redundancy or back-up systems in order to ensure that other vessels and installations are not endangered by partial failure.

305 Each anchor pattern shall be clearly shown on a chart of adequate scale. Care shall be taken in correlating different chart datum, if used.

306 Minimum clearances are to be specified between an anchor, its cable and any existing fixed or subsea installations or other pipelines or cables, both for normal operations and emergency conditions.

C 400 Positioning systems

401 Requirements for the positioning system and its accuracy for each type of vessel and application shall be specified.

402 The accuracy of horizontal surface positioning systems shall be consistent with the accuracy required for the operation and sufficient to perform survey work, placing of the pipeline, supporting structures or anchors within the specified tolerances, and to establish reference points for local positioning systems.

403 Installation in congested areas and work requiring precise relative location may require local systems of greater accuracy, such as acoustic transponder array systems. Use of ROV’s to monitor the operations may also be required.

404 The positioning system shall provide information relating to:

— position relative to the grid reference system used,

— geographical position,

— offsets from given positions, and

— offsets from antenna position.

405 Positioning systems shall have minimum 100% redundancy to allow for system errors or breakdown.

406 Documentation showing that positioning systems are calibrated and capable of operating within the specified limits of accuracy shall be available for review prior to start of the installation operations.

C 500 Dynamic positioning

501 Vessels using dynamic positioning systems for station keeping and location purposes shall be designed, equipped and operated in accordance with IMO MSC/Circ.645 (Guidelines for Vessels with Dynamic Positioning Systems), or with earlier NMD requirements for consequence class, and shall have corresponding class notations from a recognised classification society as follows:

Vessels > 5000 t displacement:

— Class 1 for operations > 500 m away from existing installations,

— Class 3 for operations < 500 m away from existing installations and for tie-in/riser installation operations,

— Class 3 for manned subsea operations or other operations where a sudden horizontal displacement of the vessel may have fatal consequences for personnel.

Vessels < 5000 t displacement:

— Class 1 for operations > 500 m away from existing installations,

— Class 2 for operations < 500 m away from existing installations and for tie-in/riser installation operations,

— Class 3 for manned subsea operations or other operations where a sudden horizontal displacement of the vessel may have fatal consequences for personnel.

C 600 Cranes and lifting equipment

601 Cranes and lifting equipment including lifting gear, lifting appliances, slings, grommets, shackles and pad-eyes, shall meet applicable statutory requirements. Certificates for the equipment, valid for the operations and conditions under which they will be used, shall be available on board for review.

C 700 Anchor handling and tug management

701 Anchor handling vessels shall be equipped with:

— a surface positioning system of sufficient accuracy for anchor drops in areas within 500 m of existing installations and pipelines, and

— computing and interfacing facilities for interfacing with lay vessel, trenching vessel or other anchored vessels.

702 Procedures for the anchor handling shall be established, ensuring that:

— anchor locations are in compliance with the anchor pattern for the location;

— requirements of owners of other installations and pipelines for anchor handling in the vicinity of the installation are known, and communication lines established;

— position prior to anchor drop is confirmed;

— anchor positions are monitored at all times, particularly in the vicinity of other installations and pipelines; and

— any other requirement due to the nature of the operations is fulfilled.

703 All anchors transported over subsea installations shall be secured on deck of the anchor handling vessel.

704 During anchor running, attention shall be paid to the anchor cable and the catenary of the cable, to maintain minimum clearance between the anchor cable and any subsea installations or obstacles.

C 800 Contingency procedures

801 Contingency procedures shall be established for the marine operations relating to:

— work site abandonment including emergency departure of the work location and when anchors cannot be recovered,

— mooring systems failure, and

— any other requirement due to the nature of the operations.

D. Pipeline Installation

D 100 General

101 The requirements of this subsection are generally applicable to pipeline installation, regardless of installation method. Additional requirements pertaining to specific installation methods are given in the following subsections.

102 Interfaces shall be established with other parties that may be affected by the operations. The responsibilities of all parties and lines of communication shall be established.
D 200 Installation Manual

201 The laying Contractor shall prepare an installation manual. As a minimum, the installation manual shall include all documentation required to perform the installation, and shall demonstrate that the pipeline can be safely installed and completed to the specified requirements by use of the dedicated spread.

202 The installation manual shall cover all applicable aspects such as:

- spread, including modifications and upgrading, if any;
- supervisory personnel, inspectors, welders and NDT personnel;
- communications and reporting;
- navigation and positioning;
- anchor handling, anchor patterns and catenary curves (if applicable);
- dynamic positioning system (if applicable);
- stress/strain and configuration monitoring, control, and recording during all phases of installation activities;
- operating limit conditions;
- normal pipe-lay;
- anode installation (where applicable);
- piggyback pipeline saddle installation (where applicable);
- piggyback pipeline installation (where applicable);
- pipe-lay in areas of particular concern, e.g. shipping lanes, platforms, subsea installations, shore approach;
- vessel pull management system;
- abandonment and recovery;
- start-up and lay-down;
- method of buckle detection;
- installation of in-line assemblies and equipment;
- pipe handling, hauling, stacking and storage;
- maintaining pipeline cleanliness during construction;
- pipe tracking;
- repair of damaged pipe coating;
- internal coating repair;
- internal cleaning of pipe before and after welding;
- welder qualification;
- welding equipment, line-up clamps, bevelling procedures, welding procedures, production welding, weld repair, welding production tests;
- NDT equipment, visual examination and NDT procedures, visual examination and NDT of welds;
- weld repair analysis extent of weld repair at repair station, determined by ECA (Ref. A 700);
- field joint coating and field joint coating repair;
- touchdown point monitoring;
- pipeline repair in case of wet or dry buckle; and
- provisions for winter laying, prevention of ice build-up, removal of ice, low temperature reservoirs in steel and concrete coating, etc.

203 The installation manual shall be supported by calculations and procedures, including contingency procedures, to an extent that adequately cover the work to be performed.

204 If the installation method used results in an accumulated plastic strain above 0.3%, an Engineering Criticality Assessment (ECA) shall be documented for the girth welds. The ECA shall establish the fracture toughness required to tolerate the defect acceptance criteria given in Appendix D Table D-4, Table D-5 or shall validate these acceptance criteria against fracture toughness values obtained during welding procedure qualification.

Alternatively the defect acceptance criteria may be established by an ECA based on fracture toughness values obtained during welding procedure qualification, see Appendix D.

205 If the accumulated plastic strain is 2% or above the fracture toughness testing and fracture mechanics assessments shall be validated according to E.

D 300 Review and qualification of the installation manual, essential variables and validity

Review of methods, procedures and calculations

301 The review of methods, procedures and calculations shall include:

- Failure mode effect analysis,
- HAZOP studies,
- installation procedures,
- contingency procedures,
- engineering critical assessments for girth welds,
- engineering critical assessments for weld repair lengths,
- other calculations made as part of the installation scope.

Review and qualification of procedures

302 Review and qualification of procedures shall as a minimum include:

- welding procedures for production and repair welding (see Appendix C);
- non-destructive testing procedures and automated NDT equipment (see Appendix D, Appendix E);
- field joint coating and field joint coating repair procedures; and
- internal and external coating repair procedures.

Qualification of vessels and equipment

303 Qualification of vessels and equipment prior to start of work shall include:

- dynamic positioning system test;
- combined review and dynamic positioning system/tensioner system tests (simulate vessel pull and tensioner failures and redundancy tests during pull);
- tensioner system review test (test combinations of tensioners, testing of single tensioner failure when running two or three tensioners, test redundancy of single tensioners, simulate main power loss and loss of signal power);
- abandonment and recovery winch test (safe fail actions, simulate main power loss and loss of signal power);
- friction clamp test (fail safe actions and test clamps during vessel pull);
- remote operated buckle detector;
- pipeline support geometry;
- stinger configuration and control devices;
- review of qualification records of critical/essential equipment, including welding machines and automated NDT equipment;
- review of maintenance records for critical/essential equipment, including welding machines and automated NDT equipment; and
- maintenance/calibration records of critical/essential equipment on support vessels.

Review of personnel qualifications

304 Review of personnel qualifications shall include:

- welders qualification/certification records,
- welding inspectors and QC personnel qualification/certification records, and
- NDT operators qualification/certification records.

305 Records from vessel qualification, testing and calibration shall be kept onboard and be available for review.

306 Essential variables shall as minimum be established for:

- Allowable variations in stress/strain and configuration control parameters where variations beyond established limits may cause critical conditions during installation;
- variations in equipment settings/performance that can cause or aggravate critical conditions;
changes in welding joint design and process parameters beyond that allowed in Appendix C;
— changes in NDT method, NDT equipment and NDT equipment calibration beyond that allowed in Appendix D and Appendix E;
— weld repair lengths/depths in areas where the pipe is subject to bending moments/axial stress. The maximum length/depth of excavation shall be determined by ECA calculations (see A.704);
— changes in field joint coating procedure;
— operating limit conditions; and
— any other requirement due to the nature of the operations.

307 The validity of the installation manual is limited to the lay-vessel/spread where the qualification was performed and to the pipeline or section of pipeline in question.

D 400 Operating limit conditions

401 Operating limit conditions shall be established and agreed.

402 The operating limit conditions shall be based on stress and strain calculations, FMEA analysis or HAZOP study data, and shall refer to objective, critical values indicated by measuring devices. The operating limit conditions shall be referred to in the procedure for stress/strain and configuration control. Continuous monitoring and recording of the measuring devices required for control of the operating limit conditions shall be performed during all phases of installation activities.

403 Operating limit criteria may, subject to agreement, be based on a defined seastate for areas where dependable historical environmental data and regular weather forecasts are available.

404 Regular weather forecasts from a recognised meteorological centre shall be available onboard the lay vessel, and shall be supplemented by historical environmental data.

405 If the critical values are about to be exceeded, preparations for lay-down shall commence. If the critical condition is weather dependent only, and if weather forecasts indicate that the weather condition will subside, the lay-down may be postponed subject to agreement.

406 Decision to recover the pipeline shall be based on comparison of the actual seastate with the limiting seastate, together with weather forecasts.

D 500 Installation procedures

501 Installation procedures meeting the requirements of this standard, including all requirements of the installation and testing specifications, shall be prepared by the Contractor for agreement.

D 600 Contingency procedures

601 Contingency procedures meeting the requirements of this standard, including all requirements of the installation and testing specifications, shall be prepared by the Contractor for agreement. The contingency procedures shall at least cover:
— failure of dynamic positioning system,
— failure of tensioner system,
— failure of anchors and anchor lines,
— ROV breakdown,
— breakdown of positioning system, and
— other critical or emergency situations identified in FMEA analysis or HAZOP studies.

D 700 Layvessel arrangement, laying equipment and instrumentation

701 The tensioners shall operate in a fail-safe mode and shall have adequate pulling force, holding force, braking capacity and squeeze pressure to maintain the pipe under controlled tension. The forces applied shall be controlled such that no damage to the pipeline or coating will occur.

702 The installation vessel tensioning system arrangement shall therefore be such that:
— the tensioners, brakes and holding clamps shall be able to hold the pipeline throughout an accidental flooding;
— the tensioning system shall have sufficient redundancy to prevent simultaneous breakdown of tensioners;
— the tensioner capacity shall have sufficient redundancy to allow failure of individual tensioners, without compromising the pipeline integrity; and
— in case of tensioner failure or failure in the tensioner system, the pipeline installation shall not re-start before the system has been repaired.

703 When applicable for the laying method, the pipeline shall be fully supported along the length of the vessel and on to the stinger by rollers, tracks or guides that allow the pipe to move axially. Supports shall prevent damage to coating, field joint coatings, anodes and in-line assemblies, and rollers shall move freely. The vertical and horizontal adjustment of the supports shall ensure a smooth transition from the vessel onto the stinger, to maintain the loading on the pipeline within the specified limits. The support heights and spacing shall be related to a clear and easily identifiable datum. The pipeline support geometry shall be verified prior to laying, and the accepted height and spacing of supports shall be permanently marked or otherwise indicated.

704 Stingers shall be adjusted to the correct configuration to ensure a smooth transition from the vessel to the outboard stinger end, and to maintain the loading on the pipeline within the specified limits. The geometry shall be verified prior to laying. If the stinger can be adjusted during laying operations, it shall be possible to determine the stinger position and configuration by reference to position markings or indicators. Buoyant stingers shall be equipped with indication devices showing the position of the rollers relative to the water surface.

705 A buckle detector shall be continuously pulled through the pipeline during laying, unless the same degree of control in detection of buckles is achieved by other means. The manner in which the same degree of control is achieved shall be documented. Exceptions are also when buckle detectors are not suitable due to the installation method, e.g. reeling, or for small diameter pipelines, where the gap between the inner pipe wall and the buckle detector disc will be very small, and contact with the internal weld bead can give false indications. The buckle detector shall be positioned such that the critical areas are monitored, (normally a distance after the touch down point). The diameter of the buckle detector disc shall be chosen with due regard to the pipeline internal diameter and tolerances on ovality, wall thickness, misalignment and internal weld bead.

706 The abandonment and recovery (A & R) winch should be able to recover the pipeline when waterfilled, or alternative methods for recovering the pipeline should be available.

707 A sufficient amount of instrumentation and measuring devices shall be installed to ensure that monitoring of essential equipment and all relevant parameters required for stress/strain and configuration control and control of the operating limit conditions can be performed.

The following instrumentation is required:

**Tensioners:**
— total pipeline tension recorders,
— tension at each tensioner,
— tensioner setting and variance to set point (dead band), and
— indication of applied pulling, holding and squeeze pressure.

**Stinger:**
underwater camera(s) and video recorders for monitoring pipeline position with respect to the last roller on the stinger (if restricted underwater visibility is expected, a sonar is required for monitoring pipeline position with respect to the rollers on the stinger);
— reaction load indicators (vertical and horizontal) on the first and last rollers on the stinger; and
— stinger configuration and tip depth for articulated stingers.

**Buckle detector:**
— pulling wire tension and length recorder, when applicable.

**Winches:**
— abandonment and recovery winches shall be equipped with wire tension and length recorder, and
— anchor winches shall meet the requirements given in C 300.

**Vessel:**
— vessel position,
— vessel movements such as roll, pitch, sway, heave,
— water depth,
— vessel draft and trim,
— current strength and direction,
— wind strength and direction, and
— direct or indirect indication of sag bend curvature and strain.

All measuring equipment shall be calibrated and adequate documentation of calibration shall be available onboard the vessel prior to start of work. All measuring equipment used shall be provided with an adequate amount of spares to ensure uninterrupted operation.

Essential equipment shall be provided with back-up.

Direct reading and processing of records from all required essential instrumentation and measuring devices, shall be possible at the vessels bridge.

Correlation of recorded data and pipe numbers shall be possible.

**708** Other equipment shall be available to monitor pipeline lay down point and other operations that are critical to the integrity of the pipeline or represent a risk for fixed installations or other subsea installations and pipelines. ROVs shall be capable of operating under the seastates expected for the operation in question.

**709** Other measuring and recording systems or equipment shall be required if they are essential for the installation operation.

**D 800 Requirements for installation**

**801** Handling and storage of materials on supply and laying vessels shall ensure that damage to pipe, coatings, assemblies and accessories are avoided. Slings and other equipment used shall be designed to prevent damage. Storage of pipes shall be in racks and suitable shoring shall be used. Maximum stacking heights shall be determined to avoid excessive loads on the pipe, coating or anodes. All material shipped for installation shall be recorded.

**802** All material shall be inspected for damage, quantity and identification upon arrival. Damaged items shall be quarantined, repaired or clearly marked and returned onshore.

**803** Pipes and in-line assemblies shall be inspected for loose material, debris and other contamination and cleaned internally before being added to the line. The cleaning method shall not cause damage to any internal coating.

**804** A pipe tracking system shall be used to maintain records of weld numbers, pipe numbers, NDT, pipe lengths, cumulative length, anode installation, in-line assemblies and repair numbers. The system shall be capable of detecting duplicate records.

**805** The individual pipes of the pipeline shall be marked in accordance with the established pipe tracking system, using a suitable quick-curing marine paint. The location, size and colour of the marking shall be suitable for reading by ROV during installation and subsequent surveys. It may be necessary to mark a band on top of the pipeline to quantify any rotation that may have occurred during installation. If damaged pipes are replaced, any sequential marking shall be maintained.

**806** Pipes shall be bevelled to the correct configuration, checked to be within tolerance, and inspected for damage. Internal line-up clamps shall be used, unless use of such clamps is demonstrated to be impracticable. Acceptable alignment, root gap and staggering of longitudinal welds shall be confirmed prior to welding.

**807** In-line assemblies shall be installed and inspected as required by the specification, and shall be protected against damage during passage through the tensioners and over pipe supports.

**808** Field joint coating and inspection shall meet the requirements given in Section 8.

**809** The parameters to be controlled by measuring devices, and the allowable range of parameter variation during installation, shall be established in a procedure for configuration control, pipeline tension and stress monitoring. The function of essential measuring devices shall be verified at regular intervals and defective or non-conforming devices shall repaired or replaced.

**810** The buckle detector load chart, if a buckle detector is used (see 705) shall be checked at regular intervals. The buckle detector shall be retrieved and inspected if there is reason to believe that buckling can have occurred. If the inspection shows indications of buckling or water ingress, the situation shall be investigated and remedial action performed.

**811** The position of pipeline start up and lay-down shall be verified as within their respective target areas prior to departure of the lay vessel from site, and adequate protection of pipeline and lay-down head shall be provided.

**812** Pipelaying in congested areas, in the vicinity of existing installations and at pipeline and cable crossings, shall be carried out using local positioning systems with specified accuracy and appropriate anchor patterns. Measures shall be taken to protect existing installations, cables and pipelines from damage. Such operations and the pipeline touch down point shall be monitored by ROV.

**813** Other critical operations such as laying in short radii curves, areas with steep slopes, use of very high or low pulling tension values etc. shall be identified and special procedures for the operation shall be prepared.

**814** In the event of buckling a survey of the pipeline shall be performed before repair to establish the extent of damage and feasibility of the repair procedure. After completion of the repair, a survey shall be performed of the pipeline over a length sufficient to ensure that no further damage has occurred.

**815** If loss or major damage to weight and corrosion coating or anodes and their cables/connectors are observed, repair shall be performed and inspected according to established procedures.

**816** Prior to abandonment of the pipeline, all internal equipment except the buckle detector shall be removed and all welds, including the abandonment and recovery head welds, shall be completely filled. In the event that the cable will have to be released from the vessel, a buoy and pennant wire should be attached to the abandonment and recovery head. The buoy shall be large enough to remain on the surface when exposed to the weight of the pennant wire, as well as any hydrodynamic
loads from waves and current.

Alternatively, seabed abandonment with a ROV friendly hooking loop may be used. Winch tension and cable lengths shall be monitored, and the specified values shall not be exceeded during the abandonment and recovery operation.

Before recovery the pipeline shall be surveyed over a length away from the abandonment and recovery head, sufficient to ensure that no damage has occurred.

817 An as-laid survey shall be performed either by continuous touch down point monitoring or by a dedicated vessel, and shall, as a minimum, include the requirements given in J.

E. Additional Requirements for Pipeline Installation Methods Introducing Plastic Deformations

E 100 General

101 The requirements of this subsection are applicable to pipeline installation by methods which give an accumulated plastic strain > 2% during installation and operation when all Strain Concentration Factors (SNCF) are included. The applicable requirements given in D shall also be satisfied.

102 The specific problems associated with these installation methods shall be addressed in the installation and testing specifications.

103 Pipes used for such installation methods shall meet the supplementary requirement, pipe for plastic deformation (P), see Section 6D 300.

104 For installation welding, the sequence of pipes included in the pipestring shall be controlled such that variations in stiffness on both sides of the welds are maintained within the assumptions made in the design. This may be achieved by matching, as closely as possible, wall thickness/diameter of the pipes and the actual yield stress on both sides of the weld.

105 Selection of welding consumables and welding of pipestrings shall be according to the requirements given in Appendix C.

106 100% automated ultrasonic testing (AUT) according to the requirements given in Appendix E should be performed.

E 200 Installation Manual

201 An installation manual shall be prepared by the Contractor for acceptance by the Purchaser and in addition to the requirements of A 500 and applicable requirements of D 200, it shall include:

— the amount of displacement controlled strain, both accumulated and maximum for each single strain cycle;
— method for control of, and allowable variation in, curvature of the pipe between the point of departure from the reel and entry into the straighteners;
— description of straighteners; and
— proposed procedure for qualification of the installation method by fracture mechanics assessment and validation testing.

E 300 Qualification of the Installation Manual

301 In addition to the applicable requirements of D 300, qualification of the installation manual shall include:

— qualification of welding procedures according to the supplementary requirements given in Appendix C, including CTOD or critical J testing and δ-R or J-R testing;
— engineering critical assessments to determine the characteristic strain capacity, εc;
— validation of engineering critical assessment by testing;
— testing of straighteners and resulting pipe straightness.

302 An Engineering Criticality Assessment shall be performed as required in Section 5D 1000.

303 The characteristic strain capacity, εc, determined by an ECA shall be validated by realistic testing of girth welded pipe, e.g. by full scale bend testing. The extent of testing and the details of the test procedure are subject to agreement, but all aspects of significance to unstable fracture shall be considered, such as:

— mechanical material properties of linepipe and girth weld, including weld metal overmatch and possible effects of strain ageing;
— geometric effects, e.g. on crack tip constraint, net section yielding and gross section yielding;
— mode of loading, multiples and magnitudes of loads and displacements;
— strain concentration effects, such as geometric mismatch, material strength mismatch of adjacent pipes, weld metal overmatch, weld toe strain concentration and coating stiffness discontinuities;
— defect type, location, shape and size; and
— effect of temperature on resistance to brittle fracture.

The testing shall demonstrate, conservatively, that possible weld defects will not result in unstable fracture during pipe laying, and will not extend by stable crack growth beyond a size that is acceptable with respect to fatigue and unstable fracture in the operational phase.

304 Bending tests on pipe coating shall also be performed to demonstrate that successive bending and straightening will not impair the pipe coating and field coating. No degradation of the coating properties shall occur. For this test the coating test may be carried out on plates.

305 The straighteners shall be qualified using pipe which is delivered to the pipeline and bent corresponding to the minimum curvature fed into the straighteners. It shall be demonstrated that the strain resulting from the straightening is within the assumptions made for the validation testing, and that the specified straightness is achieved. The straightening shall not cause damage to coating. The maximum deformation used during straightening to the specified straightness shall be recorded and regarded as an essential variable during installation.

E 400 Installation procedures

401 In addition to the applicable procedures of this subsection, the following procedures are required as applicable:

— reel loading;
— pipe straightening;
— anode and anode double plate installation;
— installation, welding and NDT of additional pipe strings; and
— any other procedure needed due to the nature of the operations.

E 500 Requirements for installation

501 Adequate support of the pipestring shall be provided when loading the reel. Tension shall be applied and monitored during reeling in order to ensure that the successive layers on the reel are sufficiently tightly packed to prevent slippage between the layers. Adequate measures shall be taken to protect the coating during reeling.

502 The reel shall not be used for control of the pipeline tension during installation, unless it can be demonstrated that such use will give acceptable redundancy and will not induce excessive stresses or have other detrimental effects.

503 The curvature of the pipe, peaking and sagging, between the point of departure from the reel and entry into the straighteners shall not exceed the maximum values assumed in design
and ECA and validated in the material testing of the girth welded pipes.

**504** Anodes should be installed after the pipe has passed through the straightener and tensioner. The electrical connection between anodes and pipe shall meet the specified requirements and shall be verified at regular intervals, see Section 8.

**F. Pipeline Installation by Towing**

**F 100 General**

**101** The specific problems associated with pipeline towing operations are to be addressed in the installation and testing specifications. The weight and buoyancy distribution control during fabrication, launching of the pipestring, tow, ballast control, environmental loads and contingencies shall be addressed when the requirements are specified.

**102** Tows may be performed as:
- surface or near-surface tows, with the pipestring supported by surface buoys;
- mid-depth tows, where the pipestring is towed well clear away from the seabed; and
- bottom tows, where the pipestring is towed in contact with, or close to, the seabed.

**103** For surface tows, all aspects pertaining to the tow are subject to agreement in each case.

**104** For bottom or near bottom tows, the pipeline route shall be surveyed prior to the tow and the route shall avoid rough seabed, boulders, rock outcrops and other obstacles that may cause damage to the pipeline, coating or anodes during the tow and installation. During bottom and near bottom tows, adequate monitoring with ROVs and of the pipeline position at critical phases is required. Satisfactory abrasion resistance of the pipe coating shall be demonstrated. All aspects pertaining to bottom tows are subject to agreement in each case.

**105** For mid-depth tows, the requirements in F 200 through F 800 are generally applicable.

**F 200 Installation Manual**

**201** An installation manual shall be prepared by the Contractor and, in addition to the requirements of A 400 and applicable requirements of D 200, it shall include:
- description of towing vessel(s) including capacities, equipment and instrumentation; and
- description of pipestring instrumentation.

**F 300 Qualification of Installation Manual**

**301** Qualification of the installation manual shall include the applicable requirements of D 300.

**F 400 Operating limit conditions**

**401** Operating limit conditions with regard to weather window for the tow, the seastate and current and allowed strain gauge values (if installed) shall be established.

**F 500 Installation procedures**

**501** Installation procedures meeting the requirements of this standard and the installation specifications shall be prepared and agreed. In addition to the applicable procedures of D 500, procedures are required for, but not limited to:
- control of weight- and buoyancy distribution,
- launching of the pipestring,
- ballast control during tow,
- ballast control during installation, and
- installation and joining of additional pipestrings.

**F 600 Contingency procedures**

**601** In addition to the applicable procedures of D 600, contingency procedures are required for:
- weather conditions in excess of the operating limit conditions,
- ballast system breakdown or partial failure,
- loss of towing tension,
- excessive towing tension,
- pre-designation of temporary mooring area(s) along the tow route, and
- third party marine activities.

**F 700 Arrangement, equipment and instrumentation**

**701** Vessels shall be equipped with:
- measuring equipment that continuously displays and records the towing speed and tensions,
- measuring equipment that continuously displays and monitors the depth of the pipestring and its distance from the seabed, and
- measuring equipment that continuously display the position of any ballast valves. The flow rates during any ballasting and de-ballasting are to be displayed.

**702** All measuring equipment shall be continuously monitored during the tow and installation.

**703** Installation of strain gauges to monitor the stresses in the pipestring during tow and installation shall be considered.

**F 800 Pipestring tow and installation**

**801** Launching of pipestrings shall be performed such that over-stressing of the pipestring and damage to the coating and anodes are avoided. If pipestrings are moored inshore awaiting the tow, adequate precautions shall be taken to avoid marine growth influencing pipestring buoyancy, weight and drag.

**802** Notification of the tow shall be given to the relevant authorities, owners of subsea installations crossed by the towing route and users of the sea.

**803** Towing shall not commence unless an acceptable weather window for the tow is available. During the tow a standby vessel shall be present to prevent interference with the tow by third party vessels.

**804** Tension in the towing line and the towing depth shall be kept within the specified limits during the tow. If required, ballasting or de-ballasting shall be performed to adjust the towing depth to the specified values.

**805** Installation shall be performed by careful ballasting and de-ballasting. Care shall be exercised to prevent over-stressing of the pipestring. The use of drag chains during the installation is recommended. The installation operation shall be monitored by ROV.

**G. Other Installation Methods**

**G 100 General**

**101** Other installation methods may be suitable in special cases. A thorough study shall be performed to establish the feasibility of the installation method and the loads imposed during installation. Such methods are subject to agreement in each case.

**102** Installation of flexible pipelines, bundles and multiple pipelines shall be performed after a thorough study to establish the feasibility of the installation method and the loads imposed during installation. The installation is subject to agreement in each case.
H. Shore Pull

H 100 General

101 The requirements of this subsection are applicable to the execution, inspection and testing of shore pull when pips-strings are pulled either from a vessel onto the shore, or vice versa.

102 Detailed requirements for the execution, inspection and testing of shore pull shall be specified, considering the nature of the particular installation site. The specific problems associated with shore pull shall be addressed in the installation and testing specifications.

H 200 Installation Manual

201 An installation manual shall be prepared by the Contractor and, in addition to the requirements of A 500 and D 200, shall cover:
— description of offshore plant arrangement, equipment and instrumentation;
— description of onshore plant arrangement, equipment and instrumentation; and
— special operations.

H 300 Qualification of Installation Manual

301 Qualification of the installation manual shall include the applicable requirements of D 300.

H 400 Operating limit conditions

401 Operating limit conditions with regard to the seastate and current shall be established if relevant.

H 500 Installation procedures

501 Installation procedures meeting the requirements of this standard and the installation specifications, shall be prepared and agreed. In addition to the applicable procedures of D 500, procedures are required for, but not limited to:
— installation of pulling head;
— tension control;
— twisting control;
— ROV monitoring where applicable;
— other critical operations;
— site preparation and winch set-up;
— buoyancy aids, where applicable; and
— position control in trench, tunnels, etc., as applicable.

H 600 Contingency procedures

601 Contingency procedures meeting the requirements of this standard and the installation and testing specification shall be prepared.

602 The contingency procedures shall cover:
— cable tension exceeding acceptable limits,
— excessive twisting of the pipestring,
— ROV breakdown, and
— other critical or emergency situations.

H 700 Arrangement, equipment and instrumentation

701 Cables, pulling heads and other equipment shall be di- mensioned for the forces to be applied, including any over- loading, friction and dynamic effects that may occur.

702 Winches shall have adequate pulling force to ensure that the pipe is maintained under controlled tension within the al- lowed stress/strain limits. The forces applied shall be control- led such that no damage to the pipeline anodes or coating will occur.

703 The winches shall be equipped with wire tension and length indicators and recorders. All measuring equipment shall be calibrated, and an adequate amount of spares to ensure un- interrupted operation shall be provided.

704 ROVs shall, if used, be equipped with video cameras, sonars, a bathymetric system, transponders, responders etc. as needed. It shall be documented that ROVs are able to operate under the seastate expected for the operation in question.

705 Other measuring and recording systems or equipment, such as strain gauges, should be provided if they are essential for the installation operation or the integrity of the pipeline.

H 800 Requirements for Installation

801 If necessary the seabed shall be prepared as required in B.

802 Satisfactory abrasion resistance of the pipeline coating shall be demonstrated for the installation conditions.

803 Installation of the pulling head shall be made in a man- ner that prevents over-stressing of the pipeline and provides a secure connection.

804 Buoyancy aids should be used if required to keep pulling tension within acceptable limits.

805 During the operation, continuous monitoring of cable tension and pulling force is required. Monitoring with ROVs may be needed.

I. Tie-in Operations

I 100 General

101 The requirements of this subsection are applicable to tie-in operations using welding or mechanical connectors. The operations can be performed onboard a laying vessel (in which case welding is the preferred method) or underwater. The specific problems associated with tie-in operations shall be ad- dressed in the installation and testing specifications.

102 Tie-in operations, by means of hot or cold taps, are sub- ject to special consideration and agreement.

I 200 Installation Manual

201 An installation manual shall be prepared by the Contrac- tor and shall, in addition to the requirements of A 500 and D 200, cover:
— description of diving plant arrangement, equipment and instrumentation; and
— special operations.

I 300 Qualification of Installation Manual

301 Qualification of the installation manual shall include the applicable requirements of D 300.

I 400 Operating limit conditions

401 Operating limit conditions with regard to the seastate, current and vessel movements shall be established.

I 500 Tie-in procedures

501 Tie-in procedures meeting the requirements of this standard and the installation specifications shall be prepared and agreed. In addition to the applicable procedures of D 500, the following procedures are required:
— lifting and deployment of the pipeline/riser section,
— configuration and alignment control, and
— mechanical connector installation.

If underwater methods are used, additional procedures are re- quired to cover the safety and operational aspects of the under- water operations.
I 600 Contingency procedures

601 In addition to the requirements of D 600, the following contingency procedure is required:

— weather conditions in excess of the operating limit conditions before completion of tie-in.

If underwater methods are used, additional contingency procedures are required to cover the safety and operational aspects of the underwater operations.

I 700 Tie-in operations above water

701 The position of the tie-in shall be verified prior to start of operations. A survey shall be performed to establish that the location is free of obstructions and that the seabed conditions will permit the tie-in to be performed as specified.

702 To avoid overstressing during lifting and lowering of the pipeline sections, the winch tension shall be monitored continuously and shall not exceed the specified for operation. Lifting arrangements and equipment shall be designed, and lifting points attached in a manner that prevents any over-stressing of the pipeline section during lifting and lowering into final position.

703 ROV/diver monitoring of the operation should be performed to confirm correct configuration of the pipeline sections from the seabed and onto the vessel.

704 The alignment and position of the tie-in ends shall be within the specified tolerances before completing the tie-in.

705 Installation of mechanical connectors shall be performed in accordance with the Manufacturer's procedure. For flanged connections hydraulic bolt tension equipment shall be used. During all handling, lifting and lowering into the final position, open flange faces shall be protected against mechanical damage.

706 A leak test to an internal pressure not less than the local incidental pressure should be performed for all mechanical connections whenever possible.

707 Corrosion protection of the tie-in area shall be performed and inspected in accordance with accepted procedures.

708 After completion of the tie-in, a survey of the pipeline on both sides of the tie-in, and over a length sufficient to ensure that no damage has occurred, should be performed.

709 It shall be verified that the position of the tie-in is within the target area prior to departure of the vessel from site. The pipeline stability shall be ensured and adequate protection of pipeline provided.

I 800 Tie-in operations below water

801 In addition to the requirements of I 700, the requirements in 802 and 803 are valid for tie-in operations involving underwater activities.

802 Diving and underwater operations shall be performed in accordance with agreed procedures for normal and contingency situations covering applicable requirements.

803 Requirements for underwater welding are given in Appendix C.

J. As-Laid Survey

J 100 General

101 These requirements are applicable to as-laid surveys performed by ROV either by continuous touch down point monitoring from the lay vessel or by a dedicated vessel.

J 200 Specification of as-laid survey

201 The installation and testing specification shall contain requirements to survey vessel, survey equipment, the extent of survey, tolerances for the as-laid pipe line, and the maximum acceptable length and gap height of spans at various locations. The extent of procedures to be prepared and qualified shall be specified.

J 300 As-laid survey

301 The as-laid survey should include the following:

— determination of the position and depth profile of the entire pipeline,
— identification and quantification of any spans with specified accuracy to length and gap height,
— determination of position of start-up and lay down heads,
— determination of the presence of debris, and
— as laid-video documentation of the pipeline to the extent specified.

J 400 As-laid survey of corrosion protection systems

401 Prior to any pipeline protection operations, a video survey of the corrosion protection system shall be carried out along the full length of the pipeline, including risers. Significant damage to the coating and sacrificial anodes shall be documented.

402 In the case of extensive damage to coating or sacrificial anodes, consequences for long-term performance shall be considered. Potential measurements at any bare surfaces should be carried out to confirm adequate protection. Corrective actions may include retrofitting of anodes and coating repairs, including risers. Satisfactory level of protection shall be documented after the corrective action has been performed.

K. Span Rectification and Pipeline Protection

K 100 General

101 The requirements of this subsection are applicable to span rectification and the protection of pipelines, e.g. by trenching and backfilling, gravel dumping, grout bags, concrete mattresses etc.

102 A specific survey of the work area should be required in addition to, or supplementing, the as-laid survey if:

— significant time has elapsed since the as-laid survey,
— a change in seabed conditions is likely,
— heavy marine activity is present in the area,
— new installations are present in the area, and
— the as-laid survey does not provide sufficient information.

103 The survey of the work area, if required, shall as a minimum include:

— a video inspection of the pipeline to identify any areas of damage to pipeline, coating and anodes;
— cross profiles of the pipeline and adjacent seabed at regular intervals;
— depth profiles along the pipeline and the seabed at both sides of the pipeline; and
— any existing subsea installations.

The undisturbed seabed level shall be included in the cross profiles.

K 200 Span rectification and protection specification

201 The requirements applicable to the specific methods of span rectification and protection regarding execution, monitoring and acceptance. Requirements for vessels, survey equipment etc. shall be addressed in the installation and testing specifications. The extent of procedures to be prepared and qualified shall be specified.
K 300 Span rectification

301 Span rectification is required for all spans exceeding the specified acceptable length or height for the specific location. Rectification of other spans shall be considered if scour or seabed settlement could enlarge the span length and gap height above maximum acceptable dimensions before the first planned pipeline inspection.

302 Adequate rectification of spans shall be documented by a video survey. All rectified spans shall be identified and the length, gap and height shall be within the requirements.

K 400 Trenching

401 Where trench excavation is performed after pipelaying, the trenching equipment shall be of a type that does not place significant loads on the pipeline and minimises the possibility of damage to the pipeline.

402 Trenching equipment shall be equipped with sufficient instrumentation to ensure that damage and excessive pipe contact is avoided.

403 Special care shall be taken during trenching operations of piggy back / bundle pipelines, so that strapping arrangements will not be disturbed / damaged during trenching. For small pipelines without any weight coating, trenching shall not damage / dismantle the anodes.

404 Where mechanical backfilling is required, it shall be carried out in a manner that minimises the possibility of damage or disturbance to the pipeline.

405 The trenching equipment monitoring system shall be calibrated and include:

- devices to measure depth of pipe,
- a monitoring system and control system preventing horizontal loads on the pipeline or devices to measure and record all vertical and horizontal forces imposed on the pipeline by trenching equipment, and devices to measure the proximity of the trenching equipment to the pipeline, horizontally and vertically relative to the pipeline;
- underwater monitoring systems enabling the trenching equipment operator to view the pipeline and seabed profile forward and aft of the trenching equipment;
- measuring and recording devices for trenching equipment tow force; and
- devices monitoring pitch, roll, depth, height and speed of the trenching equipment.

406 Jet sleds shall have a control and monitoring system for the position of the jetting arms and the overhead frame, horizontally and vertically relative to the pipeline. The location of the sled shall not be controlled by the force between sled and pipeline. Devices indicating tension in the tow line and showing the depth of the trench, shall be installed.

407 The trench depth shall be referenced to the undisturbed seabed adjacent to the pipeline and to the top of the pipeline.

408 An allowable range of values, indicated by the measuring devices of the trenching equipment, shall be established. The possibility of damage to coating shall be considered. During trenching operations the measuring devices shall be continuously monitored.

409 A post-trenching survey shall be performed immediately or as agreed after the trenching, in order to determine if the required depth of lowering has been achieved and if any remedial work is required.

K 500 Post-installation gravel dumping

501 Material used for gravel dumping shall meet the specified requirements for specific gravity, composition and grading.

502 Gravel dumping shall be performed in a continuous and controlled manner, such that the required material is deposited over and under the pipeline, supports, subsea assemblies, etc. without disturbing their vertical or lateral position, and over the adjacent seabed.

503 The gravel dumping operation shall ensure rectification of all spans to meet the specified requirements. Stabilisation of free spans should be carried out in a continuous operation, where the distance between spans to be stabilised is not too large, so as to avoid scouring and formation of free spans between gravel dumps.

504 If the fall pipe technique is used for gravel dumping, minimum clearances shall be specified such that the fall pipe cannot touch the pipeline, any other subsea installation or the seabed. Deployment operations shall be performed well away from the pipeline or any other subsea installation. Before the fall pipe is moved to the dumping location, the clearance beneath the fall pipe shall be verified. The clearance shall be continuously monitored during dumping.

505 The completed gravel dump shall leave a mound on the seabed with a smooth contour and profile and a slope not steeper than specified. If the gravel dumping is performed over cable and pipeline crossings, the gravel mound shall provide the specified depth of cover over both the raised and the crossed pipeline. During the dumping operations inspections shall be performed with a sonar survey system, or when visibility is restored, a video camera, to determine the completeness and adequacy of the dumping.

506 Upon completion of the gravel dumping, a survey shall be performed to confirm compliance with the specified requirements. The survey shall, as a minimum, include:

- a video inspection of the pipeline length covered,
- cross profiles of the mound and adjacent undisturbed seabed at regular intervals,
- length profiles of the mound,
- confirmation that minimum required buried depth is achieved, and
- any existing installations and their vicinity in order to ensure that the installation(s) have not suffered damage.

K 600 Grout bags and concrete mattresses

601 Concrete mattresses and grout bags shall meet the specification with regard to size, shape and flexibility of the material, location of filling points, and the specific gravity, composition and grading of grout.

602 Placing of grout bags and concrete mattresses shall be performed in a controlled manner, such that the bags or mattresses are placed as required. Restrictions on vessel movements during the operation shall be given.

603 During the placing operations, inspections shall be performed with a ROV-mounted video camera to determine the completeness and adequacy of the installation.

604 Upon completion of the placing operation, a survey shall be performed to confirm compliance with the specified requirements. The survey shall as a minimum include:

- a video inspection of the completed work,
- cross profiles of the placed bags or mattresses and adjacent undisturbed seabed at regular intervals, and
- length profiles of the placed bags or mattresses and the seabed at both sides of the area.

L. Installation of Protective and Anchoring Structures

L 100 General

101 Installation of protective and anchoring structures shall
be performed according to specifications and procedures meeting the requirements of the applicable design code.

M. Installation of Risers

M 100 General

101 The installation and testing specification shall cover the riser installation operations and address the specific problems associated with these operations. Diving and underwater operations shall be performed in accordance with agreed procedures covering applicable requirements.

102 The following methods may be used:

— integral installation by surface vessel, where the riser and pipeline are welded on deck of the vessel and the pipeline and riser lowered to the seabed. The riser is then positioned in clamps installed on the structure;

— installation by J-tube method, where the riser is pulled through a pre-installed J-shaped conduit on the structure, installation by bending shoe, where the pipeline is deformed around a quarter circle shaped bending shoe. Installation by bending shoe is subject to acceptance by the Purchaser in each case;

— installation of prefabricated risers, where the riser is installed in clamps fitted on the structure by a surface vessel. Hyperbaric welding or mechanical connector are then used to connect the riser and pipeline,

— stalk-on risers installed by an installation vessel, and

— flexible, free-hanging risers.

M 200 Installation Manual

201 The installation manual should, in addition to the requirements given in A 500 and D 200, cover:

— communication line and interface procedure with the platform where the riser is installed;

— description of offshore plant arrangement, equipment and instrumentation;

— procedures for offshore riser fabrication;

— procedures for measurement and control of cut-off length on the pipeline, riser bottom bend section, spool piece etc.;

— anchor pattern for installation vessel; and

— diving and/or underwater operations procedures.

M 300 Qualification of the Installation Manual

301 The installation manual shall be qualified. The qualification shall, as a minimum, include the requirements of D 300.

M 400 Operating limit conditions

401 Operating limit conditions with regard to the seastate and current shall be established such that any over-stressing of the pipe material and weldments is avoided. When adverse weather conditions require shut-down of the installation work, the vessel shall move away from the platform.

M 500 Contingency procedures

501 Contingency procedures shall be prepared for acceptance, covering dynamic positioning system breakdown, anchor dragging and anchor line failure. If underwater methods are used, additional contingency procedures are required to cover the safety and operational aspects of the underwater operations.

M 600 Requirements for Installation

601 Offshore installation welding shall be performed in accordance with Appendix C, and acceptance criteria for visual examination and non-destructive testing shall be established in accordance with Appendix D and Appendix E as applicable.

602 Transportation, storage and handling of riser pipe and appurtenances shall prevent any damage to coating and paint. In addition, special precautions shall be taken to protect flange faces and other specially prepared surfaces from damage.

603 All tolerances and measurements required in order to install the riser in accordance with drawings and specifications shall be verified in the field before installation commences. Diameter, roundness and cleanliness of J-tubes shall be checked by gauging pigs, pulling a test pipe or similar to prevent the pulling head and riser from jamming.

604 Adequate control shall be performed to ensure that the angularity and straightness of risers, the distance between risers and bracing, the spacing between adjacent risers and other critical dimensions meet the specified requirements.

605 Tie-ins between riser and pipeline shall be performed in accordance with I.

606 Prior to pull-in of risers into J-tubes, it shall be verified that the bellmouth is clear of debris and obstructions, that the bellmouth height above the seabed is within design limits, and that no damage to the bellmouth, J-tube or J-tube clamps (if applicable) has occurred. Entry of the pipeline into the bellmouth shall be monitored by ROV, and the tension in the pull-in cable shall be monitored by calibrated load cells and shall not exceed the specified maximum. Proper sealing as specified shall be ensured at the bell-mouth for a riser in a J-tube in case the corrosion protection system is designed with for a non-corrosive fluid in the annulus.

607 All clamps, protection frames, anchor flanges etc., shall be installed in accordance with specification and drawings, using appropriate bolt torque and to the specified tolerances.

608 Repair of damage to coating and paint shall be performed in accordance with accepted procedures.

609 Upon completion of the installation, a ROV or diver survey shall be performed to confirm the position of the riser relative to the platform, the position of any expansion loops, supports, etc., and the results of any trenching and protection operations.

610 Cleaning, gauging and system pressure testing shall be performed in general accordance with the requirements in O, except that wire line pigs may be used, The holding time shall be at least 2 hours and the pressure variation shall not exceed ± 0.4% unless the variation can be related to temperature variations during the test period. Visual inspection of welds and flanged connections shall be performed whenever possible.

N. As-Built Survey

N 100 General

101 All work on the pipeline, including crossings, trenching, gravel dumping, artificial backfill, subsea assemblies, riser installation, final testing etc., should be completed before the as-built survey is performed. The as-built survey of the installed and completed pipeline system is performed to verify that the completed installation work meets the specified requirements, and to document any deviations from the original design.

N 200 Specification of as-built survey

201 The specification shall contain requirements to survey vessel, survey equipment and the extent of survey. The extent of procedures to be prepared and qualified shall be specified.

N 300 As-built survey requirements

301 The as-built survey shall as a minimum include:

— detailed plot of the position of the pipeline, including location of in-line assemblies, anchoring and protective structures, tie-ins, supports etc.;

— out of straightness measurements as applicable;
— depth of cover or trench depth as applicable;
— quantification of span lengths and heights, including
  length and height reporting tolerances;
— location of areas of damage to pipeline, coating and an-
  odes;
— location of any areas with observed scour or erosion along
  pipeline and adjacent seabed;
— verification that the condition of weight coating (or an-
  choring systems that provide for on-bottom stability) is in
  accordance with the specification;
— description of wreckage, debris or other objects which
  may affect the cathodic protection system or otherwise im-
  pair the pipeline; and
— as-built video for the entire pipeline.

N 400 Inspection of impressed current cathodic corro-
    sion protection system

401 Impressed current cathodic corrosion protection systems
    shall be inspected, including cables, conduits, anodes and rec-
    tifiers. Readings from the corrosion monitoring system shall be
    verified by independent potential measurements, and adequate
    electrical insulation from other installations (if applicable)
    shall be confirmed.

402 If the required protection level is not attained, the causes
    shall be identified and adequate corrective actions performed.
    Satisfactory performance shall be documented after the correc-
    tive action.

O. Final Testing and Preparation for Operation

O 100 General

101 All work on the pipeline, including crossings, trenching,
    gravel dumping, artificial backfill, subsea assemblies, riser
    installation, as-built survey etc., should be completed before the
    final testing commences.

102 Disposal of cleaning and test fluids shall be performed
    in a manner minimising danger to the environment. Any dis-
    posal of fluids shall be in compliance with requirements from
    National Authorities.

O 200 Specification of final testing and preparation for
    operation

201 The installation and testing specification shall contain
    requirements for equipment, the extent of testing and prepara-
    tion for operation, performance of tests and preparation for op-
    eration and associated acceptance criteria. The extent of
    procedures to be prepared and qualified shall be specified.

O 300 Procedures for final testing and preparation for
    operation

301 All operations and tests shall be performed in accord-
    ance with agreed procedures.

O 400 Cleaning and gauging

401 Cleaning and gauging may be combined with the initial
    flooding of the pipeline, be run as a separate operation, or be
    combined with the weld sphere removal after completion of
    hyperbaric tie-in.

402 Appropriate measures shall be taken to ensure that any
    suspended and dissolved substances in the fluid used for this
    operation are compatible with the pipe material and internal
    coating (if applied), and that deposits are not formed within the
    pipeline.

403 Water should have a minimum quality corresponding to
    filtration through a 50 m filter, and an average content of sus-
    pended matters not exceeding 20 g/m³.

404 If water quality or the water source is unknown, water
    samples shall be analysed and suitable actions shall be taken to
    remove and/or inhibit harmful substances.

405 If water is to remain in the pipeline for an extended pe-
    riod of time, consideration shall be given to control of bacteria
    growth and internal corrosion.

406 Added corrosion inhibitors, oxygen scavengers, bio-
    cides, dyes, etc. shall be considered for possible harmful inter-
    actions and their impact on the environment during and after
    disposal of the test water.

407 The pipeline cleaning concept shall consider:

— protection of pipeline components and facilities (e.g.
    valves) from damage by cleaning fluids and pigs,
— testing devices such as isolation spheres etc.,
— removal of substances that may contaminate the product to
    be transported,
— particles and residue from testing and mill scale,
— organisms and residue resulting from test fluids,
— chemical residue and gels, and
— removal of metallic particles that may affect future inspec-
    tion activities.

408 The basic requirement for gauging is to run a metallic
    gauge plate with a diameter of 97% of the nominal inner diam-
    eter through the pipeline. Alternatively, other gauging tools
    such as electronic gauging pigs etc. may be used. Tolerances
    on diameter, wall thickness, misalignment and weld penetra-
    tions shall be considered for small bore pipelines when select-
    ing the diameter of gauge plate.

409 Cleaning and gauging train design, number and type of
    pigs, need for chemical cleaning, train velocity etc., shall be
    decided based on type and length of pipeline, steep gradients
    along the pipeline route, type of service, construction method,
    downstream process etc.

410 If cleaning and gauging are performed on separate sec-
    tions of the pipeline prior to tie-in, a minimum of one cleaning
    and gauging pig should be run through the completed pipeline
    system prior to, or during, product filling.

O 500 System pressure testing

501 A pipeline system pressure test shall be performed based
    upon the system test pressure determined according to Section
    5B.202 unless the test is waived as allowed by Section 5B.203.
    The extent of the test should normally be from pigtrap to pig-
    trap, including all components and connections within the
    pipeline system. The test shall be performed after completion
    of all installation, construction and pipeline protection works.
    The pressure test is normally performed as a combined
    strength and leak test.

502 The system may be tested as separate sections provided
    that the tie-in welds between sections have been subject to
    100% radiographic, ultrasonic and magnetic particle testing,
    or by a combination of other methods which provide the same
    or improved verification of acceptable weld quality.

503 The pipeline section under test shall be isolated from
    other pipelines and facilities. Pressure testing should not be
    performed against in-line valves, unless possible leakage and
    damage to the valve is considered, and the valve is designed
    and tested for the pressure test condition. Blocking off or re-
    moval of small-bore branches and instrument tappings, should
    be considered to avoid possible contamination.

504 End closures, temporary pigtraps, manifolds and other
    temporary testing equipment, shall be designed and fabricated
    according to a recognised code and with design pressure equal
    to the pipeline's design pressure. Such items shall be individu-
    ally pressure tested to at least the same test pressure as the
    pipeline.

505 Filling of the pipeline with test water should be per-
    formed in a controlled manner, using water behind one or more
pigs. The pig(s) shall be capable of providing a positive air/water interface. Considerations shall be given to pre-filling valve body cavities with an inert liquid, unless the valves have provision for pressure equalisation across the valve seats. All valves shall be fully open during line filling. A pig tracking system and the use of back-pressure to control the travel speed of the pig shall be considered if steep gradients occur along the pipeline route.

506 Instruments and test equipment used for the measurement of pressure, volume and temperature shall be calibrated for accuracy, repeatability and sensitivity. All instruments and test equipment shall possess valid calibration certificates, with traceability to reference standards within the 6 months preceding the test. If the instruments and test equipment have been in frequent use, calibration specifically for the test should be required.

507 Gauges and recorders shall be checked for correct function immediately before each test. All test equipment shall be located in a safe position outside the test boundary area.

508 The test pressure should be measured using a dead weight tester. Dead weight testers shall not be used before a stable condition is confirmed. When pressure testing is performed from a vessel, where a dead weight tester can not be utilised due to the vessel movements, the test pressure shall be measured by using one high accuracy pressure transducer in addition to a high accuracy large diameter pressure gauge.

509 The following requirements apply for instruments and test equipment:

- dead weight testers shall have a range of minimum 1.25 times the specified test pressure, and shall have an accuracy better than \( \pm 0.1 \) bar and a sensitivity better than 0.05 bar;
- the volume of water added or subtracted during a pressure test shall be measured with equipment having accuracy better than \( \pm 1.0\% \) and sensitivity better than 0.1\%;
- temperature measuring instruments and recorders shall have an accuracy better than \( \pm 1.0^\circ C \), and a sensitivity better than 0.1\(^\circ C\); and
- pressure and temperature recorders shall be used to provide a graphical record of the pressure test for the total duration of the test.

If a pressure transducer is used instead of a dead weight tester, the transducer shall have a range of minimum 1.1 times the specified test pressure, and the accuracy shall be better than \( \pm 0.2\% \) of test pressure. Sensitivity shall be better than 0.1\%.

510 A correlation that shows the effect of temperature changes on the test pressure, shall be developed and accepted prior to starting the test. Temperature measuring devices, if used, shall be positioned close to the pipeline, and the distance between the devices shall be based on temperature gradients along the pipeline route.

511 The test medium should be water meeting the requirements given in O 400.

512 The air content of the test water shall be assessed by constructing a plot of the pressure against volume during the initial filling and pressurisation, until a definite linear relationship is apparent, see Figure 9-1. This should be done at 35\% of test pressure. The assessed air content shall not exceed 0.2\% of the calculated total volume of the pipeline under test.

Figure 9-1 Determination of volume of air

513 During pressurisation of the pipeline, the pressure shall be increased at a maximum 1 bar per minute up to 95\% of the test pressure. The last 5\% up to the test pressure shall be raised by a linear diminishing rate down to 0.1 bar per minute. Time shall be allowed for confirmation of temperature and pressure stabilisation before the test hold period begins.

514 The pressure level requirement for the system pressure test is given in Section 5B.202.

515 The test pressure hold period after stabilisation shall be held for a minimum 24 hours.

516 Subject to agreement, shorter pressure hold periods may be accepted for pipelines with test volumes less than 5 000 m\(^3\), ref. M.610.

517 The pressure shall be continuously recorded during pressurisation, stabilisation and hold periods. Temperature and pressure shall be recorded simultaneously at least every 30 minutes during the hold period.

518 If possible, flanges, mechanical connectors etc. under pressure shall be visually inspected for leaks during the pressure test, either directly or by monitors.

519 The pressure test is acceptable if the pipeline is free from leaks, and the pressure variation is within \( \pm 0.2\% \) of the test pressure. A pressure variation up to an additional \( \pm 0.2\% \) of the test pressure is normally acceptable if the total variation (i.e. \( \pm 0.4\% \)) can be documented to be caused by temperature fluctuations or otherwise accounted for. If pressure variations greater than \( \pm 0.4\% \) of the test pressure are observed, the holding period shall be extended until a hold period with acceptable pressure variations has occurred.

520 De-pressurisation of the pipeline shall be performed as a controlled operation, normally at a rate not exceeding 1 bar per minute.

521 Documentation produced in connection with the pressure testing of the pipeline system shall include:

- pressure and temperature recorder charts,
- log of pressure and temperatures,
- calibration certificates for instruments and test equipment,
- calculation of air content,
- calculation of pressure and temperature relationship and justification for acceptance, and
- endorsed test acceptance certificate.

O 600 Cleaning, de-watering and drying

601 Upon completion of pressure testing, the pipeline should be cleaned. Residues, organisms etc. shall not remain in the
pipe after testing (see 407).

602 De-watering is required before introducing the product into the pipeline. Drying may be required in order to prevent an increase in the corrosion potential or hydrate formation, or if omission of drying is deemed to have an adverse effect on the product transported.

603 Introduction of the product may be accepted in special cases. The separation pig train between the test medium and the product will then require special qualification in order to avoid contact between the residual test water and the product.

604 Selection of de-watering and drying methods and chemicals shall include consideration of any effect on valve and seal materials, any internal coating and trapping of fluids in valve cavities, branch piping, instruments etc.

O 700 Systems testing

701 Prior to product filling, safety and monitoring systems shall be tested in accordance with accepted procedures. This includes testing of:
- corrosion monitoring systems;
- alarm and shutdown systems;
- safety systems such as pig trap interlocks, pressure protection systems etc.;
- pressure monitoring systems and other monitoring and control systems; and
- operation of pipeline valves.

O 800 Product filling

801 During product filling, care shall be taken to prevent explosive mixtures and, in the case of gas or condensate, to avoid hydrate formation. The injection rate shall be controlled so that pressure and temperature do not exceed allowable limits for the pipeline material or dewpoint conditions.

O 900 Operational verification (start-up inspection)

901 After stable production has been reached it shall be verified that the operational limits are within design conditions. Important parameters can be:
- expansion,
- movement,
- lateral snaking,
- upheaval buckling, and
- wall thickness/metal loss.

902 The need to perform baseline inspection of the wall thickness shall be evaluated based on the corrosivity of the product, the corrosion allowance used in the design, and the defect sizing capabilities of the inspection tool that will be used during operation of the pipeline.

P. Documentation

P 100 General

101 The installation and testing of the pipeline system shall be documented. The documentation shall, as a minimum, include that given in Section 3F.
SECTION 10
OPERATION, INSPECTION, AND REPAIR

A. General

A 100 Objective

101 The purpose of this section is to provide requirements for the safe and reliable operation of pipeline systems for the whole service life. Requirements are given for operation, inspection, modifications and repair.

A 200 Procedures

201 Prior to start-up of operation, detailed procedures for operation, inspections, and repairs shall be establish. These procedures shall, as a minimum, provide information with respect to the following:

— organisation and management;
— start-up and shut-down procedures;
— operational limitations;
— cleaning and other maintenance, e.g. pigging;
— corrosion control, including inspection and monitoring;
— inspection;
— emergency procedures;
— reporting procedures.

202 Procedures covering non-routine or special activities, shall be prepared as required, e.g. in case of major repairs, modifications etc.

A 300 In-Service file

301 An in-service file of historical data shall be established and maintained for the whole service life. The in-service file shall contain all important data (see 201) and shall reference all necessary supporting documents to provide a full record of information.

302 The in-service file shall, as a minimum, contain information regarding:

— results and conclusions from the in-service inspections;
— accidental events and damages to the pipeline system;
— repair and modifications; and
— operational data affecting corrosion and other deterioration (fluid composition, flow rate, pressure, temperature etc.).

303 The in-service file, together with the DFI-résumé, shall be the basis for future inspection planning see Section 3F 600.

304 The in-service file and the DFI-résumé shall be easily retrievable in case of an emergency situation.

A 400 Operation

401 Measures shall be in place to ensure that critical fluid parameters are kept within the specified design limits. As a minimum, the following parameters should be controlled or monitored:

— pressure and temperature along the pipeline;
— dew point for gas lines;
— fluid composition, flow rate, density and viscosity.

402 All safety equipment in the pipeline system, including pressure control and over-pressure protection devices, emergency shut down systems, and automatic shut down valves, shall be tested and inspected at agreed intervals. The inspection shall verify that the integrity of the safety equipment is intact and that the equipment can perform the safety function as specified.

403 Safety equipment in connecting piping systems shall be subject to regular testing and inspection.

404 For pressure control during normal operations, see Section 3B 300.

405 Operational control shall ensure that design temperature limits are not exceeded. If the design is based on a constant temperature along the whole route, control of inlet temperature will be sufficient. Additional controls are required if the design is based on a temperature profile for the pipeline.

406 If the operating conditions are changed relative to the design premises, a re-qualification of the pipeline system according to Section 1I shall be carried out.

A 500 Inspection and monitoring philosophy

501 An inspection and monitoring philosophy shall be established, and this shall form the basis for the detailed inspection and monitoring program. The philosophy shall be evaluated every 5 to 10 years.

502 Inspections and monitoring shall be carried out to ensure safe and reliable operation of the pipeline system. All inspection and monitoring requirements identified during the design phase as affecting safety and reliability during operation shall be covered in the inspection and monitoring program (see Section 3B 200 and Section 5B 300).

A 600 Special inspections

601 A special investigation shall be performed in case of any event which impairs the safety, reliability, strength or stability of the pipeline system. This investigation may initiate further inspections.

602 If mechanical damage or other abnormalities are detected during the periodic inspection, a proper evaluation of the damage shall be performed, which may include additional inspections.

B. Pipeline Configuration Survey

B 100 General

101 A pipeline configuration survey is a survey (e.g. a visual or ROV) to determine the configuration and condition of the pipelines and its components. At uneven seabed locations, the survey will verify the position and configuration of the pipeline.

B 200 Periodic survey

201 The start-up inspections shall be completed within one year from start of production, see Section 9O 900. In case of significant increase in temperature or pressure after this first inspection, the need of additional inspections should be considered.

202 A long term inspection programme reflecting the overall safety objective for the pipeline shall be established, and shall be maintained/updated on a regular basis. The following should be considered:

— operation conditions of the pipeline,
— consequences of failure,
— likelihood of failure,
— inspection methods, and
— design and function of the pipeline.

The long term program shall state the philosophy used for maintaining the integrity of the pipeline system and will form
the basis for the detailed inspection program in terms of inspection methods and intervals.

**203** The long term inspection program shall include the entire pipeline system. The following items, at minimum, should be considered:

- pipeline,
- risers,
- valves,
- Tee and Y connections,
- mechanical connectors,
- flanges,
- anchors,
- clamps,
- protecting structures,
- anodes,
- coating.

**204** A detailed inspection program including specifications for the inspections shall be prepared for each survey. The detailed inspection program should be updated based on previous inspections as required.

**205** Pipeline systems that are temporarily out of service shall also be subject to periodical survey.

**206** Inspection shall be carried out to ensure that the design requirements remain fulfilled and that no damage has occurred. The inspection program should, as a minimum, address:

- exposure and burial depth of buried or covered lines, if required by design, regulations or other specific requirements;
- free spans including mapping of length, height and end-support conditions;
- condition of artificial supports installed to reduce free span;
- local seabed scour affecting the pipeline integrity or attached structures;
- sand wave movements affecting the pipeline integrity;
- excessive pipe movements including expansion effects;
- identification of areas where upheaval buckling or excessive lateral buckling has taken place;
- integrity of mechanical connections and flanges;
- integrity of sub-sea valves including protective structure;
- Y- and Tee connections including protective structure;
- pipeline settlement in case of exposed pipeline, particularly at the valve/Tee locations,
- the integrity of pipeline protection covers (e.g. mattresses, covers, sand bags, gravel slopes, etc.);
- mechanical damage to pipe, coatings and anodes;
- major debris on, or close to, the pipeline that may cause damage to the pipeline or the external corrosion protection system; and
- leakage.

**207** The risers shall be part of the long-term inspection programme for the pipeline system. In addition to the generally applicable requirements for pipeline inspection, special attention shall be given to the following elements for riser inspections:

- riser displacement due to pipeline expansion or foundation settlement,
- coating damage,
- technique for corrosion control of any risers in closed conduits or J-tubes,
- extent of marine growth,
- extent of any previous damage due to corrosion,
- integrity and functionality of riser supports and guides, and
- integrity and functionality of protecting structure.

**208** The frequency of future external inspections shall be determined based upon an assessment of:

- degradation mechanisms and failure modes,
- likelihood and consequences of failure,
- results from previous inspections,
- changes in the operational parameters,
- repair and modifications, and
- subsequent pipelay operation in the vicinity.

**209** Critical sections of the pipeline system vulnerable to damage or subject to major changes in the seabed conditions i.e. support and/or burial of the pipeline, shall be inspected at short intervals, normally on an annual basis. The remaining sections should also be inspected, ensuring a full coverage of the entire pipeline system within a 5 to 10 years period.

### C. Inspection and Monitoring of External Corrosion

#### C 100 General

**101** In the splash zone and in the atmospheric zone, damaged and/or disbonded coatings can cause severe corrosion damage. Risers carrying hot fluids are most vulnerable to such damage.

**102** In the submerged zone, coating malfunctions are not critical unless they are combined with deficiency in the cathodic protection system. (For definition of zones, see Section 8D 100).

**103** For risers contained in J-tubes filled with non-corrosive fluid (see Section 8B.105) inspection of external corrosion may not be required if adequate properties of the fluid is verified by periodic testing.

**104** Inspection by special internal tools may be used to detect external corrosion of risers and pipelines in all three zones (see D 200) including risers contained in J-tubes, if required.

#### C 200 Risers in the Splash zone and the Atmospheric Zone

**201** In the splash and atmospheric zones, visual examination of the coating shall be performed in order to assess the needs for preventive maintenance. Besides visual indications of direct damage to the coating, effects such as rust discoloration and bulging or cracking of the coating are indicative of under-rusting. Coating systems which prevent close inspection of under-coating corrosion shall require special consideration.

**202** The frequency of the external inspection in the splash zone of risers shall be determined based on the fluid category, the line pipe material, coating properties and any corrosion allowance.

#### C 300 Pipelines and Risers in the Submerged Zone

**301** To a large extent, inspection of external corrosion protection of pipelines and risers with sacrificial anodes can be limited to inspection of the condition of anodes. Excessive anode consumption is indicative of coating deficiencies, except close to platforms, templates and other structures where current drain may lead to premature consumption of adjacent pipe anodes.

**302** Potential measurements on anodes, and at any coating damage exposing bare pipe metal, may be carried out to verify adequate protection. Electric field gradient measurements in the vicinity of anodes may be used for semi-quantitative assessments of anode current outputs.

**303** For pipelines with impressed current cathodic protection systems, measurements of protection potentials shall, at minimum, be carried out at locations closest to, and most remote from, the anode(s).
D. Inspection and Monitoring of Internal Corrosion

D 100 General

101 Inspection of internal corrosion is carried out in order to confirm the integrity of the pipeline system, primarily by means of in situ wall thickness measurements.

102 The objective of monitoring internal corrosion is to confirm that the fluid remains non-corrosive or, more often, to assess the efficiency of any corrosion preventive measures, and accordingly to identify requirements for inspection of corrosion.

103 Corrosion monitoring as defined above does not normally give any quantitative information of critical loss of wall thickness. Although monitoring may be carried out as actual wall thickness measurements in a selected area, it cannot replace pipeline inspection schemes that cover the pipeline system, or section thereof, in its full length and circumference. On the other hand, inspection techniques for internal corrosion are not normally sensitive enough to replace monitoring.

104 The requirements for corrosion inspection and monitoring, and the capability of optional techniques, shall be evaluated at an early stage of pipeline system design.

105 Pipelines and risers manufactured from Corrosion Resistant Alloys (CRA) do not normally require inspection and monitoring of internal corrosion.

D 200 Corrosion inspection

201 Internal corrosion inspection shall be carried out with a carrier tool ("inspection pig") capable of inspecting the internal surface of the pipeline along its full circumference and length, or a critical part thereof.

202 The technique for detection of internal corrosion (e.g. magnetic flux leakage or ultrasonic examination) shall be selected based on considerations of linepipe material, diameter and wall thickness, expected form of damage, and requirements to detection limits and defect sizing capability. The latter shall be determined based on pipeline design and operational parameters.

203 Candidate operators of inspection tools should be required to document the capability of their systems with respect to detection limits and sizing of relevant corrosion defects (including localised corrosion at girth welds) for the pipe dimensions considered.

204 The frequency of internal inspections shall be determined based on factors such as:

- criticality of pipeline,
- potential corrosivity of fluid,
- detection limits and accuracy of inspection system,
- results from previous surveys and monitoring,
- changes in pipeline operational parameters, etc.

See also Section 90 900.

D 300 Corrosion monitoring

301 The following major principles of corrosion monitoring may be applied:

- fluid analyses; i.e. monitoring of fluid physical parameters and sampling of fluid for chemical analysis of corrosive components, corrosion retarding additions or corrosion products;
- corrosion probes; i.e. weight loss coupons or other retrievable probes for periodic or on-line determination of corrosion rates;
- in-situ wall thickness measurements, i.e. repeated measurements of wall thickness at defined locations using portable or permanently installed equipment.

302 Techniques and equipment for corrosion monitoring shall be selected based upon:

- monitoring objectives, including requirements for accuracy and sensitivity;
- fluid corrosivity and the corrosion preventive measures to be applied;
- potential corrosion mechanisms.

303 A typical major objective of corrosion monitoring is to detect changes in either intrinsic corrosivity of the fluid, or in the efficiency of the corrosion prevention measures. For pipelines carrying dry (i.e. fully processed) gas, inspection of internal corrosion may be postponed provided that monitoring demonstrates that no corrosive liquids have entered the pipeline, or been formed by condensation downstream of the inlet.

E. Defects and Repair

E 100 General

101 Repair and modification shall not impair the safety level of the pipeline system below the specified safety level.

102 All repairs shall be carried out by qualified personnel in accordance with agreed specifications and procedures, and up to the standard defined for the pipeline. If the repair involves welding, the personnel, method, and equipment shall be agreed upon according to Appendix C.

For other types of repair the requirements for personnel, method and necessary equipment to carry out the work shall be agreed upon in each case.

103 All repairs shall be tested and inspected by experienced and qualified personnel in accordance with agreed procedures. NDT personnel, equipment, methods, and acceptance criteria shall be agreed upon in accordance with Appendix D.

104 Pipeline systems with defects may be operated temporarily under the design conditions or reduced operational conditions until the defect has been removed or repair has been carried out. It must, however, be documented that the pipeline integrity and the specified safety level is maintained, which may include reduced operational conditions and/or temporary precautions.

105 Alternatively, a pipeline system with defects may be permanently re-qualified to lower operational conditions see Section 11 and Section 5, e.g. reduced pressure, which may allow for omitting repair.

106 When a defect is observed, a evaluation of the defect shall be performed and shall, as a minimum, include:

- determined details of the defect,
- mechanisms causing the defect,
- accuracy and uncertainties in the inspection results,
- options for further operational conditions of the pipeline system,
- repair methods.

107 In each case a thorough evaluation of the defect and the impact on safety and reliability for the operation of the pipeline shall be performed. The requirements given in the following sections regarding required actions, e.g. grinding or replacement, may be waived if it can be documented that the specified safety level for the pipeline system is not impaired.
Defects that affect the safety or reliability of the pipeline shall either be removed by cutting out the damaged section of the pipe as a cylinder, or alternatively, the pipeline may be re-qualified to a lower design pressure according to Section 11 and Section 5.

Depending upon the condition of the damage, a temporary repair may be accepted until the permanent repair can be carried out. If a temporary repair is carried out, it shall be documented that the pipeline integrity and safety level is maintained either by the temporary repair itself and/or in combination with other precautions.

### E 200 Global buckling

In case of a global buckling (upheaval buckling or lateral deflection) resulting in plastic bending strains, the pipeline may continue operating until the need of repair has been evaluated, provided that the operational parameters are kept within a range that prevents the accumulation of low-cycle high strain fatigue failure in the buckled section.

### E 300 Grooves, gouges, cracks and notches

Sharp defects like grooves, gouges, and notches should preferably be removed by grinding or other agreed repair methods. For ground defects where all sharp edges are confirmed as removed, the defect can be regarded as a smooth metal loss defect, see E 400.

### E 400 Metal loss defects

Metal loss defects caused by e.g. corrosion, erosion, or grind repair shall be checked for capacity. For guidance, reference is made to DNV RP-F101, *Corroded Pipelines*.

### E 500 Dents

A dent is defined as a depression which produces a gross disturbance in the curvature of the pipe wall, and which results in a diameter variation of more than 2% of the nominal diameter (see Section 5).

A dent affecting the longitudinal or circumferential weld can result in cracks, and removal of the damaged portion of the pipe should be considered. The damaged part can be cut out as a cylinder, or repaired by installing a full encirclement welded split sleeve which is designed to take the full internal operating pressure.

### E 600 Leaks

Prior to carrying out a repair of any leak, the mechanism causing the leak shall be established.

The most suitable method for repairing a leak in the pipe depends upon e.g. the pipe material, pipe dimensions, location of leak, load conditions, pressure, and temperature. The following repair methods may be used:

a) The damaged portion is cut out of the pipe as a cylinder and a new pipe spool is installed either by welding or by a mechanical connector. For guidance, reference is made to DNV RP-F104, *Mechanical Pipeline Couplings*.

b) Clamps are installed, and tightness is obtained by either welding, filler material, friction or other qualified mechanical means.

Leaking flanges and couplings may be sealed by installing a seal clamp covering the leaking flange or coupling, increasing the bolt pre-load, or replacing gaskets and seals. Prior to increasing the pre-load in bolts, it shall be documented by calculation that no over-stressing occurs in bolts, flange or gasket/seals. In case the pre-load in the bolts is removed, e.g. due to changing of gasket, new bolts shall be used for the flange connection.

All repair clamps, sleeves, pipe spools, and mechanical connectors shall be qualified prior to installation and leak tested after installation. For guidance, reference is made to DNV RP-F104, *Mechanical Pipeline Couplings*.

### E 700 Repair by welding

Repair welding procedures and welders shall be qualified as described in Appendix C.

Repair welding above water shall be carried out as described in Appendix C.

Underwater welding shall be carried out in a dry habitat, see Appendix C.

Repair welding may, in special cases, be carried out on pipelines while operating, depending on pipe material, pipe wall thickness, product type, pressure and temperature. It shall be documented that safety for carrying out the repair is acceptable, and a safety procedure shall be established.

All repair welds shall be subject to visual and non-destructive testing, see Appendix D. Following the repair, pressure testing may be required for the repaired section.
SECTION 11
REQUALIFICATION

A. General

A 100 Objective

101 The purpose of this section is to define re-qualification and to give requirements for re-qualification of pipeline systems.

102 Re-qualification is a re-assessment of the design under changed design conditions.

Guidance note:
A re-qualification may be triggered by a change in the original design basis, by not fulfilling the design basis, or by mistakes or shortcomings having been discovered during normal or abnormal operation.

Possible causes may be:
— preference to use this standard, e.g. due to requirements for higher utilisation for existing pipelines;
— change of the premises;
— environmental loads,
— deformations,
— scour.
— change of operational parameters;
— pressure or temperature,
— corrosivity of the medium.
— deterioration mechanisms having exceeded the original assumptions;
— corrosion velocity, both internal and external,
— dynamic responses, contributing to fatigue, which may be caused by lacking supports etc.
— extended design life;
— discovered damage;
— dents,
— damage to pipeline protection,
— weld defects,
— corrosion related defects.
— damage to anodes.

B. Design Criteria

B 100 General

101 A target safety level as defined in Section 2C 600 shall apply for a re-qualification assessment.

102 Operational experience, e.g. change of operational conditions, inspection records and modifications, shall be considered in a re-qualification assessment.

B 200 System Pressure Test

201 System pressure testing may be required when:
— the original mill pressure test or system pressure test does not satisfy requirements according to this standard at the new design pressure;
— a significant part of the pipeline has not been system pressure tested e.g. new pipeline section. (for omission of system pressure test, see Section 5B.203).

B 300 Deterioration

301 All relevant deterioration mechanisms shall be evaluated. Typical deterioration mechanisms are:
— corrosion,
— external corrosion
— internal corrosion
— erosion,
— accidental loads,
— development of free spans,
— fatigue,
— settlement.

302 Sufficient reliability or safety measures shall be applied to account for the accuracy and uncertainties in the inspection results.

303 Accumulated damage experienced prior to the re-qualification shall be included in the evaluation.

Guidance note:
The same safety level shall apply for lifetime extensions of an existing pipeline as would apply for the design of a new pipeline. The reason for requiring use of this standard is in case the original standard used for design is less stringent than necessary to meet the target safety levels specified in this standard.

---end---of---Guidance---note---
SECTION 12
COMMENTARY (INFORMATIVE)

A. General

A 100  Objective

The purpose of this section is to:

— give an overview of the standard by giving cross references to subjects covered in different sections;

— give background information to the requirements in the standard; and

— give guidance reflecting good engineering practice.

The section is informative only, and some of the recommendations may not be founded on thorough work but engineering judgement only.
### B. Cross References

<table>
<thead>
<tr>
<th>Key word</th>
<th>Reference</th>
<th>Comment or aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic material strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.5 B600</td>
<td>$f_k$</td>
</tr>
<tr>
<td></td>
<td>Sec.5 B604</td>
<td>Relation to supplementary requirement U</td>
</tr>
<tr>
<td></td>
<td>Sec.5 B604 Guidance note</td>
<td>Proposed (conservative) de-rating stresses</td>
</tr>
<tr>
<td></td>
<td>Sec.5 B606</td>
<td>Reduction due to the UOU/UE process</td>
</tr>
<tr>
<td></td>
<td>Sec.5 D505 and Sec.5 D506</td>
<td>Reduction in longitudinal direction</td>
</tr>
<tr>
<td>Crossing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.2 B303</td>
<td>Evaluation of risks</td>
</tr>
<tr>
<td></td>
<td>Sec.3 C204</td>
<td>Survey</td>
</tr>
<tr>
<td></td>
<td>Sec.5 B102</td>
<td>Minimum vertical distance</td>
</tr>
<tr>
<td></td>
<td>Sec.9 B300</td>
<td>Specification</td>
</tr>
<tr>
<td>Golden weld</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.9 A807</td>
<td>Requirements</td>
</tr>
<tr>
<td>Installation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.2 C400</td>
<td>Safety class</td>
</tr>
<tr>
<td></td>
<td>Sec.5 H100(D)</td>
<td>Design criteria</td>
</tr>
<tr>
<td></td>
<td>Sec.5 H200</td>
<td>Pipe straightness</td>
</tr>
<tr>
<td></td>
<td>Sec.9</td>
<td>Installation phase</td>
</tr>
<tr>
<td>Linepipe NDT Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.5 B500</td>
<td>Design – general</td>
</tr>
<tr>
<td></td>
<td>Sec.6 B100</td>
<td>General introduction and designation</td>
</tr>
<tr>
<td></td>
<td>Table 6-13</td>
<td>NDT requirements</td>
</tr>
<tr>
<td>Mill pressure test</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.1 C200</td>
<td>Definition</td>
</tr>
<tr>
<td></td>
<td>Sec.5 B200</td>
<td>Link between mill pressure test and design</td>
</tr>
<tr>
<td></td>
<td>Sec.5 D401</td>
<td>Reduced mill test pressure implication on pressure containment capacity</td>
</tr>
<tr>
<td></td>
<td>Sec.6 E1104</td>
<td>Basic Requirement</td>
</tr>
<tr>
<td></td>
<td>Sec.6 E1105</td>
<td>Maximum test pressure</td>
</tr>
<tr>
<td></td>
<td>Sec.6 E1108</td>
<td>Waiving of mill test – UOE-pipes, conditions</td>
</tr>
<tr>
<td>Minimum wall thickness</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.5 B400</td>
<td>Minimum 12 mm and when it applies</td>
</tr>
<tr>
<td></td>
<td>Sec.5 C300</td>
<td>When to use minimum wall thickness, relation to nominal thickness and corrosion allowance</td>
</tr>
<tr>
<td>Ovality</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eq. (5-18) and Eq. (5-21)</td>
<td>Minimum allowed ovality for collapse</td>
</tr>
<tr>
<td></td>
<td>Sec.5 D800</td>
<td>Maximum allowed ovality, as installed</td>
</tr>
<tr>
<td></td>
<td>Table 6-14 and Table 6-15</td>
<td>Maximum allowed ovality, line pipe specification</td>
</tr>
<tr>
<td>Pressure - general</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.1 C200</td>
<td>Definitions</td>
</tr>
<tr>
<td></td>
<td>Sec.3 B300</td>
<td>Pressure control system</td>
</tr>
<tr>
<td></td>
<td>Table 3-1</td>
<td>Choice of Pressure</td>
</tr>
<tr>
<td></td>
<td>Table 5-7</td>
<td>Pressure load effect factors</td>
</tr>
<tr>
<td></td>
<td>Sec.4 B202, Sec.4 B203</td>
<td>Characteristic values</td>
</tr>
<tr>
<td>Pressure - incidental</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.12 F600</td>
<td>Benefit of lower incidental pressure</td>
</tr>
<tr>
<td></td>
<td>Sec.3 B300</td>
<td>Pressure control system</td>
</tr>
<tr>
<td></td>
<td>Table 3-1</td>
<td>Selection of incidental pressure during pressure test and for full shut-in pressure</td>
</tr>
<tr>
<td>Reeling</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.5 D1006</td>
<td>Fracture assessment – when supplementary requirement P comes into force</td>
</tr>
<tr>
<td></td>
<td>Sec.5 D1100</td>
<td>Engineering criticality assessment</td>
</tr>
<tr>
<td></td>
<td>Eq. (5-25)</td>
<td>Capacity formula</td>
</tr>
<tr>
<td></td>
<td>Table 5-8</td>
<td>Condition factor</td>
</tr>
<tr>
<td></td>
<td>Sec.6 D300</td>
<td>Supplementary requirement P</td>
</tr>
<tr>
<td></td>
<td>Sec.6 D400</td>
<td>Supplementary requirement D</td>
</tr>
<tr>
<td></td>
<td>Sec.9 E</td>
<td>Testing</td>
</tr>
<tr>
<td>Spiral welded</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sec.5 A204</td>
<td>Requirements</td>
</tr>
<tr>
<td>Strain hardening</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eq. 5.26</td>
<td>In capacity formula; strain</td>
</tr>
<tr>
<td></td>
<td>Eq. 5.24</td>
<td>Capacity formula SMYS/SMTS - (in $\alpha_h$)</td>
</tr>
<tr>
<td></td>
<td>Table 6-3</td>
<td>SMYS and SMTS</td>
</tr>
<tr>
<td></td>
<td>Table 6-3</td>
<td>$\alpha_h$ (YS/UTS)</td>
</tr>
</tbody>
</table>
C. Design Philosophy

C 100  Safety Class discussion

Safety class shall be specified for each part of the pipeline and for each phase. The classification shall be based on the requirements in Section 2.

The safety class concept allows the owner some flexibility in terms of risk which is both a reasonable and rational approach, e.g. this allows the owner to differentiate between the design conservatism for a flow line with a 5 year design life and a trunk line with 40 years design life.

The main aspect when determining the safety class is the consequence, typically to people, environment and cost. Note that this consequence not necessarily is limited to failure of the considered pipeline itself, but also to its impact on the total exploration. One such example may be reduction in production if a water injection line or a system for waste water fails which from an isolated point of view could be defined as safety class low.

Another example is differentiation of temporary phases. A failure during installation, normally considered as safety class low, will have a significantly smaller consequence than a failure during a shut-down period of the pipeline, where both solution and time for repair are significantly more expensive and time consuming.

However, the total safety may not always be increased by specifying a higher safety class. This may be the case when the most probable cause of failure would be draught of vessel, where the emphasis should be put on operating procedures and back-up. During such circumstances, it may not be required with a higher safety class.

The above clearly illustrates that Table 2-4 is for “normal” classification only, as stated.

C 200  Structural reliability analyses

Structural reliability methods consider structural analysis models in conjunction with available information regarding the involved variables and their associated uncertainties. The reliability as assessed by reliability methods is not an objective physical property of the pipeline itself in the given operational and environmental condition, but rather a nominal measure of the reliability given a particular physical and probabilistic modelling and analysis procedure applied.

Structural reliability analysis is only one part of a total safety concept as gross errors are not included. A gross error is defined as a human mistake during the design, construction, installation or operation of the pipeline that may lead to a safety
level far below what is normally aimed for by use of a partial safety factor design format or specific reliability analysis.

Target reliabilities have to be met in design in order to ensure that certain safety levels are achieved. A probabilistic design check can be performed using the following design format:

\[ P_{f,\text{calculated}} < P_{f,\text{target}} \]

\[ P \] is the calculated probability of failure evaluated by a recognised (accepted) reliability method and \( P_{f,\text{target}} \) is a target value that should be fulfilled for a design to be accepted.

Acceptable failure probabilities depend in general on the consequence and nature of failure, the risk of human injury, economic losses, social (political) inconvenience and the expense and effort required to reduce the failure probability. Accident statistics may be used as guidance on relative failure probability levels but only limited information about specific failure probability for SLS, ULS and FLS can be deduced from failure statistics. Structural failure probability from a SRA is a nominal value and cannot be interpreted as an expected frequency of failure.

C 300 Characteristic values

In a LRFD format, so called characteristic values are used. These are often lower fractiles for strength and resistance, not always however, and upper fractiles for loads. Typical examples of these may be SMYS for the yield stress and 100-year waves for loads.

The characteristic value in the resistance formulas is a lower fractile and the expected yield stress is typically in the order of 8% higher. On commonly overlooked implication of this is that it is not allowed to replace the \( f_y \) based upon a certificate or test. Such a replacement requires a thorough evaluation by a reliability specialist.

D. Design Premise

D 100 Monitoring

The following includes typical examples where monitoring of the pipeline will/may be necessary.

Pipelines subjected to subsidence related horizontal movements should be kept under observation during their operational life. There are normally significant uncertainties involved in the prediction of the subsidence load effects, and design accounting for these uncertainties (in order to reflect the acceptable probability of failure stated in this standard) may in some cases be unpractical. Monitoring of the subsidence progress and pipeline behaviour may in such cases be part of the design philosophy.

Pipelines installed on unstable seabed where freespans may occur or grow during their operational life should be subject to regular inspection. In extreme cases, it may be impossible to consider such events in the original design, and the only design option is to prepare a contingency philosophy for monitoring and intervention of freespans.

In cases where uncertainties in the operational conditions (medium chemical composition, water content, temperature, etc.) impose uncertainties in the prediction of the corrosion rate, close monitoring of the medium or corrosion inspection may be part of the design philosophy.

D 200 Air and sea temperatures

In cases where the air or sea temperature at the time of installation is higher than the minimum ambient temperature defined in the project design basis, the minimum ambient temperature applicable for the installation period (including sufficient contingency) should be used when applicable. This may be relevant in calculations where the temperature difference between the ambient installation temperature and the minimum or maximum design temperature is governing for the design.

E. Loads

E 100 Local pressure

The term "local" pressure was introduced in DNV’96. This denotes the internal pressure at a specific point in the pipeline system relative a reference pressure. The reference pressure shall be defined at a specific point, typically the inlet. The difference relative the reference pressure is the column weight of the content.

The following relationship exists:

\[ p_{\text{local}, \text{ref}} = p_{\text{ref}} + \rho_{\text{cont}} \cdot g \cdot h \]

The following specific local pressures exist:

\[ p_{\text{d}} = p_{\text{d}} + \rho_{\text{cont}} \cdot g \cdot h \]
\[ p_{\text{li}} = p_{\text{inc}} + \rho_{\text{cont}} \cdot g \cdot h = p_{\text{d}} \cdot \gamma_{\text{inc}} + \rho_{\text{cont}} \cdot g \cdot h \]
\[ p_{\text{f}} = p_{\text{f}} + p_{\text{c}} \cdot g \cdot h \]

where

\[ p_{\text{inc}} = p_{\text{d}} \cdot \gamma_{\text{inc}} = \text{incidental pressure} \]
\[ \gamma_{\text{inc}} = 1.10 \text{ (normally; maximum), see Section 3B 300, 1.05 (minimum)} \]
\[ p_{\text{f}} = 1.05 \rho_{\text{inc}} \]
\[ p_{\text{cont}} = \text{density of contents} \]
\[ p_{\text{c}} = \text{density of test liquid (water) content} \]
\[ g = \text{gravitational acceleration} \]
\[ h = \text{vertical distance from reference point to sea surface} \]

An example for a design pressure of 200 bar, 10% incidental pressure and a content density of approximately 200 kg/m³ is given in the figure below. The differential pressure which shall be used for pressure containment is also included.

**E 200 Conversion of pressures**

The governing pressure for design is the incidental pressure. The incidental pressure is normally defined as the pressure with an annual probability of exceedance of 10⁻⁴.

If the design pressure is given, the incidental pressure shall be determined based on the pressure regulating system and the pressure safety system tolerances and capabilities to ensure that the local incidental pressure meets the given annual probability of exceedance above. However, the design pressure can not be lower than the incidental pressure/1.10. Hence, if the incidental pressure, determined as outline above, gives a pressure which is higher than 10% above the design pressure, the design pressure should be re-defined. Likewise, if the incidental pressure becomes less than 5% above the design pressure,
it shall be taken as 5% above the design pressure.

If the pressure not can exceed the design pressure, e.g. full shut-in pressure is used, the incidental pressure may be reduced to the design pressure, see Table 3-1.

Different systems may have different definitions of design pressure and incidental pressure, e.g. between topside and a pipeline system. When converting the defined pressures in one system to pressure in another system, the conversion shall be based on pressure having an annual probability of exceedance less than 10⁻⁴. This pressure shall then be defined as the incidental pressure in the pipeline system. Determination of design pressure shall then be made based on the above principles.

### E 300 Flow velocity around cylindrical members

The increased accelerations and flow velocities in the flow around a cylinder (jacket leg/member, columns etc.) can lead to additional forces on the risers, riser supports or other pipeline system components. The following expression can be used to calculate the increased velocity:

\[
V_u = V_n \left(1 + \frac{R^2}{z^2}\right)
\]

Where:

- \(V_u\) = increased velocity
- \(V_n\) = nominal velocity
- \(R\) = cylinder radius
- \(z\) = distance between cylinder centre and the actual location (\(z \geq R\)).

### F. Design Criteria

#### F 100 General

The basis for most of the given limit states were developed within the joint industry project SUPERB and the reports may be bought from Sintef, Norway. Some results have been published, e.g. Jiao et al (1996) and Mørk et al (1997).

The SUPERB results were incorporated in DNV Rules for Submarine Pipeline Systems, 1996 (DNV’96) and modified in order to allow for additional aspects, not necessarily to be considered in a research project. Hence, all limit states may not have identical partial factors as in the SUPERB reports.

In this new standard, the LRFD format has been modified on the resistance side as described in Section 2 and the limit states from DNV’96 modified correspondingly. The local buckling formulation has, further more, included some results from the Hotpipe project, allowing a higher utilisation of pressurised pipes. See e.g. Vitali et al (1999).

#### F 200 Material de-rating

For a pipeline designed for a temperature above 50°C, a corresponding de-rated yield stress shall be determined and used for the conditions where this is the relevant temperature. The de-rated strength applies only to conditions where the elevated temperature is relevant, e.g. operation.

As an example, a grade 450 material to be operated at 100°C shall be de-rated by approximately 30 MPa to 420 MPa which shall be used in the design for operating condition unless other de-rating can be documented.

In cases where the de-rated strength of a material grade is insufficient for the intended use, the material SMYS shall not be specified higher to compensate for the reduced strength. A higher material grade shall be selected.

#### F 300 Condition load effect factors

The load condition factor \(\gamma_c = 1.07\), pipeline resting on uneven seabed refers to the load effect uncertainty due to variation in weight, stiffness, span length or heights. This implies that it is not applicable for the sag bend evaluation during installation on uneven seabed.

### F 400 Pressure containment - equivalent format

The format of the pressure containment resistance in Section 5 is given in a LRFD format. This corresponds to the traditional format, which usually is expressed in terms of allowable hoop stress, is given in Eq. (12.1).

\[
\frac{D - t_1}{2 \cdot t_1} \leq \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC} \cdot \gamma_{inc}} \cdot (SMYS - f_{ut, temp})
\]

The differential pressure is here given as a function of the local incidental pressure. Introducing a load factor, \(\gamma_{inc}\), reflecting the ratio between the incidental pressure and the design pressure, the formula can be rearranged for the reference point above water, as given in Eq. (12.2).

\[
\frac{D - t_1}{2 \cdot t_1} \leq \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC} \cdot \gamma_{inc}} \cdot (SMYS - f_{ut, temp})
\]

Introducing a usage factor as given in (12.3), the criteria can be given as in Eq. (12.4).

\[
\eta = \frac{2 \cdot \alpha_U}{\sqrt{3} \cdot \gamma_m \cdot \gamma_{SC} \cdot \gamma_{inc}} \cdot (SMYS - f_{ut, temp})
\]

\[
\frac{D - t_1}{2 \cdot t_1} \leq \eta \cdot SMYS - f_{ut, temp}
\]

The corresponding usage factors for \(\gamma_{inc} = 1.10\) (10% incidental pressure) are given in Table 12-2.

#### F 500 Calculation of nominal thickness

The negative fabrication tolerance is normally given as a percentage of the nominal thickness for seamless pipes, and as an absolute measure for welded pipes.

The pressure containment criterion gives a minimum required wall thickness, \(t_1\). Depending on the fabrication tolerance format, the implication of the corrosion allowance will be different. For a fabrication tolerance given as a percentage, \(\% t_{fab}\), Eq. (12.5) applies.

\[
t = t_1 + t_{corr} \frac{1 - \% t_{fab}}{100}
\]

Correspondingly, the nominal thickness based on an absolute fabrication tolerance, \(t_{fab}\), is given by Eq. (12.6).

\[
t = t_1 + t_{corr} + t_{fab}
\]
The collapse pressure, $p_{c}$, is a function of the:

- elastic capacity,
- plastic capacity and
- the ovality.

The formulation adopted in this standard is identical as in BS8010, apart from the safety margin. The formula is given in Eq. (12.7) with the defined elastic and plastic capacities in Eq. (12.8) and Eq. (12.9).

$$p_{c} = p_{c\text{el}} + p_{c\text{pl}} + D_{\text{c}}$$

$$p_{c\text{el}} = \frac{2E_{c\text{el}}}{1 - v^2}$$

$$p_{c\text{pl}} = \frac{2f_{y} \cdot \alpha_{fab} \cdot \frac{I_{z}}{D}}{2 - \frac{1}{3}b_{c} + d}$$

This third degree polynomial has the following analytical solution:

$$p_{c} = \frac{1}{2}b_{c}$$

where:

$$b = -p_{c\text{el}}$$

$$c = -p_{c\text{pl}} \frac{D}{f_{0\text{c}}}$$

$$d = p_{c\text{pl}} R_{c}$$

$$u = \left(\frac{1}{3} - \frac{1}{3}b_{c} + c\right)$$

$$v = \left(\frac{2}{3} - \frac{1}{3}b_{c} - \frac{1}{3}b_{c} + d\right)$$

$$\Phi = \cos^{-1}\left(\frac{-v}{u}\right)$$

$$y = -2\sqrt{\nu \cos\left(\frac{\Phi}{3} + \frac{60\pi}{180}\right)}$$

The propagating pressure is the pressure required to continue to develop/run a buckle along a pipe. This means that in order to experience a running buckle, a dent or buckle has to exist prior to the propagating buckle. The propagating buckle will continue to propagate until the pressure is less than the propagating pressure.

Pipelines are usually not designed to resist the propagating pressure in the sense that it will not be governing for the design. For many pipelines, however, the pipe will resist the propagating pressure due to shallow water depth or high internal pressure (requiring thick wall for pressure containment). In cases where the pipe not will resist the propagating pressure, buckle arrestors are installed with a specific spacing, based on a cost evaluation, in order to avoid flattening too large portions of the pipeline.

Test performed to determine the propagating pressure is usually performed in a static manner, a volume of water is pumped into the pressure chamber where the specimen, with an initial buckle, is located and the maintain pressure is the propagating pressure. This procedure deviates quite substantially from a real propagating buckle. Such differences may be:

- the pressure at the buckle is higher due to the lack of inertia;
the deformation pattern may be different; this may also imply that typical strains experienced during the buckling propagation may be different; and
— the stress-strain relationship will correspond to a static case while in the real case a much higher value may be experienced due to the high strain rate.

In the real situation, however, the running buckle will stop when it reach a water depth corresponding to a too low pressure. At this point, the running buckle will change from a dynamic condition to a static condition. The very important conclusion from this is that the most conservative estimate from a dynamic and static condition should always be used, since the buckle will experience both. And, this will not necessarily be as conservative as it may look at the first glance.

The safety factors provided on the propagating pressure is based upon a conditioned probability, i.e. including the probability for a buckle to occur in addition to the probability of the pipe failing to resist the pressure. This implies that the failure probability of the propagating pressure resistance in itself (isolated) is 1-2 decades higher than for other ULS limit states.

F 1100 Local buckling - Buckle arrestors

The buckle arrestor is usually designed to resist the propagating pressure. The propagation pressure resistance of a pipe is based upon an “infinite” pipe, and the length has to be considered when designing the buckle arrestor. A short buckle arrestor needs to be thicker than a longer buckle arrestor.

Most formulas on design of buckle arrestors are build up from three components:
— propagating pressure of the pipeline,
— propagation pressure of the buckle arrestor and
— so called cross-over pressure.

The cross over pressure is a pressure which normally approach the propagating pressure of the pipeline when the buckle arrestor short enough and the propagating pressure of the buckle arrestor itself when it becomes longer. Hence, the crossover pressure is a function of the propagating pressure of the pipeline, the buckle arrestor and the length of the buckle arrestor.

Even though the safety factor is provided in the propagating pressure formula, it is recommended to decrease this with 15% (from 35 to 30) for the propagating pressure resistance of the buckle arrestor. This to decrease the failure probability to the unconditioned safety level in line with normal ULS checks.

Discussion regarding buckle arrestors are e.g. given in Sriskantharajah (1987).

F 1200 Local buckling - Allowable stress design format

This Allowable Stress Design (ASD) check may be used as a preliminary simplified criterion of the local buckling check in an early design stage for internal over-pressure. It does not supersede the LRFD criterion which shall be applied in the final design.

The following stress conditions are to be satisfied:

\[ \sigma_c \leq \eta \times f_y \]
\[ \sigma_l \leq \eta \times f_y \]

Where:

\[ \sigma_c = \sqrt{\left( \frac{\sigma_h^2}{2\gamma l_h} \right) + \left( \frac{\sigma_f^2}{\gamma f_c} \right)} \]
\[ \sigma_h = \Delta P_{d} \left( \frac{D - t_{2}}{2t_{2}} \right) \]

\( \sigma_c \) = the equivalent stress
\( \sigma_l \) = longitudinal stress
\( \gamma \) = usage factor as given by Table 12-3.
\( f_y \) = yield stress, see Table 5-2
\( \eta \) = usage factor as given by Table 12-3.
\( \gamma f_c \) = stress concentration factor
\( \gamma l_h \) = tangential shear stress

<table>
<thead>
<tr>
<th>Safety class</th>
<th>Low</th>
<th>Normal</th>
<th>High</th>
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<tr>
<td>( \eta )</td>
<td>1.00</td>
<td>0.90</td>
<td>0.80</td>
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</table>

All Load Factors are to be equal to unity for the stress check. Condition load factor shall be applied when relevant and on relevant stress components.

F 1300 Local buckling - Adding moments

For a pipe section exposed to bending moments acting in different directions, the factorised load effects should be added, e.g. a functional moment in the x-direction and an environmental moment in the y-directions should be added as in:

\[ M_d = \gamma (\gamma f_c \cdot M_{F,x})^2 + (\gamma f_c \cdot M_{F,y})^2 \]  \hspace{1cm} (12.11)

Load effect factors shall be applied on each individual component.

F 1400 Ovalisation

Pipe ovalisation is mentioned in three different places within this standard:

— Section 5D 800, where the maximum allowable ovalisation \( f_0 = 3\% \). This applies for the pipeline as installed condition. This limitation is due to the given resistance formulations which not includes the ovality explicitly, as well as other functional aspects as stated in the paragraph.
— Section 5D 503, where the minimum ovalisation \( f_0 = 0.5\% \) to be accounted for in the system collapse check; and the combined loading. The collapse formula includes the ovality explicitly giving a lower resistance for a larger ovality, hence a minimum ovality is prescribed.
— Table 6-14 and Table 6-15, dimensional requirements, where the maximum allowable out of roundness to be delivered from Manufacturer is specified.

The ovality of a pipe exposed to bending strain may be estimated by Eq. (12.12). This is a characteristic formula without any safety factors.

\[ f'_0 = f_0 + \left[ \frac{0.030(1 + \frac{D}{120t})}{2(\gamma f_c \cdot D)} \cdot \left( \frac{P_c}{P_c} \right)^2 \right] \]  \hspace{1cm} (12.12)

For further information, reference is made to Murphey (1985)
G. Fracture Mechanics

G 100 Engineering Criticality Assessment (ECA) - Strain based design

The fracture mechanics models for unstable fracture assessments described in BS 7910 are formulated for stress based assessments and are recommended for load controlled situations. For pipe laying methods introducing plastic strain these models are usually not directly applicable. Therefore, some guidelines for strain based design are given below with the objective to define input parameters needed to carry out assessments using the format of BS 7910:1999. For nomenclature it is referred to BS 7910:1999.

A necessary condition for safe use of strain based design at strain levels considerably above yielding is that the pipe is predominantly loaded in global displacement control. This can be regarded as fulfilled when the magnitude of load resulting from load controlled sources alone including appropriate safety factors is well below the plastic collapse level.

No assumption of local displacement control involving relaxation of the stress level due to crack growth should be made.

Strain based design should preferably be carried out at assessment Level 3 which require that the fracture resistance curve (J-R or δ-R curve) is established by testing according to BS 7448 Part 4 or equivalent standards. This is to ensure that a possible weld defect will not lead to collapse due to ductile tearing. Further, an assessment at Level 3 for the installation phase provide information about the defect size after installation which is needed for assessing possible fatigue crack growth and unstable fracture during operation.

Assessment at Level 2 is considered safe provided that the girth welds will not be subjected to conditions during operation that may lead to failure by fatigue crack growth or unstable fracture.

It is acceptable to increase the load ratio limit to \( \frac{L_{\text{max}}}{\sigma_f} \), i.e. the ultimate tensile strength (in true stress) to yield stress ratio.

The material specific Failure Assessment Diagram (FAD), which requires knowledge of the material stress strain curve, must be used to avoid non-conservative or excessively conservative predictions. For assessing defects located within the weld metal the FAD should be derived from all-weld metal tensile tests. For assessing defects at the fusion line and within the HAZ the FAD should be derived from parent material tensile tests. The respective yield stress values at 0.2% permanent strain or at the lower yield point should be derived from the same stress-strain curves.

The design strain should be calculated by an elastic-plastic analysis considering strain concentrations and safety factors. In lack of a relevant strain concentration factor (SNCF), the SNCF may be approximated from elastic stress concentration factors (SCF) for the same geometry and mode of loading in accordance with Neuber's rule. (For simplicity the SNCF may conservatively be taken as the square of the SCF.) SCFs applied directly on the primary stress may lead to overly conservative results.

The primary stress should be taken from the parent material’s true stress-true strain curve at the design strain.

Note that the parent material stress-strain curve is decisive for the primary stress as well as for the FAD for defects located at the fusion line and within the HAZ. It is essential to use the same parent material stress strain curve for both purposes in order to avoid gross errors. Also note that for conservative strain based assessments the parent material stress-strain curve should represent an upper bound curve giving an upper bound predicted primary stress. However, a lower bound weld metal stress-strain curve should be applied for constructing a conservative FAD for assessment of defects located in the weld metal.

Welding residual stresses may be included as secondary stress as described by BS 7910:1999 with the relaxation by increasing primary stress. An alternative approach is to add the corresponding welding strain (welding stress divided by the modulus of elasticity) to the design strain used to determine the primary stress. In the latter case no relaxation by increasing primary stress is allowed.

G 200 ECA - Cyclic loading into the plastic regime

The mechanisms for crack extension by ductile tearing under cyclic loading, such as pipe laying by reeling, are at present not well understood. However, some recommendations for conducting an unstable fracture assessment at Level 3 are given below. Due to the uncertainty related to these recommendations the results should be verified experimentally for large values of accumulated strain.

It is assumed that stable crack extension is taking place only under tensile stress. Plastic deformation under tensile loading in each load cycle may contribute to stable crack extension, while purely elastic unloading and reloading do not.

For each stress-strain cycle the plastic strain between the up-crossing at zero stress and the following down-crossing at zero stress should be determined. The total applied strain should be taken as the sum of the plastic strains of all load cycles plus the elastic strain for the single load cycle of maximum stress.

The design strain should be taken as the applied strain multiplied by relevant safety factors. Further assessment should be carried out as prescribed in G.

G 300 Fracture toughness testing

The resistance to cleavage fracture and to ductile tearing is known to depend on the crack tip constraint. Standardised fracture toughness test specimens are usually deeply notched and loaded in bending, which give maximum crack tip constraint and lower bound fracture toughness values. However, pipeline weldments are usually predominately subjected to membrane stress and contain weld defects of smaller heights than the notch length of standardised specimens. It is therefore justified to use non-standard test specimens that more closely reflects the crack tip constraint of pipeline weld defects.

The formulas given by the test standards for deriving the fracture toughness from the load vs. displacement records may not be valid for non-standard specimen configurations. The fracture toughness shall therefore be derived by one of the techniques described below or another proven method.

SENB test specimens with reduced notch length, but otherwise in accordance with BS 7448 or equivalent standards, may be used for deriving the fracture toughness for use in an ECA provided that the specimen notch length is not chosen shorter than the height of the most severe weld defect assessed in the ECA.

The fracture toughness for SENB test specimens can be derived from the load vs. clip gauge displacement record according to the following formulas:

\[
J = \left[ \frac{FS}{BW} \right] \left( 1 + \frac{a}{W} \right) + \frac{\eta_p A_p}{B(W - a)}
\]

\[
\eta_p = 3, 785 - 3, 101 \left( \frac{a}{W} \right) + 2, 018 \left( \frac{a}{W} \right)^2
\]

where \( A_p \) is the area under the load vs. crack mouth displacement (CMOD) curve. For definitions of the other parameters it is referred to BS 7448.

301 If the total displacement, \( V_{CMOD} \), is measured at a distance \( z \leq 0.2a \) from the physical crack mouth then the CMOD can be calculated from:
The CTOD-value, $\delta$, can be calculated from $J$ according to the following formulas:

$$\delta = \frac{J}{m \sigma_{YS} + \sigma_{TS}}$$

$$m = 1.221 - 0.739 \frac{\sigma}{W} + 2.751n - 1.418n \frac{a}{W}$$

$$= 1.724 - 6.098 \left( \frac{\sigma_{YS}}{\sigma_{TS}} \right) + 8.326 \left( \frac{\sigma_{YS}}{\sigma_{TS}} \right)^2 - 3.965 \left( \frac{\sigma_{YS}}{\sigma_{TS}} \right)^3$$

Other test specimen configurations, such as specimens loaded in tension, may be used for deriving the fracture toughness for use in an ECA provided that it is justified that the crack tip constraint of the test specimen is not smaller than for the most severe pipeline weld defect assessed in the ECA.

The fracture toughness can be derived from the load vs. clip gauge displacement record using one of the following principles:

- The J-value vs. the crack mouth displacement or load point displacement can be derived by non-linear elastic-plastic finite element analysis using the stress-strain curve of the material to be tested.
- The CTOD value can be measured by using a double clip gauge technique. The displacement due to separation of the crack faces is measured at two different distances from the crack mouth, $z_1$ and $z_2$, e.g. at zero and at 2 mm. The CTOD is calculated from the load-displacement curve as

$$\delta = \frac{1 - v^2}{2E} K_I^2 + V_{p1} - \frac{a + z_1}{z_2 - z_1} (V_{p2} - V_{p1})$$

where

$K_I$ is the stress intensity factor at the subject load

$V_{p1}$ and $V_{p2}$ are the plastic parts of the clip gauge displacements at $z_1$ and $z_2$ respectively.

### Table 12-4 API Material Grades

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<th>Grade</th>
<th>SMYS MPa</th>
<th>SMTS MPa</th>
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<td>42</td>
<td>289</td>
</tr>
<tr>
<td>X46</td>
<td>46</td>
<td>317</td>
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<tr>
<td>X52</td>
<td>52</td>
<td>358</td>
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<td>X56</td>
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<td>386</td>
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<td>X60</td>
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<tr>
<td>X65</td>
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<td>448</td>
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<tr>
<td>X70</td>
<td>70</td>
<td>482</td>
</tr>
<tr>
<td>X80</td>
<td>80</td>
<td>551</td>
</tr>
</tbody>
</table>

ksi = 6.895 MPa; 1 MPa = 0.145 ksi; ksi = 1000 psi (lb f/in²)

### I. Components and assemblies

#### I 100 Bends

It should be noted that the mother pipe shall be subject to hydrostatic testing in accordance with Section 6 E1100. This does however not include the relaxed requirement of Section 6 E1108.

For bends made of clad or lined pipe special care should be taken to prevent disbonding and/or wrinkling of the clad/lining layer. It may be difficult or impossible to obtain bending radii of the order of 3D or 5D without disbonding and/or wrinkling.

#### I 200 Riser Supports

Riser Supports are to be designed to ensure a smooth transition of forces between Riser and support.

Inspection/control methods are to be specified so that proper installation is ensured, in accordance with the design assumptions.

Where the Riser Support relies on friction to transfer load, appropriate analytical methods or experimental test results are to be used to demonstrate that adequate load transfer will be developed and maintained during the life of the structure. The design of the studbolts are to be such that it is possible to monitor the remaining bolt tension during the design life time. This can be done by utilising mechanical bolt load indicators in some of the studbolts in each connection.

The minimum remaining pretension level in the studbolts at which pre-tensioning must be performed is to be determined during the design phase.

The design is to be such that all the studbolts in one connection can be pre-tensioned simultaneously by means of bolt tensioning jacks.

All relevant loads are to be considered when calculating the fatigue life of the Riser Supports.

#### I 300 J-tubes

The J-tube system is to be designed to perform satisfactorily during its entire planned life. It is to be designed against relevant failure modes.

- The routing is to be based on the following considerations:
  - platform configuration and topsides layout
  - space requirements
  - movements of the J-tube
  - cable/Pipeline approach
  - J-tube protection
  - in-service inspection and maintenance
  - Installation considerations.

The J-tube spool is normally to be joined by welding.
For J-tubes, loads during Installation include:
- load-out
- transportation
- lifting
- launching
- upending
- docking
- pressure testing
- temporary supporting.

The effect of deflections due to a connected Pipeline's thermal expansion or contraction is to be taken into account.

Loads caused by deflections of the J-tube, or the structure to which the support is attached, are to be considered.

Loads on the J-tube and supports as a result of foundation settlements are to be considered. Accidental loads are loads to which the J-tube and support system may be subjected in connection with incorrect operation or technical failure such as fire, explosions and impact loads. The relevant accidental loads and their magnitude are to be determined on the basis of a risk analysis.

The effect of impact by vessels is to be considered for the J-tube and support system within the splash zone. Normally the J-tubes and supports are to be routed inside the structure to avoid vessel impact.

Consideration is to be given to accidental loads caused by falling objects such as:
- falling cargo from lifting gear
- falling lifting gear
- unintentionally swinging objects.

### J. Material and Design Links

#### J 100 General

Optimisation of pipeline design requires a closer link between material and design. In this standard, this is evident and it is of vital importance to have a common understanding between the disciplines on the choice and requirements of the material. The sub-section will go through some of the aspects linking design with material and vice versa.

An overview of the links between material and design is given in Figure 12-2. The different aspects will be discussed in the following.

The design premise will state content, transport requirement, description of the content etc.

The material type and grade will be decided by a life cycle cost analyses considering both operational and design aspects.

#### J 200 Supplementary requirements

The supplementary requirements are described in Section 6D

**Sour service (S)** is required if the fluid is defined as sour according to the NACE definition, see Section 6D.101.

**Fracture arrest (F)** is required for pipelines transporting gas or mixed gas, see Section 5D.1103 and 1104, Section 6D 200.

Supplementary requirement for plastic deformation (P) is required if the accumulated plastic strain exceed 2%. The supplementary requirement also requires testing of strained material which implies that information about the expected strain cycles should also be given, see Section 5D.1006.

**Supplementary requirement for dimensions (D)** is required by supplementary requirement P and else when tight dimensional control is required.

**Supplementary requirement for increased utilisation (U)** shall be determined on a cost benefit evaluation. This supplementary requirement usually implies that 4% less steel is required, see Section 5B 600.

#### J 300 Links based on accumulated strain

The requirement to NDT levels as well as to supplementary requirements P and F depend on the accumulated strain that the pipeline will experience during its life.

Figure 12-3 gives an overview of the different criteria for the different supplementary requirements.
Fig. 12-3 Illustration of when supplementary requirements U and D as well as Linepipe NDT level 1 is required.

Note that it is required in addition to specify P, specify the anticipated strain cycles.

J 400 Material data sheet

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Standard</th>
<th>Scope</th>
<th>Supplementary requirements</th>
<th>Qualifications</th>
<th>References in Section 6 of the Standard</th>
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</thead>
<tbody>
<tr>
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<td>DNV-OS-F101 Submarine Pipeline Systems</td>
<td>This Material Data Sheet (MDS) specifies the selected options in the referred standard and modified requirements which supersedes the corresponding requirements in the referred standard.</td>
<td>S Sour service</td>
<td>MPS to be qualified</td>
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<td></td>
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<td>F Fracture arrest properties</td>
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<td>P Pipe for plastic deformation</td>
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K. Installation

K 100 Safety class definition

Installation of pipeline and pipeline components is normally defined as safety class Low. However, if the installation activity impose a higher risk to personnel, environment or the assets, a higher “safety class” should be used. Such activities may typically be repair, where the system is shut down, but the production medium is still within the system, modifications to existing system or installation operations where failure may lead to extensive economic loss.

K 200 Coating

In case no other data is available the following criterion should be used. The mean overbend strain:

$$\varepsilon_{\text{mean}} = \frac{D}{2R} + \varepsilon_{\text{axial}}$$  (12.13)
should satisfy:

\[ \gamma_{cc} \epsilon_{\text{mean}} \geq \epsilon_{\text{cc}} \]  

(12.14)

where

\[ R = \text{stinger radius} \]
\[ \epsilon_{\text{mean}} = \text{calculated mean overbend strain} \]
\[ \epsilon_{\text{axial}} = \text{axial strain contribution} \]
\[ \gamma_{cc} = 1.05 \text{ safety factor for concrete crushing} \]
\[ \epsilon_{cc} = \text{limit mean strain giving crushing of the concrete. Positive strain denotes tensile strain.} \]

The mean overbend strain at which concrete crushing first occurs depends on the pipe stiffness, the concrete strength and thickness, the axial force and the shear resistance of the corrosion coating. Crushing occurs at lower mean overbend strains for lower concrete strength, lower axial force, higher pipe stiffness and higher shear resistance. If no other information is available, concrete crushing may be assumed to occur when the strain in the concrete (at the compressive fibre in the middle of the concrete thickness) reaches 0.2%.

For concrete coating of 40 mm thickness or more, together with asphalt corrosion coating, a conservative estimate of \[ \epsilon_{cc} \] is 0.22% for 42" pipelines and 0.24% for 16" pipelines, with linear interpolation in between.


K 300 Simplified laying criteria

This simplified laying criteria may be used as a preliminary simplified criterion of the local buckling check during early design stages. It does not supersede any of the failure mode checks as given in the normative part of the standard.

In addition to the simplified stress criteria given below, the limit states for Concrete Crushing (K200), Fatigue (Sec.5 D700) and Rotation (Sec.5 H203) shall be satisfied. Reference is further made to Endal et. al. (1995) for guidance on the Rotation limit state.

Overbend

For static loading the calculated strain shall satisfy Criterion I in Table 12-5. The strain shall include effects of bending, axial force and local roller loads. Effects due to varying stiffness (e.g. strain concentration at field joints or buckle arrestors) need not be included.

For static plus dynamic loading the calculated strain shall satisfy Criterion II in Table 12-5. The strain shall include all effects, including varying stiffness due to field joints or buckle arrestors.

<table>
<thead>
<tr>
<th>Table 12-5 Simplified criteria, overbend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
</tbody>
</table>

Sagbend

For combined static and dynamic loads the equivalent stress in the sagbend and at the stinger tip shall satisfy the allowable stress format ASD as given in F1200, however, \[ \eta \] shall be 0.87.

Effects due to varying stiffness or residual strain from the overbend may be ignored.

For the sagbend in deeper water, where collapse is a potential problem, the normative buckling criteria in the standard shall also be satisfied.

Calculation requirements

The following requirements to the lay analysis apply both when using Limit State Criteria and Simplified Criteria:

- The analysis shall be conducted using a realistic non-linear stress-strain (or moment-curvature) representation of the material (or cross-section).
- For calculation of strain concentration at field joints, non-linear material properties of the steel, the concrete and the corrosion coating shall be considered.
- The characteristic environmental load during installation is to be taken as the most probable largest value for the sea-state (\( H_s, T_p \)) considered with appropriate current and wind conditions. The sea-state duration considered is not to be less than 3 hrs.
- If the dynamic lay analysis is based on regular waves, it shall be documented that the choice of wave heights and periods conservatively represents the irregular sea-state (\( H_s, T_p \)).

K 400 Reeling

A pipeline that is reeled onto a spool will be subjected to large plastic strains. When two abutting pipe joints have dissimilar tangential stiffness, e.g. due to different wall thickness or varying material properties, a discontinuity will occur. The result of this is a concentration of compressive strains in the softer joint in an area close to the weld. Experience has shown that variations in properties (within fabrication tolerances) may cause the pipe to buckle.

Figure 12-4 and Figure 12-5 attempt to illustrate the reeling situation from two different points of view. It is recognised that these illustrations, and the description below, are simplified and only take into account global effects.

In Figure 12-4 the sudden increased curvature is visualised by looking at the moment curvature relationship for the two abutting joints. It is seen that the required moment equilibrium across the weld will lead to an increase in curvature in the weaker pipe. This figure also shows clearly that an increased stiffness difference will increase the sudden increase in curvature in the weaker joint.

Figure 12-4 Moment curvature relationship for plastic bending of pipes with different stiffness.

Figure 12-4 provides a different illustration: The distribution of moment and corresponding tangential stiffness is schematically plotted along the pipeline.

At the left hand side of the figure the pipe is assumed to lie tight onto the reel with a constant bending moment well into the plastic regime. From the point where the pipe first touches the reel, to the point at the right hand side where back tension is applied, the moment is assumed to decay linearly to zero.

(Note that this moment will not vanish if the caterpillars, through which the back tension is applied, restrain rotation.) Furthermore, Figure 12-5 illustrates the scenario where a field joint approaches the reel and a weak/soft joint follows a stronger/stiffer one.

The lower part of this figure shows the tangential stiffness along the pipeline. Attention should be paid to the sudden drop...
in stiffness at the weld. It is obvious that this loss of stiffness will attract deformations, i.e. increased curvature in the weaker pipe close to the weld.

![Figure 12-5 Schematic illustration of bending moment and stiffness along the pipe](image)

FE analyses have shown that the most important parameters, with respect to stiffness variations are variations, in yield stress and wall thickness. Under disadvantageous circumstances, variations within normal fabrication tolerances may lead to buckling of the pipe cross section.

Over-matching (girth) weld materials are often used in pipes. These will introduce stiffness variations, however the effect of these are not normally significant from a buckling point of view.

If a thick and relatively stiff coating is applied with gaps across field joints, stress concentrations due to variations in yield stress and wall thickness will be amplified.

Analyses have also shown that accurate non-linear material modelling is essential for the accuracy of FE analyses. Especially important in this respect is the tangential material stiffness, often defined through the yield stress to ultimate stress ratio, SMYS/SMTS. High ratios increase significantly the cross section’s tendency to buckle. Obviously a high $D/t$ ratio will have a similar effect.

During reeling, application of a high back tension is the major remedy available for reducing the possibility for pipe buckling, and both practical experience and FE analyses have shown that this is a viable and mitigating measure in this context.

Hence: in order to reduce the probability of buckling during reeling, one should:

— specify a low thickness fabrication tolerance,
— specify a low variation in yield stress,
— specify a low yield stress to ultimate stress ratio and
— apply a high and steady back tension during reeling.

For further information, reference is made to Crome (1999).

### L. References

Crome, Tim; "Reeling of Pipelines with Thick Insulating Coating, Finite Element Analyses of Local Buckling", OTC, Houston, 1999.


Ness O. B. and Verley R.; "Strain Concentrations in Pipelines with Concrete Coating: An Analytical Model", Proceedings of OMAE'95 conference, Copenhagen, Denmark


APPENDIX A
SUPPLEMENTARY REQUIREMENTS TO ISO

A. General

A 100 General

101 For C-Mn steel linepipes, a comparison is made between this offshore standard and ISO/FDIS 3183-3 (final draft) regarding requirements to material properties and manufacture.

B. Differences observed

B 100 Chemical composition and mechanical properties

101 Requirements to chemical composition are in general comparable. The DNV standard applies for wall thicknesses up to 35 mm for welded linepipes, while ISO applies up to 25 mm. DNV specifies limits on residual elements when scrap material is being used in steel production.

102 Requirements to tensile properties and Charpy V-notch energy values are identical. Regarding Charpy V-notch test temperature, the requirements are comparable for gas-conveying pipelines. For liquid-conveying lines, the ISO standard is 10°C stricter.

103 The DNV standard specifies strain ageing tests to be carried out if cold forming during pipe manufacture exceeds 5% strain.

104 The DNV standard specifies fracture toughness testing during qualification for the base material and the weld metal (welded linepipes). Measured CTOD values shall be a minimum of 0.20mm for both base material and weld metal at the design temperature. The ISO standard specifies CTOD testing as an optional agreement, to be carried out in accordance with ISO 12135 during MPS qualification with notches in weld metal, HAZ and base metal. Sampling procedure shall be subject to agreement.

105 Hardness measurements are specified by both standards. However, DNV gives detailed acceptance limits.

B 200 Weldability

201 The DNV standard states that a weldability test program shall be performed or relevant weldability documentation may be accepted. For steels with SMYS>415 MPa, a more extensive program shall be carried out. The Charpy V-notch energy requirements to weld area are equal to 10% of SMYS in J. Detailed requirements to personnel qualification are given with references to EN 287/ISO 9606 and EN 1418.

202 References are made to EN 719 and EN 729 regarding quality assurance of welding. Detailed requirements are given to procedure qualification. Batch testing of welding consumables is specified.

203 Regarding ISO, the Manufacturer shall, subject to agreement, supply weldability data or perform weld tests. Acceptance criteria are to be agreed. Charpy V-notch energy requirements for weld area = 40J.

B 300 Samples and test pieces

301 Both standards refer to the general conditions of ISO 377. The DNV standard states that for linepipe outer diameters > 300mm, tensile properties shall be tested in both transverse and longitudinal direction of the pipe axis. The YS/TS ratio in the longitudinal direction shall not exceed the maximum specified value in the transverse direction by more than 0.020 for standard material, and more than 0.030 for sour service material. SMTS in the longitudinal direction can be 5% less than the required values in transverse direction.

302 The ISO standard requires transverse tensile test pieces for outer diameters ≥ 210 mm. However, for deep water pipelay application additional longitudinal tests may be specified. Requirements shall be subject to agreement.

B 400 Frequency of testing during manufacture

401 DNV specifies testing of one pipe from each lot or once per 50 pipes, whichever gives the highest test frequency.

402 The ISO standard specifies tensile, Charpy V-notch and bend testing to be carried out on one pipe per lot. For outside diameters ≤ 508 mm; this testing shall be at least once per 100 pipes. For all other pipes, testing shall be at least once per 50 pipes. Macro/metallographic examination shall be once per shift or when pipe size is changed. With respect to hardness measuring, it is stated that hard spots shall be examined.

B 500 NDT

501 Both DNV and ISO refer to the same basic standards. DNV has introduced requirements in addition to the basic standards. In the DNV standard C-Mn steel linepipes with longitudinal or helical weld seams have been divided into two (2) NDT levels; NDT Level I and NDT Level II. NDT Level II is comparable to ISO and is restricted to load controlled conditions. NDT Level I allows use of displacement controlled criteria (strain based design) and has more stringent requirements to NDT with respect to transverse imperfections.

B 600 Dimensions

601 The standard dimensional requirements given in the DNV standard are comparable to the ISO requirements.

B 700 Documentation

701 The DNV standard specifies Inspection Certificate 3.1B (EN 10204) or accepted equivalent.

702 According to the ISO standard, the Purchaser shall state the documentation level required.

B 800 Special requirements for sour service

801 Both standards specify HIPC testing during production. The DNV standard states requirements for the Ca/S ratio (greater than 1.5) and gives detailed requirements for re-testing.

802 For NACE listed materials, SSC testing is not specified under the DNV standard. The ISO standard states that 3 test pieces shall be taken per sample pipe (qualification of the MPS only).

B 900 Special requirements for fracture arrest

901 The DNV standard specifies that a Charpy V-notch transition curve shall be established for the base material in both the non-strain-aged and the strain-aged condition. The Charpy V-notch energy values to be fulfilled are stricter than corresponding requirements in the ISO standard. In addition, ISO does not specify testing in the strain-aged condition.

B 1000 Mill pressure test

1001 The mill test pressure is lower in ISO than in this stand-
ard. The ISO requirement is:
This hoop stress formula for the ISO mill pressure test is different from the formula in ISO 13623 and DNV (which are identical). Hence, the mill test pressure difference compared to this standard depends on D/t.
APPENDIX B
MECHANICAL TESTING AND CORROSION TESTING

A. Mechanical Testing

A 100 General

101 This appendix addresses methods for mechanical testing of materials and products.

102 Test laboratories shall meet the requirements of ISO Guide 25, "General requirements for the competence of calibration and testing laboratories", or an accepted equivalent.

A 200 Selection and preparation of samples and test pieces

201 Selection of samples and preparation of test pieces shall be in accordance with the general conditions of ISO 377, as far as applicable. The following requirements apply:

a) Test samples from linepipe shall be taken from pipe ends in accordance with Fig. B-1 and Appendix C Table C-3, taking into account the supplementary details specified in A 300-A1 000 and in Appendix C Fig. C-1.

b) For other welds including girth weld, samples shall be taken in accordance Appendix C Fig. C-1 and Fig. C-2.

c) Samples from fittings shall be taken in accordance with the recognised standard or specification used for manufacture.

d) For bolts, structural items, flanges, pressure containing equipment and other components and equipment (see Section 7), samples shall be taken in accordance with the recognised standard or specification used for manufacture.

A 300 Chemical analysis

301 Methods and procedures for chemical analysis shall be in accordance with recognised industry standards, of acceptable uncertainty. Results from chemical analyses shall be given with the same number of digits as given in the specification of the product and/or in this standard. All digits shall be significant.

Guidance note:
ISO/TR 9796 gives a list of available international standards providing chemical analysis methods, with information on the application and precision of the various methods.

Chemical analysis of weld overlay

302 The chemical composition of the weld overlay shall be obtained at the surface of the overlay after machining of the overlay such that the minimum distance from the surface to the fusion line is either 3 mm or the minimum thickness specified for the finished component, whichever is the lesser.

A 400 Tensile test

401 Tensile testing shall be carried out in accordance with the requirements in this appendix and ISO 6892. The specimen configuration and possible specimen flattening shall be the same for all the delivered items.

Conversion of elongation values

402 Conversion of elongation requirements for tensile test specimens shall be performed according to:

- ISO 2566/1 for carbon and low alloy steels, in normalised, QT and TMCP condition; and
- ISO 2566/2 for austenitic steels (and duplex steel).

The value $(5.65 \times \sqrt{S_0})$ is adopted as the preferred proportional gauge length for tensile test specimens.

Guidance note:
This conversion is not applicable to API 5L type specimens

Rectangular cross sectional specimen used for base material

403 A rectangular cross sectional specimen shall be of full material thickness. Apart from the following exceptions, flattening of test specimens is not allowed:

- pipe material tensile tests taken transverse to pipe axis shall be flattened, and
- specimen grip ends may be flattened or machined to fit the test machine's grips.

The extensometer shall be attached to a machined surface. Double sided extensometers should be used. Test acceptance criteria are given in Section 6 Table 6-3, Table 6-6 as applicable.

Circular cross sectional specimen used for base metal and "all weld metal" tensile test

404 The circular cross sectional specimen used for base metal shall have the maximum size possible dependant upon wall thickness, up to 20 mm diameter of the gauge length.

All-weld tensile test specimens shall have a circular cross section being of maximum obtainable diameter allowed by the weld geometry and dimensions. The specimens may have a diameter of 20, 10, 8, or 6 mm with other dimensions as given in ISO 5178.

Test acceptance criteria are given in Appendix C Part F.

Transverse weld tensile test

405 Tensile test specimens shall have a rectangular cross section being of full material thickness and with the dimensions as given in ISO 4136. The weld reinforcement shall be removed on both the face and root sides by machining or grinding.

There shall be no flattening of the test specimen except for testing of longitudinal or spiral seams of welded pipe. Grip ends may be flattened to fit test machine grips.

Transverse weld tensile test of clad/lined pipes shall be performed on full thickness of the carbon steel, after removal of the corrosion resistant cladding/lining, taking care not to reduce the carbon steel wall thickness.

Test acceptance criteria are given in Appendix C Part F.

All-weld tensile testing of weld overlay

406 Tensile test specimens shall have circular cross section of maximum obtainable diameter allowed by the weld geometry and dimensions. The specimen shall be machined from the weld overlay transverse to the welding direction.

Test acceptance criteria are given in Appendix C Part F.

A 500 Bend test

General

501 Bend testing shall be performed in accordance with ISO 5173 or ISO 5177 as appropriate.

- Bend test specimens shall have full wall thickness. The width of root and face bend specimens shall be approximately 25 mm. The width of side bend specimens shall be 10 mm. The edges may be rounded to a radius of 1/10 of the thickness.
The specimens shall be sampled 2 mm below the surface. A Test acceptance criteria are given in Section 6 Table 6-3 or temperature shall be in accordance with Section 6 Table 6-4 or as shall be prepared in accordance with ISO 148 without any prior the requirements of this Appendix and ISO 148. The test pieces The impact test shall be carried out in accordance with 601 A 600 Charpy V-notch impact test Test acceptance criteria are given in Appendix C Part F. Longitudinal root bend testing on clad/lined pipes 502 Longitudinal root bend test shall include the corrosion resistant alloy. — The longitudinal axis of the weld shall be parallel to the specimen, which is bent so that the root surface is in tension. — The width of the longitudinal root bend specimen shall be at least twice the width of the internal weld reinforcement or maximum 25 mm. The edges may be rounded to a radius of 1/10 of the thickness. — The internal and external weld reinforcement shall be removed flush with the original surfaces. — The thickness of the specimen shall be equal to the base material thickness or a maximum of 10 mm, as shown in Fig. B-3. — The specimen shall be bent to an angle of 180° using a former with diameter 90 mm.

Test acceptance criteria are given in Appendix C Part F. Bend testing of weld overlay 503 Side bend test specimens shall be used. The test specimens shall be sampled perpendicular to the welding direction. — For pipes the test specimens shall sample the full thickness of the weld overlay and the base material. For heavy sections the thickness of the base material in the specimen shall be at least equal to 5x the thickness of the overlay. — The thickness of side bend specimens shall be 10 mm. The edges may be rounded to a radius of 1/10 of the thickness. The central portion of the bend test specimen shall include an overlap area. — The specimens shall be bent to an angle of 180°. For base materials with SMYS up to 415 MPa the former diameter shall be 4x thickness of the test specimen. For base materials with SMYS equal to or exceeding 415 MPa, the former diameter shall be 5x thickness of the test specimen.

Test acceptance criteria are given in Appendix C Part F. A 600 Charpy V-notch impact test 601 The impact test shall be carried out in accordance with the requirements of this Appendix and ISO 148. The test pieces shall be prepared in accordance with ISO 148 without any prior flattening of the test material. Standard (i.e. full size) specimens shall be used whenever possible. Each set shall consist of three specimens taken from the same test coupon. The test temperature shall be in accordance with Section 6 Table 6-4 or as relevant.

Test acceptance criteria are given in Section 6 Table 6-3 or Table 6-6 as applicable.

The specimens shall be sampled 2 mm below the surface. A smaller distance than 2 mm shall be used if necessary (due to the dimensions of the material) to make specimens with the largest possible cross section. The notch shall be perpendicular to the surface.

Base material 602 The specimens shall be taken transverse to rolling direction/forging direction/pipe axis whenever possible. However, for pipes with D<300 mm, the specimens shall be taken parallel to pipe axis.

Charpy V-notch testing of welds. 603 The location of specimens is given in Appendix C Fig. C-1. When the wall thickness exceeds 20 mm for double sided welds, four additional sets of Charpy-V notch test specimens shall be sampled from the weld metal, FL+ (sampling 50% of HAZ), FL+2 mm and FL+5 mm in the root area, see Fig. B-6. Impact testing of clad/lined pipes shall be performed in the carbon steel portion of the material.

Charpy V-notch testing of load bearing weld overlay 604 When the weld overlay material is designated to transfer the load across the base material/weld overlay fusion line, impact testing of the weld overlay and HAZ shall be performed (i.e. when the overlay is a part of a butt joint or acts as a transition between a corrosion resistant alloy and a carbon steel). The longitudinal axis of the specimen shall be perpendicular to the fusion line and the notch parallel to the fusion line. Test acceptance criteria are given in Appendix C Part F. A 700 Drop weight tear test (DWTT) 701 Drop weight tear test shall be carried out in accordance with API RP 5L3.

Drop weight tear test specimens 702 Full thickness specimens are preferred. Reduced specimen may be used subject to Purchaser agreement. If reduced thickness specimens are used, both surfaces shall be equally machined to the thickness of 19.0 mm. The testing temperature reduction given in API RP 5L3 shall apply.

The specimens shall be taken transverse to the rolling direction or pipe axis, with the notch perpendicular to the surface. Reference is made to Section 6D.204.

A 800 Fracture toughness testing Fracture toughness testing (CTOD or J testing and d-R or J-R testing) shall be carried out in general compliance with the latest revisions of the relevant parts of BS 7448 or an equivalent standard.

The number of valid CTOD or critical J tests for each location shall be minimum 3. The characteristic CTOD or critical J value shall be taken as the lowest from 3 valid tests or selected in accordance with BS 7910. For testing specimens with notch location in fusion line/HAZ, it is recommended to test at least 6 specimens in order to obtain 3 valid specimens. Only specimens that are qualified with respect to crack tip location by post-test metallographic examination shall be considered valid.

Qualification of linepipe 801 The following applies when the requirements to fracture toughness are set as workmanship criteria with respect to qualification of linepipes: Testing of weld metal and of base material only. The test specimen geometry shall be in accordance with the test standard using through thickness notched specimens. Testing of parent material shall be conducted on specimens taken both in the longitudinal and the transverse pipe direction. Either through thickness notched specimens of rectangular sections (Bx2B) or surface notched specimens of square sections (BxB) shall be used. (With the notation used by BS 7448 assuming axial grain flow the test specimens are to of type X-
Y or X-Z and of Z-Y or Y-Z.)

Testing of weld metal shall be conducted on through thickness notched specimens with orientation transverse to the weld direction. (The corresponding notation used by BS 7448 is NP). The notch is to be located in the weld metal centre line.

If critical J testing has been carried out the required critical J is to be calculated from the required CTOD as

\[ J = CTOD \times \sigma_Y \]

where \( \sigma_Y \) is the actual yield stress of the material used for fracture toughness testing as defined by the test standard for CTOD testing. Unless stated otherwise testing shall be conducted at the minimum design temperature.

**ECA of girth welds.**

802 The following applies when CTOD or critical J fracture toughness testing is carried out in conjunction with an Engineering Critical Assessment (ECA):

Testing shall be conducted at the minimum design temperature. Additional testing at higher temperature(s) may be carried out in order to provide less conservative input to the ECA for loading conditions that will not occur below the respective test temperature(s).

Testing of weld metal shall be conducted on through thickness notched specimens of rectangular sections (Bx2B) with orientation transverse to the weld direction. (The corresponding notation used by BS 7448 is NP). The notch is to be located in the weld metal centre line.

Testing of fusion line/HAZ shall be conducted on surface notched specimens of square sections (BxB) with orientation transverse to the weld direction. (The corresponding notation used by BS 7448:1991 is NQ). The specimen shall be notched so that the direction of crack extension cross the fusion line from the weld metal side or is parallel with the fusion line.

Following testing of fusion line/HAZ each specimen shall be qualified with respect to the location of the fatigue pre-crack tip by post-test metallography as outlined in the test standard. The specimen is considered qualified if

a) the pre-crack tip is not more than 0.5 mm from fusion line

b) grain coarsened heat affected zone (GCHAZ) micro-structure is present within a region confined by a line perpendicular to the crack plane through the crack tip and a parallel line 0.5 mm ahead of the crack tip.

803 The following applies when determination of the fracture resistance curve (J-R or J-R curve) is carried out in conjunction with an Engineering Critical Assessment (ECA):

Testing shall be conducted at a temperature representative of the most severe loading condition.

The geometric configurations of the test specimens shall be as stated in 802.

Following testing of fusion line/HAZ each specimen shall be qualified with respect to the location of the fatigue pre-crack tip as required in 802.

804 When CTOD or critical J fracture toughness testing is carried out in conjunction with an Engineering Critical Assessment (ECA), the fabrication of test specimen geometry and loading mode in order to reduce unintended conservatism are acceptable provided that all modifications are well founded on generally accepted fracture mechanics theory and experimental documentation.

Further guidelines for use of such specimens are given in Section 12 of this document.

A 900 Shear strength test

901 Shear testing shall be in accordance with ASTM A264 (Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate, Sheet and Strip).

A 1000 Metallographic examination and hardness testing

**Macro examination**

1001 Macro examination shall be performed at 5x to 10x magnifications. Macro examination shall be conducted on specimens given in Figs. B-4 a), b), c) as applicable. The macro section shall include the whole weld deposit and in addition include at least 15 mm of base material on each side measured from any point of the fusion line. The macro-section shall be prepared by grinding, polishing, and etched on one side to clearly reveal the fusion line and HAZ.

Acceptance criteria are given in Appendix C Part F.

The macro examination of weld overlay shall be sampled transverse to the welding direction. The width of the macro section shall be minimum 40 mm. The face exposed by sectioning shall be prepared by grinding, polishing and etched by a suitable etchant to clearly reveal the weld and heat affected zone.

Acceptance criteria for weld overlay are given in Appendix C Part F.

**Micro examination**

1002 Samples for optical metallography shall be prepared using standard procedures, and further etched in an applicable etchant in order to reveal the microstructure. For quenched and tempered forgings and castings in low-alloy steels the requirements of Section 7F shall apply in addition.

Micro examination of duplex stainless steels shall be performed at a minimum magnification of x400.

Acceptance criteria are given in Section 6C 300, C 400, C 500 as applicable.

**Hardness testing of base material**

1003 Hardness testing of base material shall be carried out according as shown in Fig B-4a. The Vickers HV10 method according to ISO 6507.

**Hardness testing of welds**

1004 Hardness testing shall be performed in accordance with ISO 6507-1 on the specimens used for macro examination.

The Vickers method HV10 shall be used. Indentations shall be made along traverses, each 1.5 mm ±0.5 mm below the surface at either side of the weld.

In the weld metal, a minimum of 3 indentations equally spaced along each traverse shall be made. In the HAZ, indentations shall be made along the traverses for each 0.5 mm into unaffected material, and starting as close to the fusion line as possible. A minimum of 3 indentations on either side of the weld shall be made into the unaffected material spaced approximately 1 mm. Refer to Fig. B-4.

For double sided welds, one additional hardness traverse shall be made through the root area, see Fig. B-4 b).

Hardness testing of clad/lined pipes shall have one additional hardness traverse located in the thickness centre of the cladding. Refer to Fig. B-5 a) in for longitudinal welds in pipes and Fig. B-5 b) for girth welds.

Acceptance criteria are given in Appendix C Part F.

For hardness testing of weld overlay, the Vickers method HV10 shall be used. Hardness testing shall be performed at a minimum of 3 test locations each: in the base material, in the HAZ and in each layer of overlay up to a maximum of 2 layers.

Acceptance criteria are given in Appendix C Part F.

A 1100 Strain ageing test

**Base material**

1101 A test coupon shall be machined from the material. The
orientation of the coupon shall be transverse to the pipe axis for pipes with \( D \geq 300 \text{ mm} \). For smaller diameters, the coupon shall be oriented parallel to pipe axis. The coupon may be straightened prior to uniform tension in order to obtain full size specimens.

The test coupon shall be of either full or reduced wall thickness. The reduced (parallel) section of the coupon shall have a width and thickness sufficient to produce the required number of standard (full size) Charpy V-notch specimens needed for the test.

After preparation the test coupon shall be aged at 250\(^\circ\)C for one hour. Thereafter, the specified number of Charpy V-notch specimens shall be machined from the middle of the coupon. The orientation of the specimens shall be longitudinal to the coupon centreline, with the notch perpendicular to the surface of the test coupon.

Acceptance criteria are given in Section 6D.203.

### B. Corrosion Testing

#### B 100 General

101 For certain linepipe material and fluid combinations where improper manufacture or fabrication can cause susceptibility to corrosion related damage, the need for corrosion testing during qualification and/or production shall be assessed. Certain corrosion tests are applicable to confirm adequate manufacturing and fabrication procedures affecting the microstructure.

This subsection describes test requirements and methods for corrosion testing.

Test laboratories shall meet the requirements in A.102 above.

#### B 200 Pitting corrosion test

201 This test is applicable to verify CRA resistance to pitting and crevice corrosion by oxidising and chloride containing fluids, e.g. raw seawater and other water containing fluids (including treated seawater) with high residual contents of oxygen and/or active chlorine. For duplex stainless steels, this test is further applicable to verify adequate microstructure related to manufacturing and fabrication procedures affecting e.g. toughness and weldability in addition to corrosion resistance.

202 The test shall be carried out according to ASTM G48 "Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless steels and Related Alloys by the Use of Ferric Chloride solutions", Method A.

203 Requirements for frequency and extent of testing during manufacture and installation are defined in Section 6E 800 and Section 9A 800, respectively. Location of specimens is given in Fig. B-2.

204 Test specimens from clad/lined pipe shall be machined to remove the carbon steel portion and are to contain the full weld and any heat affected zone in the corrosion resistant alloy.

205 The minimum recommended size of test specimens is 25 mm wide by 50 mm long by full material thickness. For welds, at least 15 mm of the base material on each side of the weld shall be included in the test specimen.

206 Rolled surfaces shall be tested "as-received", i.e. without mechanical preparation. The root and the cap side of the welds are only to be prepared with the intention of removing "loose material" that will interfere with weighing prior to and after testing. Cut faces shall be ground (500 grid) and sharp edges smoothed off. The specimen shall subsequently be pickled to reduce the susceptibility of cut surfaces to end-grain attack. For duplex stainless steels and austenitic grades with PRE > 30, 20% nitric acid + 5% hydrofluoric acid, 5 minutes at 60\(^\circ\)C is adequate.

207 The test solution shall be prepared according to the referenced standard. For 25 Cr duplex and austenitic CRAs with a specified PRE value of minimum 40 (see Section 6 Table 6-5) the test temperature shall be:

- 50\(^\circ\)C for base materials (including longitudinal weld, if applicable);
- 35\(^\circ\)C and 40\(^\circ\)C for girth welds in 25 Cr duplex and austenitic CRAs respectively.

The test period shall be 24 hours.

Corrosion testing of weld overlay

208 Specimens for corrosion testing of the weld overlay shall be machined from the base material side. The remaining surface of the specimen shall be representative for the weld overlay at the minimum distance from the fusion line (equal to 3 mm or the minimum weld overlay thickness specified for the finished machined component, whichever is the lesser). The opposite surface of the specimen shall be machined such that the thickness of the specimen is 2 mm. The size of the specimen shall be 25 x 25 mm in length and width.

#### B 300 Hydrogen Pressure Induced Cracking test

301 Hydrogen Pressure Induced Cracking (HPIC) testing shall be carried out based on NACE TM0284 "Evaluation of Pipeline Steels for Resistance to Stepwise Cracking" modified according to EFC Publication Number 16 "Guidelines on Materials Requirements for Carbon Steel and Low Alloy Steels for HS-containing Environments in Oil and Gas Production".

302 Evaluation and acceptance criteria shall comply with EFC Publication Number 16.

#### B 400 Sulphide Stress Cracking test

401 Linepipe materials to be used for sour service and not meeting the general requirements in Section 6D 100, shall be qualified by testing for resistance to Sulphide Stress Cracking (SSC) as specified in Section 6D.102.

402 For qualification of new materials (i.e. not listed for sour service in the latest edition of NACE MR0175), testing shall be conducted on specimens from at least 3 heats of material. If qualification is to be performed for a material listed for sour service in NACE MR0175 but not meeting the requirements for a specific property in Section 6D 100, e.g. maximum hardness or contents of alloying or impurity elements, then testing shall be carried out on material representing the worst case conditions to be qualified.

403 Qualification testing shall include testing of simulated girth welds and for welded pipe also seam welds. Specimen preparation, testing procedures and acceptance criteria shall comply with either EFC publication No. 16 and 17 for C-Mn and CRA linepipe respectively, or NACE TM0177-96.
Figure B-1 Samples position for linepipe
Figure B-2 Bend test specimens

Figure B-3 Longitudinal root bend test specimens
a) Hardness location in seamless pipe

b) Hardness location in fusion welded joints

c) Hardness location in HFW or non fusion welded joints

Figure B-4 Hardness locations
The "FL" specimen shall sample 50% WM and 50% HAZ. The FL+2mm and FL+5mm specimens shall be sampled 2 and 5 mm from the fusion line nose formed where the two fusion lines come together.

Figure B-5 Hardness locations cladded materials

Figure B-6 Charpy V-notch specimen location for testing in the root area of double sided welds

The "FL" specimen shall sample 50% WM and 50% HAZ. The FL+2mm and FL+5mm specimens shall be sampled 2 and 5 mm from the fusion line nose formed where the two fusion lines come together.
APPENDIX C
WELDING

A. Application

A 100 General

101 This appendix applies to all fabrication involving shop-, site- or field welding including post weld heat treatment.

102 The materials covered by this appendix are:
   — C-Mn steel;
   — clad/lined steel; and
   — corrosion resistant alloys (CRA) including ferritic austenitic (duplex) steel, austenitic stainless steels, martensitic stainless steels ("13% Cr"), other stainless steels and nickel based alloys.

The materials are addressed with and without requirements for sour service. The material requirements are specified in Section 6 and Section 7.

A 200 Welding processes

201 Welding may be performed with the following processes unless otherwise specified:
   — Shielded Metal Arc Welding (SMAW / 111),
   — Flux Cored Arc Welding without gas shield (FCAW /114),
   — Flux Cored Arc Welding with external gas shield (GFCAW / 136),
   — Gas Metal Arc Welding (GMAW / 135),
   — Gas Tungsten Arc Welding (GTAW / 141),
   — Submerged Arc Welding (SAW / 12), and
   — Plasma Arc Welding (PAW / 15).

Guidance note:
GMAW and FCAW are regarded as methods with high potential for non-fusing type defects
---end of Guidance note---

202 Pre-qualification shall be performed to document that welds meeting all specified requirements under realistic field conditions can be consistently produced.

Pre-qualification testing is considered necessary for the following welding process:
   — resistance welding (high frequency welding),
   — flash butt welding,
   — friction welding,
   — radial friction welding,
   — electron beam welding, and
   — laser welding

203 Prior to qualification testing, general information of the welding procedure and possibly reference to practical experience and joint quality shall be documented. The extent and the content of the pre-qualification program shall be agreed before start up.

A 300 Quality Assurance

Requirements for Quality Assurance are given in Section 2B 500.

B. Welding Equipment, Tools and Personnel

B 100 Welding equipment and tools

101 Inspection of the workshop, site or vessel prior to start of production shall be required. This shall include verification of calibration and testing of all tools and welding equipment used during qualification/production welding.

B 200 Personnel

201 All personnel involved in welding related tasks shall have adequate qualifications and understanding of welding technology. The qualification level shall reflect the tasks and responsibilities of each person in order to obtain the specified quality level.

Welding co-ordinator

202 The Manufacturer organisation shall nominate at least one authorised welding co-ordinator in accordance with EN 719.

Welding operators, welders and air-arc gaugers

203 Through training and practise prior to qualification testing, the welding personnel shall have a understanding of:
   — fundamental welding techniques,
   — welding procedure specifications,
   — relevant methods for non-destructive testing, and
   — acceptance criteria.

204 Welders and welding operators shall be certified in accordance with EN 287, ISO 9606 or other relevant and recognised standards, for the respective positions, material grades and welding processes.

205 Qualification testing according to EN 1418 or equivalent is required for welding operators where their tasks are to preset, adjust, start, guide and stop the welding operation.

206 Welders shall be qualified for single side butt welding of pipes in the required principal position. Welders may be qualified for part of the weld, root, fillers or cap by agreement. Repair welders may be qualified for partial thickness repair on a representative test configuration provided only such weld repairs are made.

207 The qualification test shall be carried out with the same or equivalent equipment to be used during production welding, and should be at the actual premises, i.e. work shop, yard, and vessel. Use of other premises shall be specially agreed.

208 Qualification testing shall be based on 100% visual examination, 100% radiographic or ultrasonic testing, and 100% magnetic particle or liquid penetrant testing. Test requirements shall be in accordance with Appendix D, H.

209 When using processes which have high potential for non-fusing type defects, bend testing shall be performed. The number of bend tests is specified in Table C-1.

Table C-1 Number of bend tests required for welder qualification

<table>
<thead>
<tr>
<th>Pipe diameter(mm)</th>
<th>Wall Thickness (mm)</th>
<th>Face-bendtests</th>
<th>Root-bendtests</th>
<th>Side-bendtests</th>
</tr>
</thead>
<tbody>
<tr>
<td>D ≤ 100</td>
<td>t &lt; 0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>100 &lt; D ≤ 300</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>D &gt; 300</td>
<td>t ≥ 20</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D ≤ 100</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>100 &lt; D ≤ 300</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D &gt; 300</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: Face and root bend test specimens may be replaced by side bend specimens subject to agreement.

Sampling of test specimens is shown in Figure C-2.

210 A welder or welding operator who has produced a com-
C. Welding Consumables

C 100 General

101 Welding consumables shall be suitable for their intended application, giving a weld with the required properties and corrosion resistance in the finally installed condition.

102 Welding consumables for arc welding shall be classified according to recognized classification schemes.

103 Low hydrogen consumables and processes shall be used for welding of all C-Mn steels. However, cellulose coated electrodes may be used for welding C-Mn steels with SMYS ≤ 415 provided special welding procedures preventing hydrogen induced cracking are established.

104 Low hydrogen consumables shall give a diffusible hydrogen content of maximum 5 ml/100g weld metal. Hydrogen testing shall be performed in accordance with ISO 5690 or BS 6693-5.

105 Welding steels with SMYS ≥ 415 MPa shall be given special consideration in order to ensure safety against cold cracking in the HAZ and/or the weld metal. Attention shall also be given to the requirements for the relationship between the yield and tensile strength of weld metal and base material.

106 Welding consumables for processes other than manual or mechanised arc welding may require special consideration with respect to certification, handling and storage.

107 All welding consumables shall be individually marked and supplied with an inspection certificate type 3.1B according to EN 10204 or equivalent. Certificate type 2.2 is sufficient for SAW flux.

Data Sheet

108 Each welding consumables or combination of welding consumables shall be delivered in accordance with a data sheet. The data sheet shall give guaranteed limits and/or minimum values for composition and mechanical properties, determined under defined reference conditions. The data sheet should give recommendations for handling/recycling of the welding consumables in order to meet the any guaranteed maximum value for hydrogen in the weld metal. Recommendations for post weld heat treatment (maximum temperature, holding time, etc.) should also be provided.

Guidance note:
The Contractor responsible for the welding and the welding consumable Manufacturer should agree on the content and the specified limits in the data sheets.

---end---of---G-u-i-d-a-n-c-e---n-o-t-e---

C 200 Chemical composition

201 All welding consumables shall be delivered in accordance with Manufacturer's data sheets, which shall state the minimum and maximum levels of C, Mn, Si, P, S, micro-alloying elements and any other intentionally added elements.

202 When sour service is specified, the chemical composition of the welding consumables shall comply with NACE MR-0175. The Ni-content may be increased up to 2.2% in welding consumables for girth welds, provided that other requirements in EFC 16 are fulfilled, and that the welding procedure has been tested for resistance to SSC.

203 The selection of welding consumables shall be given special attention in order to avoid any types of preferential weld corrosion. This applies particularly to material with enhanced corrosion properties, and for selection of welding consumable for the root pass in systems for seawater service.

204 The chemical composition of the weld overlay materials shall comply with the material requirements specified for the applicable type of overlay material or with a project specification.

C 300 Mechanical properties

301 The weld metal shall, as a minimum, have strength, ductility and toughness meeting the requirements of the base material. The yield stress (Rt0.5) of welding consumables should be within the range 80 - 250 MPa above the SMYS of the respective base material.

302 For girth welds, all batches of consumables used in production including possible wire / flux combinations shall be qualified by testing according to C 400.

303 Welding consumables for welds in pipelines exposed to accumulated plastic strain from the installation method and/or operational loads requires special attention for selection of yield stress, see E 600 and Section 6D 300. The yield stress (Rt0.5) of welding consumables should be within the range 80 - 200 MPa above the SMYS of the respective base material. Response to straining and ageing shall meet the requirements of the base material when tested in accordance with E 600.

C 400 Batch testing – Girth welds

401 The purpose of batch testing is to verify that the consumables used for girth welds remain nominally equivalent to that used for welding procedure qualification, with respect to chemistry and mechanical properties.

402 Batch testing shall be conducted when ECA is performed and always for steels with SMYS ≥ 415MPa for all welding consumables, including possible wire/flux combinations when new batches other than the one used for welding procedure qualification is to be used for installation welding.

403 For this standard a batch is defined as the volume of product identified by the supplier under one unique batch number, manufactured in one continuous run from batch controlled raw materials.

404 Each individual product (brand name and dimensions) shall be tested once per batch, except for solid wire originating from the same heat, where one diameter may represent all. SAW fluxes do not require individual testing, however, SAW
wires shall be tested in combination with a selected, nominal batch of flux.  

405 The testing shall be performed on samples taken from girth welds welded according to the welding procedure to be used in production. Three samples shall be removed from the I2 and 6 o’clock position and from the 3 or 9 o’clock position. The testing of each sample shall include:

— 1 all-weld metal tensile test. Hardness testing (HV10) of the centre at the end of each grip;
— 1 macro section taken adjacent to the all-weld metal tensile test. The macro section shall be hardness tested (HV10) vertically through the weld centre line with indentations spaced 1.5mm apart;
— 1 set of Charpy V-notch test at weld centre line in half thickness. Test temperature shall be the same as for qualification of the relevant procedure; and
— If required due to ECA, fracture toughness testing shall be performed of the weld metal at the minimum design temperature.

Chemical analysis  

406 For solid wire and metal powders the analysis shall represent the product itself. For coated electrodes and cored wires, the analysis shall represent the weld metal, deposited according to EN 26847 (ISO 6847). The analysis shall include:

— all elements specified in the relevant classification standard and the relevant data sheet, see 201; and
— the N content.

Mechanical properties  

407 The properties shall represent all deposited weld metal. The mechanical properties shall meet the minimum specified requirements in 301. If an ECA is performed, the relevant mechanical properties of the weld metal shall meet the properties used as input in the ECA, considering any partial safety factors used.

408 Batch tests shall be documented by an inspection certificate EN 10204 3.1B, with reference to a recognised product qualification standard and containing all specified results.

C 500 Handling and storage of welding consumables  

501 Welding consumables shall be treated with care in order to avoid contamination, moisture pick-up and rusting, and shall be stored under dry conditions. Whenever recycling of flux is used, the flux shall be vacuum cleaned directly from the weld into a flux holding box. The recycling process and the ratio of new/recycled flux shall be suitable to prevent any detrimental degradation of the flux quality, e.g. moisture pick-up and change of grain size.

502 A detailed procedure for storage, handling, recycling and re-baking of welding consumables shall be prepared and, as a minimum, shall be in accordance with the Manufacturer's recommendation. The procedure shall be reviewed and agreed prior to start of the production.

503 For underwater welding, the storage and handling routines of welding consumables on the support vessel and in the welding chamber, as well as the sealing and transfer procedures to the welding chamber, shall be specified.

D. Welding Procedures  

D 100 General  

101 Detailed welding procedures shall be prepared for all welding covered by this Appendix. The welding procedures may be based on previously qualified welding procedures provided that all the specified requirements can be fulfilled.

102 All welding shall be based on welding consumables and welding techniques proven to be suitable for the type of material and type of fabrication in question. A welding procedure specification shall as a minimum contain the following information:

— material standard, quality level, grade and project specification;
— diameter and wall thickness (or range);
— groove preparation and design, including tolerances;
— welding process;
— number and location of welders;
— welding consumable, trade name and recognised classification;
— gas mixture and flow rate;
— welding rod / wire diameter;
— quantity of added metal powder or wire;
— welding parameters: current, voltage, type of current, polarity, travel speed, wire stick out and wire angle for each arc (or range);
— number of welding arcs as well as cold and hot wire addition;
— welding position(s) and direction;
— stringer or weaving;
— nozzle size;
— number of passes;
— number of passes before barge move-up;
— clamping (internal or external);
— maximum time laps between passes;
— minimum preheat and interpass temperature range; and

103 For underwater welding the welding procedure specification shall contain, in addition to D102:

— water depth (minimum/maximum),
— pressure inside the chamber,
— gas composition inside the chamber,
— humidity, maximum level,
— temperature inside the chamber (minimum/maximum),
— length, type and size of the welding umbilical,
— position for voltage measurements, and
— welding equipment.

D 200 Preliminary welding procedure specification  

201 A preliminary welding procedure specification (pWPS) shall be prepared for each new welding procedure qualification. The pWPS shall specify the ranges for all relevant parameters.

202 The pWPS shall be submitted for review and acceptance by the Purchaser prior to commencing the welding procedure qualification.

D 300 Welding procedure qualification record  

301 The welding procedure qualification record (WPQR) shall be a record of the parameters used during qualification welding and subsequent non-destructive, destructive and corrosion test results. The WPQR shall be submitted for review and agreement prior to start of production. However, the welding procedure qualification for linepipe production may be carried out during first day production on the Manufacturer(s) own risk.

D 400 Welding procedure specification  

401 A welding procedure specification (WPS) is a specification based on a WPQR and accepted in accordance with those requirements. The WPS is the pWPS revised to reflect the welding variables qualified by the WPQ. All production welding of pipeline and riser systems shall be performed in accordance with a WPS.
D 500  Welding procedure specification for repair welding

501 A repair welding procedure specification shall be prepared, based on a WPQR for the type of weld repair to be applied. A repair WPS shall contain the following information in addition to the information given under D100:

— method of removal of the defect, preparation and design of the weld area;
— minimum and maximum repair depth and length; and
— visual examination and NDT to be performed of the excavated area before welding as well as of the final weld repair.

D 600  Essential variables for welding procedures

601 A qualified welding procedure remains valid as long as the essential variables are kept within acceptable limits and production tests are performed regularly. When one or more variations outside the acceptable limits for essential variables occur, the welding procedure shall be considered invalid, and shall be re-specified and qualified.

602 The essential variables and the acceptable limits of variables shall be as described in 603 and 604 below. For special welding system processes, other essential parameters and acceptable variations may need to be applied.

603 An acceptance of a welding procedure of a particular manufacturer is valid for welding in workshops or sites under the same technical and quality control of that manufacturer.

The following changes shall lead to a new qualification:

Materials:

— A change from a lower to a higher strength grade but not vice versa;
— A change in the supply condition (TMCP, Q/T or normalised);
— A change between the processes rolled, forged or cast;
— Any increase in F_{cm} of more than 0.02, CE of more than 0.03 and C content of more than 0.02%;
— Any change in base material origin (steel mill) for steels with SMYS above 415 MPa.

Diameter: A change in diameter from one to another of the following ranges:

— D < 100 mm,
— 100 mm < D < 300 mm and
— D > 300 mm.

Thickness: A change outside the thickness interval 0.75 t to 1.5 t for t ≤ 30 mm, where t is the nominal thickness of the test joint, excluding the thickness of any corrosion resistant cladding. For t > 30 mm a change outside the thickness interval 0.75 t to 1.25 t.

Groove configuration: Any change in groove dimensions outside the tolerances specified in the agreed WPS.

Line-up clamps: Change from external to internal or vice versa.

Welding process: Any change.

Number of wires: Change from single-wire to multiple-wire system or vice versa.

Welding equipment:

— Any change in equipment type and model for mechanised welding;
— Any change in equipment type and model when semi-mechanised welding equipment (equipment with wire feeding for manual welding) is used for installation welding (including underwater welding).

Arc characteristics: Any changes affecting the transfer mode or deposit rate.

Welding consumable: Any change of type, classification, diameter and brand as well as addition or omission of powder, hot or cold wire.

Wire stick-out: Any change in stick-out outside the tolerances specified in the agreed WPS.

Gas shielding: A change outside (10% of specified mixture, nominal composition and nominal flow rate.

Welding position: A change to a principal position not being qualified according to Table C-2.

Welding direction: A change from vertical down to vertical up or vice versa.

Number of passes: Change from multipass to singlepass or vice versa.

Polarity: Any change.

Heat input:

— For steels with SMYS up to and including 415 MPa any change beyond (15%).
— For materials with SMYS above 415 MPa the heat input variations shall not be more than (±10% unless otherwise qualified.

Time lapse between root pass and first filler pass: Any delay significantly increasing the cold cracking risk in excess of that qualified.

Preheating: Any decrease in the minimum qualified temperature.

Interpass temperature: Any change beyond + 25°C of the maximum interpass temperature.

Cooling of welds: Any change in cooling method resulting in shorter cooling time than qualified (installation welding).

Post weld heat treatment: Any change from the qualified post weld heat treatment procedure.

Stringer/Weave: Stringer to weave more than three times the specified diameter.

Numbers of welders: Decrease in numbers of welders for root and hot pass.

<table>
<thead>
<tr>
<th>Test position</th>
<th>Applicable welding position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G (PA)</td>
<td>1G (PA)</td>
</tr>
<tr>
<td>2G (PC)</td>
<td>1G+2G (PA+PC)</td>
</tr>
<tr>
<td>5G (PF/PG)</td>
<td>1G+3G+5G (PA+PF/PG)</td>
</tr>
<tr>
<td>2G + 5G (PC+PF/PG)</td>
<td>All</td>
</tr>
<tr>
<td>6G (H-L045)</td>
<td>All</td>
</tr>
</tbody>
</table>

Note 1 qualification welding on butt joints may also be applicable for welding of fillet welds, e.g. 1G and 5G may also be applicable for 1F and 5F respectively.

604 The essential parameters for underwater welding are those specified above plus the following:

Pressure inside the chamber: Any change.

Gas composition inside the chamber: Any change.

Humidity: Any increase beyond + 10% RH of the maximum level during qualification.

E. Qualification of Welding Procedures

E 100 General

101 Qualification welding shall be performed based upon the accepted pWPS, using the type of welding equipment to be used during production welding, and under conditions that are representative of the actual working environment for the work.
shop, site, vessel or the habitat where the production welding will be performed (see D 200, D 300, D 400).

102 The number of test joints shall be sufficient to obtain the required number of specimens for the destructive tests specified. Allowance for re-testing should be considered when deciding the number of test joints to be welded.

103 The test joints for qualification welding shall be of sufficient size to give realistic restraint during welding.

104 The welding qualification test shall be representative for the production welding with respect to angle of pipe axis, interpass temperature, application of preheat, heat conduction, time between each layer, etc. The base material selected for the qualification testing should be representative of the upper range of the specified chemical composition for C-Mn steel, and of the nominal range of the specified chemical composition for corrosion resistant alloys. If tack welds are to be fused into the final joint during production welding, they shall be included when welding the test piece.

105 For qualification welding of procedures for linepipe or linepipe components containing longitudinal welds, attention should be paid to the requirement for obtaining a macro and hardness test specimen from the longitudinal weld, see note 2 in Fig. C-2 and note 8 in Table C-3. For all welding positions, except 1G (PA) and 2G (PC), it is recommended that one of the pipes used for the welding procedure qualification test be fixed with the longitudinal weld in the 6 or 12 o’clock position.

106 Fillet welds to pressure containing pipes or components may be qualified by a full penetration butt joint, provided that the essential variables in D 600 are applied.

107 Qualification of weld overlay shall be performed on a test sample which is representative for the size and thickness of the production base material. The minimum weld overlay thickness used for the production welding shall be used for the welding procedure qualification test.

108 Welds in pipelines exposed to accumulated plastic strain from the installation method and/or operational loads (see Section 6D 300), require additional testing for qualification of the girth weld welding procedures, see E 600 and Table C-4.

109 Each test weld shall be subject to 100% visual examination, radiographic testing, ultrasonic testing and surface crack detection. Test requirements shall be in accordance with Appendix D, H. Mechanical and corrosion testing as applicable for the type of material and welding in question shall be as specified in E 300 to E 700.

110 Except for installation and tie-in welding, previously qualified welding procedures may be transferred to a new production provided that they recently have been applied for production to the same or more stringent requirements. Successful application of such procedures shall be documented through recent, relevant tests.

E 200 Qualification of repair welding procedures

201 Repair welding shall be qualified by a separate weld repair qualification test. The scope of qualification testing shall be agreed based on the types and extent of repair welding applicable.

202 Preheat for repair welding shall be minimum 50°C above minimum specified preheat for production welding.

203 When a heat treated pipe or component is repaired by welding, a new suitable heat treatment may be required to be included in the qualification of the weld repair procedure, depending on the effect of the weld repair on the properties and microstructure of the existing weld and base material.

204 Extent of NDT, mechanical testing and corrosion testing (if applicable) shall be as for the production welding procedure qualification, but with additional impact testing in the HAZ between existing weld metal and repair weld. The number and location of the additional impact test sets shall be agreed on a case by case basis. Repair welding procedures shall meet the same requirements as the original weld. Full and half thickness repair shall be tested as a main procedure. For other repairs: macro, bend and hardness.

205 The qualification test shall be made on pipe nipples or pipe components in a manner realistically simulating the repair situation to be qualified, e.g.

— full and 1/2 thickness repair,
— shallow surface repair of the weld seam, and
— single pass repair.

The length of the pipe nipple or test material shall be sufficient to give realistic restraint.

206 Weld repairs performed from the inside of a single-sided joint shall be qualified separately, when internal weld repairs are agreed.

E 300 Qualification of longitudinal and spiral welds in linepipe and linepipe components

301 Pre-qualification testing is required for manufacturers with limited experience of fabrication of linepipe and linepipe components to the actual or similar specifications.

302 Welding shall be performed in accordance with a detailed pWPS or WPS as specified in D. The pWPS shall be qualified by NDT, mechanical testing and corrosion testing (if applicable).

303 The type and number of tests are given in Table C-3 with method and acceptance criteria specified in F below.

E 400 Qualification of girth welds in risers, expansion loops and pipe strings for towing

401 Pre-qualification testing is required for Contractors having limited experience with the actual type of fabrication to the actual or similar specification.

402 Qualification of welding procedures for risers, expansion loops and pipe strings for towing may be performed by any of the arc welding processes specified in A 200.

403 Mechanised welding systems where previous experience is limited, or where the system will be used under new conditions, shall be subject to a more extensive pre-qualification programme or documentation before they may be used. The extent and the contents of a pre-qualification programme for such mechanised welding systems shall be accepted by Purchaser. The Contractor shall prove and document that the welding systems are reliable and that the process can be continuously monitored and controlled.

404 The type and number of destructive tests for welding procedure qualification are given in Table C-4 with methods...
and acceptance criteria as specified in F below.

<table>
<thead>
<tr>
<th>Wall thickness (mm)</th>
<th>Transverse Weld Tensile</th>
<th>All-weld tensile</th>
<th>Root bend</th>
<th>Face bend</th>
<th>Side bend</th>
<th>Charpy V-notch set</th>
<th>Macro and hardness</th>
<th>Corrosion tests</th>
<th>Fracture toughness</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤20</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>.8</td>
<td>6 (9)</td>
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<tr>
<td>&gt;20</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>.8</td>
<td>6 (9)</td>
</tr>
</tbody>
</table>

**Notes**

1) For HFW pipes, the tensile specimen shall be located along the weld seam within the heat-treated area.
2) Two additional side bend specimens shall be tested for clad/lined pipe.
3) Each Charpy V-notch set consists of 3 specimens. Impact testing shall be carried out with the V-notch in the weld metal, in the fusion line (FL), in FL+1 mm and FL+5 mm. Impact testing is not required for t < 6 mm.
4) Where several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions, if the region tested cannot be considered representative for the complete weld.
5) For double sided welds on C-Mn steels with SMYS > 415 MPa, four additional sets of Charpy V-notch test specimens shall be sampled from the weld metal, FL (sampling 50% of HAZ), FL + 2 mm and FL + 5 mm in the root area, refer Fig. B-6 in Appendix B.
6) When the wall thickness exceeds 20 mm for single sided welds, two additional sets of Charpy V-notch test specimens shall be sampled from the weld metal root and FL in the root area.
7) For HFW pipes, impact testing shall be conducted with the Charpy V-notch located in the FL, FL+2 mm and in the Transformation Line (TL) (TL which has been formed during the local heat treatment subsequent to welding).
8) Requirements for corrosion tests and microstructure examination are specified in F and depend on service and the type of material.
9) Three base material and three weld metal specimens. Fracture toughness testing is not required for t < 13 mm.
10) For HFW pipes, the tensile specimen shall be located along the weld seam within the heat-treated area.
11) Bend tests on clad/lined pipes shall be performed as side bend tests.
12) Fracture toughness testing shall only be performed when required for Engineering Critical Assessment (ECA), see F.314. Extent of testing shall be in accordance with Appendix BA 800, unless specified otherwise.

**Table C-4 Qualification of welding procedures for girth welds**

<table>
<thead>
<tr>
<th>Wall thickness (mm)</th>
<th>Transverse Weld Tensile</th>
<th>All-weld tensile</th>
<th>Root bend</th>
<th>Face bend</th>
<th>Side bend</th>
<th>Charpy V-notch set</th>
<th>Macro and hardness</th>
<th>Corrosion tests</th>
<th>Fracture toughness</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤20</td>
<td>2</td>
<td>-</td>
<td>2 1)</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>.9</td>
<td>.9</td>
</tr>
<tr>
<td>&gt;20</td>
<td>2</td>
<td>2 (1)</td>
<td>4 1)</td>
<td>4 1)</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>.9</td>
<td>.9</td>
</tr>
</tbody>
</table>

**Notes**

1) For welding processes with high potential for non-fusing type defects, side bend tests shall be performed instead of root and face bend tests.
2) Impact testing is not required for t < 6 mm.
3) Each Charpy V-notch set consists of 3 specimens.
4) Impact testing shall be carried out with the V-notch in the weld metal, in the fusion line (FL), in FL+2 mm and FL+5 mm.
5) For double sided welds on C-Mn steels with SMYS > 415 MPa, four additional sets of Charpy V-notch test specimens shall be sampled from the weld metal, FL (sampling 50% of HAZ), FL + 2 mm and FL + 5 mm in the root area, refer Fig. B-6 in Appendix B.
6) When the wall thickness exceeds 20 mm for single sided welds, two additional sets of Charpy V-notch test specimens shall be sampled from the weld metal root and FL in the root area.
7) Where several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions, if the region tested cannot be considered representative for the complete weld.
8) For girth welds in welded pipe, one macro and hardness shall include a longitudinal pipe weld.
9) Requirements for corrosion tests and microstructure examination are specified in F, and depend on the service and type of material, see Section 6.
10) Bend tests on clad/lined pipes shall be performed as side bend tests.
11) Longitudinal bend tests are only applicable for clad/lined pipe.
12) Fracture toughness testing shall only be performed when required for Engineering Critical Assessment (ECA), see F.314. Extent of testing shall be in accordance with Appendix BA 800, unless specified otherwise.

**E 500 Qualification of girth welds for installation and tie-in**

**501 Installation, general**

**502 Pre-qualification testing is required for Contractors having limited experience with installation and tie-in welding to the agreed specification.**

**503 Qualification of welding procedures for installation and tie-in of pipelines systems and pipeline components may be performed by any of the arc welding processes specified in A200.**

**504 The WPS shall be qualified by NDT, mechanical testing and corrosion testing (if applicable) prior to start of any production welding.**

**505 The type and number of destructive tests for welding procedure qualification are given in Table C-4 with method and acceptance criteria as specified in F below. For welding in position 1G (PA) and 2G (PC), the number of mechanical tests may be reduced to half of what is specified in Table C-4 subject to acceptance by Purchaser.**
506 Mechanised welding systems where previous experience is limited or where the system will be used under new conditions will require a more extensive pre-qualification programme or documentation before they can be accepted for use. The extent and the contents of a pre-qualification programme for such mechanised welding systems shall be agreed upon before it is commenced. The Contractor shall prove and document to the Purchaser that the welding systems are reliable and that the process can be continuously monitored and controlled.

E 600 Qualification of girth welds exposed to accumulated plastic strain

601 Welds in pipelines exposed to accumulated plastic strain from the installation method and/or operational loads, see Section 6D 300. The weld metal and/or the HAZ may receive excessive plastic deformation caused by differences in the yield stress in the base material and weld metal and variations in wall thickness or diameter between the two pipe ends. To avoid local excessive strain concentrations and subsequent risk for strain ageing, the welding procedure shall demonstrate that the weld and the adjacent base material have as uniform mechanical properties as possible, and that the weld metal shows the same response to strain hardening and ageing as the pipe material.

Table C-5 Additional testing for qualification of welding procedures for girth welds exposed to accumulated plastic strain

<table>
<thead>
<tr>
<th>THE JOINT</th>
<th>NUMBER OF EACH SPECIFIED TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness (mm)</td>
<td>D (mm)</td>
</tr>
<tr>
<td>&lt;20</td>
<td>&lt;300</td>
</tr>
<tr>
<td>&gt;300</td>
<td>2</td>
</tr>
<tr>
<td>≥20</td>
<td>&lt;300</td>
</tr>
<tr>
<td>&gt;300</td>
<td>2</td>
</tr>
</tbody>
</table>

Notes:
1) The test specimens shall be sampled from 1 and 7 o'clock position.
2) All-weld tensile testing is not required for t < 10 mm.
3) The test samples shall be sampled as for pipes with OD > 300 mm (ref. Fig.C-2).
4) For girth welds in welded pipe, one macro and hardness test shall include a longitudinal pipe weld.
5) Impact testing is not required for t < 6 mm.
6) Each Charpy V-notch set consists of 3 specimens.
7) Impact testing shall be carried out with the V-notch in the weld metal, in the fusion line (FL), in FL+2 mm and FL+5 mm.
8) Where several welding processes or welding consumables are used, impact testing shall be carried out in the corresponding weld regions, if the region tested cannot be considered representative for the complete weld.
9) Extent of testing and details of the test procedure are subject to agreement.

Table C-6 Qualification of overlay welding procedures

<table>
<thead>
<tr>
<th>TEST JOINT</th>
<th>NUMBER OF EACH SPECIFIED TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness base material</td>
<td>Side-bend specimens 1)</td>
</tr>
<tr>
<td>All</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes:
1) Side-bend tests are to be taken transverse to the welding direction.
2) Only required when the design considers the overlay material to be load bearing.
3) Only required when the weld overlay is load bearing across the overlay/base material fusion line.
4) Each Charpy V-notch set consists of 3 specimens. Impact testing shall be carried out with the V-notch in the weld metal, in the fusion line (FL), in FL+2 mm and FL+5 mm.
5) Only when required by F 600.

E 700 Qualification of underwater welding for tie-in

701 The qualification test program shall consist of a minimum of one completed joint for manual welding, and a minimum of three joints for mechanised welding systems. The qualification test shall consist of a minimum of three joints for mechanised welding systems.

602 Documentation from mechanical testing of plastically deformed and straightened welds shall be provided. This documentation shall be relevant with respect to the type and strength of the base material, degree of plastic deformation, time between each deformation cycle, type of welding consumable, welding parameters and the mechanical properties of the weld. Special considerations shall be given to laying operations with long time or high temperature between the different deformation cycles, which may cause ageing to take place before subsequent deformation of the pipe.

603 For welding procedure qualification additional material testing shall be performed on material samples, including the girth weld, that have successively been deformed by uni-axial tension and compression and artificially aged as specified in Section 6D 300, prior to visual examination and non-destructive testing.

604 The type and number of additional destructive tests for welding procedure qualification is given in Table C-5 with acceptance criteria specified in Section 6D 300 and F below.

605 The number of test joints shall be sufficient to cover the required number of destructive tests that have been specified. Allowance for re-testing should be considered when deciding the number of test joints to be plastically deformed and straightened.
The qualification program may be extended in cases where the underwater welding will occur under conditions where previous experience is limited, or will be undertaken by a company with limited experience in this field.

If a welding procedure is to be used over a large range of depths, it may, subject to special evaluation in each case, require qualification testing at one or several pressures.

Voltage and amperage of the welding circuits should preferably be continuously monitored at the arc. If voltage is measured at the power source, calibration should be performed taking into consideration the type, lengths and cross section areas of the welding cables.

Overlay welding shall be performed with GTAW or pulsed GMAW. Other methods may be used subject to agreement. The WPS shall be qualified by NDT, mechanical testing and corrosion testing (if applicable) prior to start any production welding.

The type and number of destructive tests for welding procedure qualification are given in Table C-2 with method and acceptance criteria specified in F below.

Unless the production welding procedure can be applied, the repair welding procedure shall be qualified. Weld repair performed on weld overlay machined to the final thickness shall be separately qualified.

Welding procedures for structural components, supplied as a part of the pipeline systems, shall be qualified in accordance with EN 288-3. The requirements shall be appropriate for the structural categorisation of the members and stresses in the structure. The extent of tensile, hardness and impact testing and the test temperatures shall in general be in compliance with this standard.

All visual examination, non-destructive testing, mechanical testing and corrosion testing of test pieces shall be performed in the as welded or post weld heat treated condition, whatever is applicable for the final product.

Each test joint shall undergo 100% visual examination and non-destructive testing as specified in Section 6, Section 7 and Section 9, as applicable, with acceptance criteria as required for the production welding.

Weld overlay shall be non-destructively tested with a surface and weld thickness which is representative for the production welding, i.e. after machining the overlay thickness to 3 mm or the thickness representative for the thickness on the finished component.

The type and number of mechanical tests and microstructure evaluations for qualification tests are given in Table C-3 to Table C-6. Sampling of test specimens is shown in Fig. C-1 and Fig. C-2 for longitudinal welds in linepipes and linepipe components and girth welds respectively.

Test specimen dimensions and methods for testing are given in Appendix B.

If test results are influenced by improper sampling, machining, preparation, treatment or testing, then the test sample and specimen (as relevant) shall be replaced by a correctly prepared sample or specimen and a re-test may be performed.

A test failing to meet the specified requirements may be re-tested. The reason for the failure shall be investigated and reported before any re-testing is performed. The re-testing shall consist of two further test specimens/sets of test specimens. If both re-tests meet the requirements, the test should be regarded as acceptable. All test results, including the failed tests, shall be reported.

The ultimate tensile strength of the joint shall be at least equal to the specified ultimate tensile strength for the base material. When different material grades are joined, the ultimate tensile strength of the joint shall be at least equal to the minimum specified tensile strength of the lower grade.

The ultimate tensile strength of the joint shall be at least equal to the specified ultimate tensile strength for the base material. When different material grades are joined, the ultimate tensile strength of the joint shall be at least equal to the minimum specified tensile strength of the lower grade.

Figure C-1 Welding procedure qualification test - sampling of test specimens for longitudinal welds, manufacture of linepipes or linepipe components
The upper yield or the \( R_{0.5} \) and the tensile strength shall not be less than those specified for the weld metal (see C 300) and the elongation shall not be less than that specified for the base material. When different material grades are joined, the acceptance level of the weld metal shall be at least equal to the minimum specified strength of the lower grade.

Note 1: The indicated location of the test specimens are not required for qualification of welding in the 1G (PA) and 2G (PC) positions, where sampling positions are optional.

Note 2: For welded pipe, one macro and hardness shall include a longitudinal pipe weld.

**Figure C-2 Welding procedure qualification test - girth welds, sampling of test specimens**

*All-weld tensile testing*

306 The upper yield or the \( R_{0.5} \) and the tensile strength shall not be less than those specified for the weld metal (see C 300) and the elongation shall not be less than that specified for the base material. When different material grades are joined, the acceptance level of the weld metal shall be at least equal to the minimum specified strength of the lower grade.
**Bend testing**

307 The guided bend tests shall not disclose any open defects in any direction exceeding 3 mm. Minor ductile tears less than 6 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

**Longitudinal root bend testing on clad/lined pipes**

308 The guided bend tests shall not disclose any open defects in any direction exceeding 3 mm. Minor ductile tears less than 6 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

**Charpy V-notch impact testing**

309 The average and single Charpy V-notch toughness at each position shall not be less than specified for the base material in the transverse direction (KVT values), see Table 6-3, Table 6-4, Table 6-6. Any requirement for fracture arrest properties as listed in shall not apply for the weld and HAZ.

310 When different steel grades are joined, a series of impact tests shall be performed in the HAZ on each side of the joint. The weld metal shall meet the more stringent energy requirement.

**Macro section**

311 The macro section shall be documented by photographs (magnification of at least 5x).

312 The macro section shall show a sound weld merging smoothly into the base material without weld defects according to the visual examination and NDT acceptance criteria in Appendix D.

**Hardness testing**

313 The maximum hardness shall not exceed the limits given in Section 6C 200, Section 6C 300, and Section 6D 100 as applicable for the intended service and type of material tested.

**Fracture toughness testing**

314 Fracture toughness shall not be less than specified for the base material and weld in Section 6C. For girth welds fracture toughness testing shall only be performed when required for Engineering Critical Assessment (ECA), see Section 9E. Extent of testing shall be in accordance with Appendix BA 800.

**Testing of girth welds exposed to accumulated plastic strain**

315 The girth weld shall be plastically deformed and aged in accordance with E 600. The mechanical testing specified by Table C-1 shall meet the requirements in Section 6C 300. The difference in values obtained for the yield stress of base material and weld metal should be within a range of 100 MPa.

**F 400 Sulphide stress cracking test**

401 Sulphide stress cracking testing is to be performed to qualify materials not meeting the requirements for sour service according to Section 6D 100. Testing procedures are specified in Appendix BB 400

**F 500 Corrosion Testing and Microstructure Examination**

**Corrosion test**

501 25 Cr duplex stainless steel shall be subject to pitting corrosion test. Testing procedures are specified in Appendix BB 200, and the acceptance criteria are given in Section 6C 300.

**Microstructure examination:**

502 Welds in duplex stainless steel shall have the microstructure examined in accordance with Section 6C 300.

503 Clad/lined steel pipes shall have the microstructure of the corrosion resistant portion of the weld examined in accordance with Section 6C 500.

504 Other CRA’s shall have the microstructure examined in accordance with Section 6C 400.

**F 600 Testing of weld overlay**

601 When the weld overlay is not contributing to strength, tensile testing and Charpy V-notch testing of the weld overlay material are not required. When the weld overlay strength is considered as a part of the design, such mechanical testing of the weld overlay material is required.

602 The base material shall retain the minimum specified mechanical properties after any post weld heat treatment. The base material properties in the post weld heat treated condition shall then be documented by additional testing and recorded as a part of the welding procedure qualification.

603 The testing in 604 through 607 shall, as a minimum, be performed when the overlay material is not considered as part of the design and when the base material has not been affected by any post weld heat treatment.

**Bend testing of weld overlay**

604 The bend testing shall be performed in accordance with Appendix B A 500. The guided bend tests shall disclose no defects exceeding 3 mm. Minor ductile tears less than 6 mm, originating at the specimen edge may be disregarded if not associated with obvious defects.

**Macro examination of weld overlay**

605 The macro sections shall be documented by micrographs. The macro section shall show a sound weld merging smoothly into the base material without weld defects according to the visual examination and NDT acceptance criteria in Appendix D.

**Hardness testing of weld overlay**

606 The maximum hardness for base material and HAZ shall not exceed the limits given in Section 6 C 200, Section 6 C 300, Section 6 C500, Section 6 D 100 as applicable for the intended service and type of material. The maximum hardness for the overlay material shall not exceed the limits given in NACE MR-0175 for sour service, unless otherwise specified.

**Chemical analysis of weld overlay**

607 The chemical composition shall be obtained in accordance with Appendix B A 300. The location for the chemical analysis shall be considered as the minimum qualified thickness to be left after any machining of the corrosion resistant weld overlay. The chemical composition of the weld deposit metal shall comply with the applicable specification for the type of alloy specified for the overlay material.

**All-weld tensile testing of load bearing weld overlay**

608 All-weld tensile testing shall be performed in accordance with Appendix B A 400.

609 The yield stress and ultimate tensile strength of the weld deposit shall be at least equal to the material strength used in the design.

**Charpy V-notch impact testing of load bearing weld overlay**

610 When the weld overlay material is designed to transfer the load across the base material/weld overlay fusion line, impact testing of the weld overlay and HAZ shall be performed (i.e. when the overlay is a part of a butt joint or acts as a transition between a corrosion resistant alloy and a carbon steel).

611 The average and single Charpy V-notch toughness at each position shall not be less than specified for the base material. When different steel grades are joined, a series of impact tests shall be considered in the HAZ on each side of the joint. The weld metal shall meet the more stringent energy requirement.

**Corrosion testing and microstructure examination of weld overlay**

DET NORSKE VERITAS
handling. Prior to restart after an interruption, preheating to the sufficient strength to avoid plastic yielding and cracking during welding shall not be interrupted before the joint has suf-ficent flaws in order to cause minimum distortion of the pipeline or components.

203 Longitudinal welds shall be staggered at least 50 mm and should be located in the upper half of the linepipe if possible.

204 The minimum preheat temperature shall be measured at a distance of minimum 75 mm from the edges of the groove at the opposite side of the heating source when practically possible. If not possible. The adequacy of the measuring at the outside only shall be demonstrated.

205 The interpass temperature shall be measured at the edge of the groove immediately prior to starting the following pass.

206 Number of welders and the weld sequence shall be selected in order to cause minimum distortion of the pipeline or the components.

207 Line-up clamps should not be removed before the first two passes are completed. The release of line-up clamp shall be qualified and simulated during WPQ. When tack welds are necessary for alignment, these shall only be made in the weld groove if qualified in the welding procedures. Defective tack welds shall be completely removed.

208 Start and stop points shall be distributed over a length of weld and not "stacked" in the same area.

209 Welding shall not be interrupted before the joint has sufficient strength to avoid plastic yielding and cracking during handling. Prior to restart after an interruption, preheating to the minimum interpass temperature of the pass in question shall be applied.

210 Supports, attachments, lifting devices etc. used for permanent positioning of risers and pipelines shall be welded to a doubler ring or plate. Doubler rings for temporary use should be clamped. Welding of temporary attachments shall be subject to agreements.

211 Permanent doubler rings and plates shall be made of materials satisfying the requirements for pressure containing parts. Doubler rings shall be made as fully encircling sleeves with the longitudinal welds made with backing strips, and avoiding penetration into the main pipe material. Other welds shall be continuous, and made in a manner minimising the risk of root cracking and lamellar tearing.

212 Transitions where the material thickness or yield stress is unequal shall be in accordance with ASME B 31.8 Appendix I or equally recognised codes.

213 Field bevelling shall preferably be by means of beveling machines.

214 After cutting of linepipe or plate material for new bevel preparation, a new lamination check by ultrasonic and magnetic particle/dye penetrant testing shall be performed.

215 Maximum root gap for fillet welds should be 2 mm. Where the root gap is > 2 mm but ≤ 5 mm, this shall be compensated by increasing the throat thickness on the fillet weld by 0.7 mm for each mm beyond 2 mm gap. Welding of fillet welds with root gap > 5 mm is subject to repair based on an agreed procedure.

G. Fabrication and Welding Requirements

G 100 General

101 All welding shall be performed using the type of welding equipment and under the conditions that are representative for the working environment during procedure qualification welding (see E.101). Pre-qualification testing shall be performed for welding systems where the Contractor has limited previous experience, or where the system will be used under new conditions. All welding equipment shall be maintained in good condition in order to ensure the quality of the weldment.

102 All welding shall be performed under controlled conditions with adequate protection from detrimental environmental influence such as humidity, dust, draught and large temperature variations.

103 All instruments shall have valid calibration certificates and the adequacy of any control software shall be documented.

G 200 Production welding

201 All welding shall be carried out strictly in accordance with the accepted welding procedure specification and the requirements in this subsection. If any parameter is changed out-side the limits of the essential variables, the welding procedure shall be re-specified and re-qualified. Essential variables and variation limits are specified in D 600.

202 The weld bevel shall be free from moisture, oil, grease, rust, carbonised material, coating etc., which may affect the weld quality. Welding of CRAs or clad/lined materials require cleaning of internal and external surface of the pipe up to a distance of at least 20 mm from the bevels.

203 Longitudinal welds shall be staggered at least 50 mm and should be located in the upper half of the linepipe if possible.

204 The minimum preheat temperature shall be measured at a distance of minimum 75 mm from the edges of the groove at the opposite side of the heating source when practically possible. If not possible. The adequacy of the measuring at the outside only shall be demonstrated.

205 The interpass temperature shall be measured at the edge of the groove immediately prior to starting the following pass.

206 Number of welders and the weld sequence shall be selected in order to cause minimum distortion of the pipeline or the components.

207 Line-up clamps should not be removed before the first two passes are completed. The release of line-up clamp shall be qualified and simulated during WPQ. When tack welds are necessary for alignment, these shall only be made in the weld groove if qualified in the welding procedures. Defective tack welds shall be completely removed.

208 Start and stop points shall be distributed over a length of weld and not "stacked" in the same area.

209 Welding shall not be interrupted before the joint has sufficient strength to avoid plastic yielding and cracking during handling. Prior to restart after an interruption, preheating to the minimum interpass temperature of the pass in question shall be applied.
Long defects may require repair in several steps to avoid resistance of welded joints against sulphide stress cracking, this shall be performed for all thicknesses.

Post weld heat treatment shall be carried out at 580°C to 620°C unless otherwise recommended by the steel Manufacturer or the welding consumables Manufacturer. For quenched and tempered material, the post weld heat treatment temperature shall as a minimum be 25°C below the tempering temperature of the base material.

Heating, soaking and cooling shall be performed in a controlled manner according to an approved procedure. The soaking time shall be 2 minutes/mm, but with minimum soaking time 1 hour. Where local heat treatment is performed, the specified temperature shall be maintained in a band extending at least 3 times the wall thickness on each side of the weld. The temperature at the edge of the insulation band shall be maximum half the soaking temperature. When the temperature at all parts has dropped below 300°C, the joint may be cooled in still air.

The heat treatment temperature cycle shall be available for verification if requested.

G 500  Welding of linepipe and linepipe components

The Manufacturer shall be capable of producing welded linepipe and linepipe components of the required quality.

Welds containing defects may be locally repaired by welding. Weld deposit having unacceptable mechanical properties shall be completely removed before re-welding.

Testing during production of linepipe shall be performed according to Section 6E 800.

Production tests should be required during the production of linepipe components. The tests shall be performed in a manner which, as far as possible, reproduces the actual welding, and covers the welding of a sufficient large test piece in the relevant position. Production welds, cut out due to NDT failure, may be used.

G 600  Fabrication of risers, expansion loops, pipe strings for towing.

The Contractor shall be capable of producing welded joints meeting the required quality. This may include welding of girth welds, overlay welding and post weld heat treatment of the components. Relevant documentation of the Contractor's capabilities shall be available if requested by the Purchaser.

Production tests should be required during the production Section 9A 900. The tests shall be performed in a manner which, as far as possible, reproduces the actual welding and covers the welding of a sufficient large test piece in the relevant position. Production welds cut out due to NDT failure, may be used.

When production testing is required, the same number of tests as specified in E 400 (and Table C-5 when applicable) shall be carried out.

Testing of the test weld shall be performed immediately after welding. The number of mechanical tests is half that required for welding procedure qualification. Provided that the same welding habitat, equipment and welding procedures are used consecutively on the same pipeline under comparative conditions, further confirmation test welds are not required.

Welding cables shall be of the same dimension and approximately the same length (e.g. ± 5%) as those used during the welding procedure qualification test. Use of artificial resistance to simulate the actual cable dimension and length may be used, if this is agreed.

All relevant welding parameters shall be monitored and recorded at the surface control station under supervision by a video system that can be remotely controlled from the control station.

H. Material and Process Specific Requirements

H 100  Internally clad/lined carbon steel

Production welding

Welding of the corrosion resistant cladding portion may be performed by the welding processes listed in A 200, except Flux Core Arc Welding without gas shield (FCAW / 114). The welding shall be double sided whenever possible. Welding of the root pass in single sided (field) joints will generally require welding with Gas Tungsten Arc Welding (GTAW / 141) or Gas Metal Arc Welding (GMAW / 135).

The final weld bevel preparation shall be made by machining or grinding. The grinding wheels used for the corrosion resistant cladding material shall not have previously been used for carbon steel. Thermal cutting shall be limited to plasma arc cutting.

Stainless steel wire brushes shall be used for interpass cleaning of the corrosion resistant weld metal and clad/lined material.

All operations during welding of the pipeline system shall be carried out with adequate equipment and/or in a protected environment to avoid carbon steel contamination of the corrosion resistant material. Procedures for examination of
surfaces and removal of any contamination shall be prepared.

Welding consumables

105 Welding consumables for corrosion resistant materials shall be selected to suit the cladding/lining material. The corrosion resistance of the welding consumable shall be better than that of the cladding/lining material. For single sided (field) joints, the same type of welding consumable should be used for all passes needed to complete the joint. Alternative welding consumables may be considered for fill and capping passes after depositing a weld thickness not less than 2 times thickness of the cladding/lining. The alternative welding consumables must be documented to be compatible with the welding consumables used for the root area, the base material and the applicable service. Any effect on the probability for detecting weld defects by the applicable NDT procedures is also to be considered. Extent of testing and documentation shall be agreed before commence of qualification testing.

H 200 Duplex stainless steel

Production welding

201 Welding of 22 Cr / 25 Cr duplex stainless steel may be performed by the welding processes listed in A 200, except for Flux Cored Arc Welding without gas shield (FCAW / 114). Welding of root pass in single sided joints will generally require welding with Gas Tungsten Arc Welding (GTAW / 141).

202 Thermal cutting shall be limited to plasma arc cutting.

203 Fabrication of duplex stainless steel shall be performed in a workshop, or part thereof, which is reserved exclusively for this type of material. Grinding wheels and steel brushes shall be suitable for working on duplex stainless steel and not previously used for carbon steel.

204 The heat input should be kept within the range 0.5 - 1.5 kJ/mm, avoiding the highest heat input for smaller wall thicknesses.

205 In case of a second weld repair, a separate welding procedure qualification shall be performed.

Welding consumables

206 Welding consumables with enhanced nickel and nitrogen content shall be used unless full heat treatment after welding is performed. Sufficient addition of material from the welding consumables is essential for welding of the root pass and the two subsequent passes.

Backing or shielding gases shall not contain hydrogen. The oxygen content of the backing gas shall be less than 0.1% during welding of the root pass.

H 300 Martensitic (13% Cr) stainless steel

Production welding

301 Welding of martensitic stainless steel may be performed by the welding processes listed in A 200, except for Flux Cored Arc Welding without gas shield (FCAW / 114). Welding of root pass in single sided joints will normally require welding with Gas Tungsten Arc Welding (GTAW / 141).

302 Thermal cutting shall be limited to plasma arc cutting.

303 Fabrication of martensitic stainless steel shall be performed in a workshop or part thereof, which is reserved exclusively for this type of material. Grinding wheels and steel brushes shall be suitable for martensitic stainless steels and shall not previously have been used on carbon steel materials.

Post weld heat treatment

304 A suitable post weld heat treatment may be performed if sour service is required.
APPENDIX D
NON-DESTRUCTIVE TESTING (NDT)

A. General

A 100 Scope

101 This Appendix specifies the requirements for methods, equipment, procedures, acceptance criteria, and the qualification and certification of personnel for visual examination and non-destructive testing (NDT) of C-Mn steels, duplex steels, other stainless steels and clad steel materials and weldments for use in pipeline systems.

102 This Appendix does not cover automated ultrasonic testing (AUT) of girth welds. Specific requirements pertaining to AUT of girth welds are given in Appendix E. Appendix E shall be read and interpreted in conjunction with this Appendix.

103 Requirements for NDT and visual examination of other materials shall be specified and shall be in general agreement with the requirements of this Appendix.

A 200 Codes and standards

201 The following codes and standards are referred to in this Appendix:

- **ASME** Boiler and Pressure Vessel Code, Section V, Article 2 and Article 5.
- **ISO 1106-3** Recommended practice for radiographic examination of welded joints Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness
- **ISO 2504** Radiography of welds and viewing conditions for films - Utilisation of recommended patterns of image quality indicators (I.Q.I.)
- **ISO 5579** Non-destructive testing - Radiographic examination of metallic materials by X- and gamma rays - Basic rules
- **ISO 5580** Non-destructive testing - Industrial radiographic illuminators - Minimum requirements.
- **ISO 9002** Quality Systems, Model for Quality Assurance in Production, Installation and Servicing.
- **ISO 9303** Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes - Full peripheral ultrasonic testing for the detection of longitudinal imperfections
- **ISO 9304** Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes - Eddy current testing for the detection of imperfections
- **ISO 9305** Seamless tubes for pressure purposes - Full peripheral ultrasonic testing for the detection of transverse imperfections
- **ISO 9402** Seamless and welded (except submerged arc welded) steel tubes for pressure purposes - Full peripheral magnetic transducer/flux leakage testing of ferromagnetic steel tubes for the detection of longitudinal imperfections
- **ISO 9598** Seamless steel tubes for pressure purposes - Full peripheral magnetic transducer/flux leakage testing of ferromagnetic steel tubes for the detection of transverse imperfections
- **ISO 9765** Submerged arc-welded steel tubes for pressure purposes - Ultrasonic testing of the weld seam for the detection of longitudinal and/or transverse imperfections
- **ISO 10124** Seamless and welded (except submerged arc-welded) steel tubes for pressure purposes - Ultrasonic testing for the detection of laminar imperfections
- **ISO 10543** Steel tubes for pressure purposes - Full peripheral magnetic transducer/flux leakage testing of ferromagnetic steel tubes for the detection of transverse imperfections
- **ISO 1106-1** Recommended practice for radiographic examination of welded joints Part 1: Fusion welded butt joints in steel plates up to 50 mm thick
- **ISO 1106-2** Recommended practice for radiographic examination of welded joints Part 2: Fusion welded butt joints in steel plates thicker than 50 mm and up to and including 200 mm in thickness
- **ISO 11484** Non-destructive testing - Qualification and certification of non-destructive testing (NDT) personnel
- **ISO 11496** Seamless and welded steel tubes for pressure purposes - Ultrasonic testing of the weld seam for the detection of laminar imperfections
- **ISO 12084** Seamless and hot-stretch reduced welded steel tubes for pressure purposes - Full peripheral ultrasonic thickness testing
- **ISO 12093** Welded steel tubes for pressure purposes - Ultrasonic testing for the detection of laminar imperfections in strips or plates used in manufacture of welded tubes
- **ISO 12094** Welded steel tubes for pressure purposes - Ultrasonic testing of tube ends for the detection of laminar imperfections
- **ISO 12095** Seamless and welded steel tubes for pressure purposes - Liquid penetrant testing
- **ISO 13663** Welded steel tubes for pressure purposes - Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections

A 709 Standard Guide for Magnetic Particle Examination.


E 1444 Standard Practice for Magnetic Particle Examination.

E 1417 Standard Practice for Liquid Penetrant Examination.

D 10543 Classification Note No. 7: Ultrasonic Inspection of Welded Joints.

EN 473 Qualification and certification of NDT personnel - General principles.

EN 1711* Non-Destructive Examination of Welds: Eddy Current Examination by Complex Plane Analysis.

EN 12084* Eddy Current testing - General Principles of the Method.

ISO 1027 Radiographic image quality indicators for non-destructive testing - Principles and identification.

ISO 1106-1 Recommended practice for radiographic examination of welded joints Part 1: Fusion welded butt joints in steel plates up to 50 mm thick.

ISO 1106-2 Recommended practice for radiographic examination of welded joints Part 2: Fusion welded butt joints in steel plates thicker than
ISO 13664 Seamless and welded steel tubes for pressure purposes - Magnetic particle inspection of tube ends for the detection of laminar imperfections
ISO 13665 Seamless and welded steel tubes for pressure purposes - Magnetic particle inspection of tube body for the detection of surface imperfections

Unless final approval of the EN's, reference is made to the corresponding prEN's.

A 300 Quality Assurance

301 NDT Contractors shall as a minimum have an implemented quality assurance system meeting the general requirements of ISO 9002 and supplemented with the requirements given in ASTM E 1212.

302 Further requirements for quality assurance are given in Section 2B 500.

A 400 Non-destructive testing methods

401 Methods of NDT shall be chosen with due regard to the conditions influencing the sensitivity of the methods. The methods' ability to detect imperfections shall be considered for the material, joint geometry and welding process used.

402 As the NDT methods differ in their limitations and/or sensitivities, combination of two or more methods may be required in order to ensure optimum probability of detection of harmful defects.

403 For detection of surface imperfections in ferromagnetic materials, magnetic particle or eddy current testing shall be preferred. For detection of surface imperfections in non-magnetic materials, either dye penetrant testing or eddy current testing shall be preferred.

404 For detection of internal imperfections either ultrasonic and/or radiographic testing shall be used. It may be necessary to supplement ultrasonic testing by radiographic testing or vice versa, in order to enhance the probability of detection or characterisation/sizing of flaws.

Radiographic testing is preferred for detection of volumetric imperfections. For material thicknesses above 25 mm radiographic testing should be supplemented by ultrasonic testing.

Ultrasonic testing is preferred for detection of planar imperfections. Whenever determination of the imperfection height and depth is necessary, e.g. as a result of an ECA, ultrasonic testing is required.

405 Alternative methods or combination of methods for detection of imperfections may be used provided that the methods are demonstrated as capable of detecting imperfections with an acceptable equivalence to the preferred methods.

A 500 Non-destructive testing procedures

501 Non-destructive testing shall be performed in accordance with written procedures that, as a minimum, give information on the following aspects:
  — applicable code(s) or standard(s),
  — welding method (when relevant),
  — joint geometry and dimensions,
  — material(s),
  — method,
  — technique,
  — equipment, main and auxiliary,
  — consumables (including brand name),
  — sensitivity,
  — calibration techniques and calibration references,
  — testing parameters and variables,
  — assessment of imperfections,
  — reporting and documentation of results,
  — reference to applicable welding procedure(s), and — acceptance criteria.

502 If alternative methods or combinations of methods are used for detection of imperfections, the procedures shall be prepared in accordance with an agreed code or standard. The need for procedure qualification shall be considered in each case based on the method's sensitivity in detecting characterising imperfections and the size and type of defects to be detected.

503 Non-destructive testing procedures shall be signed by the responsible Level 3 person.

A 600 Personnel qualifications

601 Personnel performing manual or semi-automatic NDT and interpretation of test results shall be certified according to a certification scheme which meets the requirements of EN 473 (Qualification and certification of NDT personnel-General principles) and shall possess a valid certificate of proficiency. The certificate shall state the qualification level and categories for which the operator is certified.

602 Personnel calibrating and interpreting results from automated equipment for NDT shall be certified to an appropriate level according to a certification scheme meeting the requirements of EN 473. In addition, they shall be able to document adequate training and experience with the equipment in question, and shall be able to demonstrate their capabilities with regard to calibrating the equipment, performing an operational test under production/site/field conditions, and evaluating size and location of imperfections.

603 Personnel operating automated equipment for NDT during manufacture of linepipe shall be certified according to ISO 51484 or equivalent certification scheme.

604 Preparation of NDT procedures and execution of all NDT shall be carried out under the responsibility of Level 3 personnel and shall be performed by personnel holding at least Level 2 qualifications. Personnel holding Level 1 qualifications may carry out NDT under the direct supervision of Level 2 personnel.

605 Personnel performing visual examination shall have documented training and qualifications according to NS477, EWE Welding Inspector, or equivalent.

606 Personnel interpreting radiographs, performing ultrasonic testing, interpreting results of magnetic particle and liquid penetrant testing and performing visual examination shall have passed a visual acuity test, such as Jaeger J-2, within the previous 12 months.

A 700 Reporting

701 All NDT shall be documented such that the tested areas may be easily identified and such that the performed testing can be duplicated. The reports shall identify the defects present in the weld area and state if the weld satisfies the acceptance criteria or not.

A 800 Timing of NDT

801 Whenever possible, NDT of welds shall not be performed until 24 hours has elapsed since completion of welding.

802 If welding processes ensuring a diffusible hydrogen content of maximum 5ml/100g of weld metal are used, adequate handling of welding consumables is verified, shielding gas content of H₂ is controlled, or measures (such as post heating of the weldments) are taken to reduce the contents of hydrogen, the time in 801 above can be reduced.

803 Cellulose electrodes may be used for the root and hot pass of C-Mn steel with SMYS less than 415 MPa provided the heat input from subsequent welding passes reduces the hydrogen content sufficiently to prevent hydrogen induced cracking. See Appendix C 103.
B. Manual Non-destructive Testing and Visual Examination of Welds

B 100 General

101 Manual non-destructive testing of welds shall be performed as required in the following and in general compliance with these standards:

Radiography

Ultrasonic
- ASME Boiler and Pressure Vessel Code, Section V, Article 5.
- DNV Classification Note No. 7- Ultrasonic Inspection of Welded joints.
- ASTM E 1417.
- ASTM E 309.

B 200 Radiographic testing

201 Radiographic testing shall be performed by use of X-ray according to agreed procedures. Use of radiographic isotopes (gamma rays) may be required in some situations and is subject to agreement in each case.

202 Radiographic testing procedures shall contain the information in A 500 and:
- radiation source;
- technique;
- geometric relationships;
- film type;
- intensifying screens;
- exposure conditions;
- processing;
- Image Quality Indicator sensitivities in percent of the wall thickness, based on source and film side indicators respectively;
- backscatter detection method;
- density;
- film side Image Quality Indicator identification method;
- film coverage; and
- weld identification system.

203 Film and intensifying screen classification shall be according to ISO 5579.

For X-ray exposure, fine-grained film in combination with lead screens shall be preferred. For gamma ray exposure, ultra fine grained film and lead intensifying screens shall be used.

204 Image Quality Indicators (IQI) according to document ISO 1027 and of required number shall be used. The IQIs shall be clearly identifiable. Subject to agreement, other types of IQIs providing the same accuracy of information regarding sensitivity of radiographs, may be used.

205 Each radiographic procedure and the consumables used shall be qualified by making radiographic exposures of a welded joint with the same or typical configuration and dimensions, and of material equivalent to that which shall be used.

The IQIs shall be placed in line with the same or typical configuration and dimensions, shall be qualified by making radiographic exposures of a weld joint with the same or typical configuration and dimensions, and of material equivalent to that which shall be used.

206 The sensitivities obtained by both IQIs during procedure qualification shall be recorded and the sensitivity of the source side IQI is at least to meet the requirement shown in Fig. D-1.

(Sensitivity requirements for material thickness < 10 mm shall be agreed in each case)

207 IQIs shall whenever possible be placed on the source side during exposure. If the IQIs must be placed on the film side during production radiography this shall be indicated by projecting the letter F onto the film. The sensitivity of the film side IQI from the procedure qualification shall be used as acceptance criterion.

208 Exposed radiographs shall have an average H & D density at the sound weld metal image of minimum 2.0. The maximum density allowed shall be according to the capabilities of the available viewing equipment, but not more than 4.0.

209 Evaluation of radiographs shall be performed under conditions satisfying the requirements of ISO 2504 and ISO 5580. Radiographs from the radiographic procedure qualification shall be available as reference at the place where evaluation of production radiography is performed.

210 Processing and storage shall be such that the films maintain their quality for a minimum of 5 years without deterioration. Thiosulphate tests shall be performed at regular intervals. If film storage time in excess of 5 years is required, the radiographs should be digitised using methods giving adequate resolution and stored in electronic media in an agreed manner.

B 300 Manual ultrasonic testing

301 Ultrasonic testing shall be performed according to agreed procedures.

302 Ultrasonic testing procedures shall contain the information in A 500 and:
- type of instrument;
- type and dimensions of probes;
- range of probe frequencies;
- description of reference block;
- calibration details, range and sensitivity;
- surface requirements, including maximum temperature;
- type of coupling medium;
- scanning techniques supplemented with sketches, showing the probes used and area covered; and
- recording details.

303 No special procedure qualification test shall be required when manual methods are used. The procedure shall be subject to agreement.

304 Manual ultrasonic testing equipment shall:
- be applicable for the pulse echo technique and for the double probe technique;
- cover as a minimum the frequency range from 2 to 6 MHz;
305 Ultrasonic equipment, including probes, shall have calibration pertaining to the characteristics of the equipment. The characteristics of cables shall be known and documented.

306 Calibration of the ultrasonic equipment shall be carried out whenever it has been out of function for any reason including on/off, and whenever there is any doubt concerning proper functioning of the equipment.

307 The IIW/ISO calibration block (ISO 2400) shall be used for calibration of range and for angle determination.

308 For testing of welds reference blocks shall be used for gain calibration and construction of the reference curves. The reference block shall be manufactured from the actual material to be examined. Reference blocks manufactured from other materials may be acceptable provided that the material is documented to have acoustic properties similar to the actual material to be examined (e.g. the maximum variation in refracted angle should be less than 1.5°). The reference block shall have length and width dimensions suitable for the sound beam path for all probe types and the material dimension(s) to be tested.

For testing of pipes, girth welds and similar geometries a reference block with side drilled holes shall be used. The thickness of the reference block, diameter and position of the drilled holes shall be as shown in Fig. D-2 and Table D-1.

**Fig. D-2. Reference block dimensions**

<table>
<thead>
<tr>
<th>Material thickness (t) mm</th>
<th>Thickness of reference block (T) mm</th>
<th>Position of side drilled hole</th>
<th>Diameter of side drilled hole mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>t &lt; 25 mm</td>
<td>20 or t</td>
<td>1/4 T &amp; 1/2 T &amp; 3/4 T</td>
<td>3.0</td>
</tr>
<tr>
<td>25 mm ≤ t ≤ 50 mm</td>
<td>38 or t</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>50 mm ≤ t ≤ 100 mm</td>
<td>75 or t</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>100 mm ≤ t ≤ 150 mm</td>
<td>125 or t</td>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

309 For testing of longitudinal welds in pipe and similar geometries the reference block shall be used in addition to the features required in 308, have a curvature equal to the pipe to be tested. The reference reflectors shall be radially drilled holes as detailed in G 800.

310 Calibration of ultrasonic equipment shall be undertaken in accordance with those procedures documented in DNV Classification Note No. 7. Other methods of calibration according to a recognised code or standard may be agreed.

311 For evaluation of indications a reference curve (DAC curve) shall be established using 3 points. The curve shall be plotted on the instrument screen, unless the equipment is equipped with software capable of constructing user-defined DAC curves.

312 For ultrasonic testing the contact surface shall be clean and smooth, i.e. free from dirt, scale, rust, welding spatter, etc. which may influence the result of the testing. Correction for differences in surface conditions and attenuation between the reference block and the actual work piece shall be performed using the double probe technique. The maximum correction allowed on flat surfaces is 6 dB.

313 Welds shall wherever possible be tested from both sides. If testing from one side only must be performed, a refined testing technique shall be employed to ensure detection of defects. The testing shall include the area adjacent to the weld for laminations. The testing technique shall be performed using the double probe technique. The maximum correction allowed on flat surfaces is 6 dB.

314 For flaw detection the corrected primary gain may be increased by maximum 6 dB. Defect size evaluation shall not be performed at this increased gain level.

315 The indications shall be investigated by maximising the echoes by rotating the probes and by using different angle probes with DAC curves established according to 312. All indications exceeding 20% of the reference curve shall be investigated with and all indications exceeding 50% shall be reported. Investigation shall be performed to the extent that the operator can determine the shape and location of the indication. For dimensional evaluation, either the “6 dB-drop” method or time of flight or maximum amplitude method shall be used.

**B 400 Manual magnetic particle testing**

401 Magnetic particle testing shall be performed according to agreed procedures.

402 Magnetic particle testing procedures shall contain the information in A 500 and:

- type of magnetisation;
- type of equipment;
- surface preparation;
- wet or dry method;
- make and type of magnetic particles and contrast paint;
- magnetising current (for prod magnetising, the prod type and spacing shall be stated);
- demagnetisation; and
- description of the testing technique.

403 No special procedure qualification tests should be required. The procedure shall be subject to agreement.

404 The equipment shall establish a field strength between 2.4 kA/m (30 Oe) and 4.0 kA/m (50 Oe) for probes. The equipment shall be tested at maximum 6 months interval to verify that the required field strength is established at the maximum leg spread/prod spacing to be used. The results shall be recorded.

405 Prods shall be soft tipped with lead or similar. Sparks between the prods and the material tested shall be avoided.

406 Electromagnetic AC yokes shall develop a minimum field strength of 20 kA/m (300 Oe) for yokes and 25 kA/m (350 Oe) for AC magnetic pole pieces. Prods shall be soft tipped with lead or similar. Sparks between the prods and the material tested shall be avoided.
shall be checked prior to start of any testing and at regular intervals during testing.

407 Use of permanent magnets is not permitted. DC yokes may only be used for specific applications if required by national regulations.

408 The surface to be tested shall be clean and dry, free from dirt i.e. paint, grease, oil, lint, scale, welding flux etc. which may interfere with the testing.

409 Testing using fluorescent wet magnetic particles should be the preferred method.

410 If non-fluorescent wet or dry particles are used they shall provide adequate contrast with the background or the surface being tested.

411 To ensure detection of discontinuities having axes in any direction, the testing of each area shall be performed with the direction of the magnetic field in at least two directions approximately perpendicular to each other, and with sufficient overlap to cover the area to be tested.

412 Testing with fluorescent magnetic particles shall be conducted in a darkened area with maximum 20 lux background light, using filtered ultraviolet light with wave lengths in the range of 3200 to 3800 Å. Operators/interpreters shall allow sufficient time for eyesight to adjust to the dark surroundings. Interpreters shall not wear photo-chromatic viewing aids.

413 Magnetic particle testing shall not be performed on parts with surface temperatures exceeding 300°C. Between 60°C and 300°C, only dry magnetic particle testing shall be used.

B 500 Manual liquid penetrant testing

501 Liquid penetrant testing shall be performed according to agreed procedures and shall only be used on non-ferromagnetic materials or materials with great variation in magnetic permeability, unless otherwise agreed.

502 Liquid penetrant testing procedures shall contain the information in A 500 and:
- surface preparation;
- make and type of penetrant, remover, emulsifier and developer;
- details of pre-testing cleaning and drying, including materials used and time allowed for drying;
- details of penetrant application: the time the penetrant remains on the surface, the temperature of the surface and penetrant during the testing (if not within the 15°C to 35°C range);
- details of developer application, and developing time before evaluation; and
- method for post-test cleaning.

503 When the temperature of the surface and the penetrant is within the range 15°C to 35°C, no special procedure qualification tests should be required. The procedure shall be subject to agreement.

Outside the temperature range 15°C to 35°C, the procedure shall be qualified and a suitable comparator block shall be used to compare indications from surface defects tested within and outside the range during the procedure qualification.

B 600 Manual eddy current testing

601 Eddy current testing shall be performed according to EN 12084 and EN 1711 and accepted procedures.

602 Eddy current testing procedures shall contain the information in A 500 and:
- type of instrument,
- type of probe,
- frequency setting,
- calibration details,
- surface condition requirements,
- scanning details, and
- recording details.

603 In general no special procedure qualification test is required when manual methods are used. The procedure is considered qualified based on agreed testing procedure specifications.

604 Manual eddy current testing equipment shall have:
- single or dual frequency,
- frequency range to include 1000Hz to 1MHz,
- gain/noise, a 1mm deep artificial defect shall be indicated as a full screen deflection through a coating thickness corresponding to the maximum expected on the structure to be tested. Further, a 0.5 mm deep artificial defect shall be indicated through the same coating thickness with a minimum noise/signal ratio of 1 to 3;
- the evaluation mode shall be a complex plane display,
- as a minimum, the signal display shall be in the x-y mode with storage facility. The trace shall be clearly visible as well under daylight as under dark conditions, and
- the phase control shall be able to give complete rotation in steps of no more than 10° each.

605 Eddy current probes for measuring thickness of coating shall be capable of providing a full screen deflection lift-off signal on the instrument when moved from an uncoated spot on the reference block to a stop covered with the maximum coating thickness expected on the structure to be tested. The probe shall be clearly marked with its operating frequency range.

606 Eddy current probes for weld examination shall be optimised for examination of welds of the actual type to be tested. Such probes shall be able to operate when covered by a thin layer of non-metallic wear-resistant material over the active face. If used with such a cover, it shall always be mounted during calibration as well.

607 A standard reference block of the same material as the test component shall be used. It shall have narrow slots of 0.5, 1.0 and 2.0 mm depth. Tolerance of the slot depth shall be ±0.1 mm. Recommended width of slots shall be 0.1mm but acceptable up to 20% of the maximum depth (= 0.4 mm). All slots shall have the same width in the same block.

The standard reference block shall have length, width and thickness dimensions and slot positions, distances and lengths depending on probes to be used such that calibrations can be made without interference between slots or with edges.

608 Eddy current equipment, including probes and cables, shall have calibration certification pertaining to the characteristics of the equipment.

609 Calibration of the eddy current equipment shall be carried out whenever it has been out of function for any reason including on/off, and whenever there is any doubt concerning proper functioning of the equipment.

610 Surface conditions - excess weld spatter, scale, rust and loose paint can influence sensitivity by separating the probe from the test object and shall be removed before the inspection.

611 The weld surface and the heat-affected zones shall be scanned with the chosen probe(s) in a raster like scan. As far as the geometry of the test object permits it, the probe shall be moved in a direction perpendicular to the main direction of the expected defect. As least two probe runs shall be carried out perpendicular to each other. For differential coil types, the sensitivity for defect detection is also dependent on the coil orientation. Therefore care shall be taken that this is also controlled during examination.

612 All indications exceeding 50% signal amplitude from a 2.0mm deep slot in the reference block and all crack like indications shall be reported with information about the location of...
the defect, approximate length of the defect and maximum signal amplitudes unless otherwise agreed with Purchaser.

B 700 Visual examination

701 Visual examination shall be carried out in a sufficiently illuminated area, (approximately 500 lx). A sufficient amount of tools, gauges, measuring equipment and other devices shall be available at the place of examination.

C. Manual Non-destructive testing of Base Materials and Weld Overlay

C 100 General

101 All non-destructive testing of base materials shall be done according to agreed procedures as required in A 500, B 200, B 300, B 400, B 500 and B 600.

102 Manual non-destructive testing of base material, welds and weld overlay shall be done on general compliance with the requirements given in subsection B and the referenced standards.

103 Acceptance criteria for manual non-destructive testing of base material and weld overlay are given in subsection I.

C 200 Plate and pipe

201 These requirements are not applicable for plate and strip covered by subsection F or linepipe covered by subsection G.

202 Manual ultrasonic thickness measurements shall be done on accordance with ASTM E 797 or equivalent standard.

203 Manual ultrasonic testing for detection of laminar flaws in C-Mn, ferritic-austenitic (duplex), other stainless steels and nickel based corrosion resistant alloys (CRA) shall be done in accordance with ISO 12094 or equivalent standard.

204 Manual ultrasonic testing for detection of laminar flaws in clad/lined steel shall be done in accordance with ASTM A 578/578M or equivalent standard.

205 Manual ultrasonic testing for detection of flaws other than laminar, shall be done on accordance with ASTM A 577/577M or equivalent standard using a rectangular notch.

206 Manual magnetic particle testing of plate, strip and pipe edges shall be done in accordance with ASTM E 709, ASTM E 1444 or equivalent standard.

207 Manual liquid penetrant testing of plate, strip and pipe edges shall be done in accordance with ASTM E 1417 or equivalent standard.

208 Manual eddy current testing of plate, strip and pipe edges shall be done in accordance with ASTM E 309 or equivalent standard.

C 300 Forgings

301 Manual ultrasonic testing of forgings shall be done according to ASTM A 388/ASTM A 388/M or equivalent standard. For angle beam testing of duplex or austenitic steel forgings longitudinal wave angle beam probes should be used.

Straight beam examination

302 The flat bottom holes shall be 3 mm ø flat bottom holes at 3 depths through the thickness. One hole shall have a metal depth of 5 mm, one hole shall be at mid thickness and one hole shall have a metal depth equal to the thickness – 5 mm. A DAC curve shall be established using the different holes.

Angle beam examination

303 The DAC curve shall be established using rectangular OD and ID notches with a depth of 3% of the thickness.

304 Reference blocks shall be material from the actual forgings and in the same heat treatment condition.

305 Manual magnetic particle testing of forgings shall be done in accordance with ASTM E 709, ASTM E 1444 or equivalent standard.

306 Manual liquid penetrant testing of forgings shall be done in accordance with ASTM E 1417 or equivalent standard.

C 400 Castings

401 Manual ultrasonic testing of castings shall be done according to ASTM A 609 using the flat bottom hole calibration procedure with 3 mm ø flat bottom holes and the supplementary requirement S1 with basic reference hole of 3 mm ø. Equivalent standard may be used.

Straight beam examination

The flat bottom holes shall be 3 mm ø flat bottom holes at 3 depths through the thickness. One hole shall have a metal depth of 10 mm, one hole shall be at mid thickness and one hole shall have a metal depth of the thickness – 10 mm.

402 Radiographic testing of castings shall be done according to ASME, section 5, article 2 or equivalent standard.

403 Radiographic procedures shall in addition to the requirements of B 202 give the following information:

— shooting sketches,
— coverage,
— source location,
— location of IQI, and
— acceptance criteria

404 Manual magnetic particle testing of castings shall be done in accordance with ASTM E 709, ASTM E 1444 or equivalent standard.

405 Manual liquid penetrant testing of castings shall be done in accordance with ASTM E 1417 or equivalent standard.

C 500 Weld overlay

501 NDT and visual examination on magnetic weld overlay deposits shall be performed as 100% visual examination and 100% magnetic particle testing.

502 NDT and visual examination on non-magnetic weld overlay deposits shall be performed as 100% visual examination and as 100% liquid penetrant or eddy current testing on non-magnetic weld deposits.

D. Automated Non-Destructive Testing

D 100 General

101 These requirements are applicable to all automated NDT processes except automated ultrasonic testing of girth welds where specific requirements are given in Appendix E. The requirements given in this subsection are additional to the requirements of any code or standard where automated NDT methods are prescribed or optional.

102 The performance automated NDT equipment shall be documented by statistical records. Items subject to documentation include:

— brief functional description of the equipment;
— detailed equipment description;
— operation manual including type and frequency of functional checks;
— calibration;
— limitations of the equipment with regard to material or weld features including size, geometry, type of flaws, surface finish, material composition etc.; and
— repeatability.

103 Equipment shall have documentation of calibration per-
formed within the previous 6 months.

D 200 Automated ultrasonic testing

201 Specific requirements for automated ultrasonic testing (AUT) of girth welds are given in Appendix E.

202 The requirements herein are additional to D 100 above and are applicable to all automated ultrasonic testing other than automated ultrasonic testing of girth welds.

203 Requirements to the calibration of equipment, reference blocks and equipment set-ups are given in subsections F and G for each specific application.

The configuration of automated ultrasonic testing equipment shall be described and documented with regard to:

- reference to code, standard or guideline used for design and operation of the equipment,
- number and type of probes with description,
- function of scanning device,
- ultrasonic instrument, number of channels and data acquisition,
- recording and processing of data,
- reference blocks,
- couplant,
- couplant monitoring method,
- temperature range for testing and limitations,
- coverage achieved,
- maximum scanning velocity and direction,
- documentation of method for calibration and sensitivity settings, and
- reporting of recordable indications.

204 The equipment shall incorporate continuously operating systems for:

- weld seam centring (if applicable),
- alarm for loss of return signal (loss of coupling),
- alarm for serious malfunctions of the equipment,
- alarm or recording for indications exceeding the trigger or alarm level, and
- marking or indication of areas where indications exceed the trigger or alarm level.

205 The type and number of ultrasonic probes shall be sufficient to ensure that the base material, or the weld and the area adjacent to the weld, is:

- scanned from both sides of the weld for flaws oriented parallel to the longitudinal weld axis,
- scanned from both directions approximately parallel to longitudinal weld axis for flaws oriented transverse to the longitudinal weld axis,
- fully covered by ultrasound beams that are approximately perpendicular to the surface of flaws that are reflecting the ultrasound.

It may be necessary to include tandem, TOFD and/or focused probes in order to enhance the probability of detection or characterisation of flaws.

206 For equipment using multiplexing, the scanning velocity shall be selectable. The scanning velocity shall be set low enough so that the length between the activation of each probe (spatial resolution) is sufficiently short, i.e. the distance the probe travels while inactive, shall be significantly less than the maximum length of allowable imperfections. The scanning velocity $V_C$ shall be determined according to:

$$V_C \leq \frac{W_C \cdot PRF}{3}$$

Where $W_C$ is the narrowest -6dB beam width at the appropriate distance of all probes within the array and PRF is the effective pulse repetition frequency per probe.

207 For calibration of the equipment, one or more special reference blocks shall be prepared and used. These blocks shall be identical to the pipe or part of pipe to be tested with regard to material, acoustic properties, surface finish, diameter and thickness. For welded pipe the reference block shall contain a typical production weld.

208 The reference block shall contain artificial reflectors representing potential defects, and to verify positioning accuracy.

209 Other types of reflectors may be necessary for determining the detection capabilities of the equipment and for specific applications.

210 The reference block shall be of a size allowing dynamic checks with the same velocity and under the same conditions as during production testing.

211 The dimensional accuracy of the reference block shall be documented.

212 Reference blocks and calibration of the equipment shall be as required in subsections F and G.

213 Procedures for automated ultrasonic testing shall as a minimum contain the following information:

- functional description of equipment;
- reference standards and guidelines;
- instructions for scanning device, ultrasonic electronics, hardware and software for recording, processing, display or presentation and storage of indications;
- equipment configuration: number of probes, types, coverage;
- description of the probe operating mode(s), probe angles and probe firing sequence;
- sketches showing the area covered by each probe indicated by the beam centre and lines showing -2dB, -3dB and -6dB;
- equipment settings;
- static calibration method, gate and sensitivity settings;
- dynamic check acceptance criteria;
- identification of test starting point and indication of length tested;
- method for scanner alignment and maintenance of alignment;
- allowed temperature range;
- coupling and coupling control;
- probe and overall functional checks;
- surface condition and preparation;
- description of testing work;
- interpretation of results;
- acceptance criteria;
- reporting; and
- example of recorder charts.

E. Non-Destructive Testing Acceptance Criteria

E 100 General

101 Acceptance criteria for NDT applicable to pipeline systems or parts thereof are given in:

- subsection F for plate and strip,
- subsection G for pipe steel,
- subsection H for Pipeline girth welds were the accumulated strain resulting from the installation and operation will not exceed 0.3%, when all strain concentration factors (SNCF) are included, and
- subsection 1 for base materials, pipeline components, equipment and structural items (including castings and forgings).

102 Acceptance criteria for pipeline girth welds where the
accumulated strain resulting from installation and operation is above 0.3% but will not exceed 2.0%, shall be established by an ECA (see E 200).

The ECA shall determine the fracture toughness values required to tolerate the defects permitted in subsection H. Alternatively can "fitness for purpose" type acceptance criteria be established based on fracture toughness values actually achieved.

103 Acceptance criteria for pipeline girth welds where the accumulated strain resulting from installation and operation is above 2.0%, shall be established based on an ECA (see E 200), and validated by testing according to the requirements of Section 9E.

104 For some welding methods an unambiguous correlation can be established between variation in welding parameters and occurrence of defects. For such methods the acceptance criteria given in this Appendix may, subject to special consideration and agreement, in part be substituted by welding parameter records showing a variation within acceptable limits. Such substitution shall be based on a comprehensive documentation of the correlation.

Verification of the validity of the correlation by conventional, relevant NDT methods shall be performed during the entire period the method is in use. The extent and type of NDT used for the verification and the associated acceptance criteria, shall be agreed in each case.

105 The method(s) of NDT and acceptance criteria for materials other than steel shall be agreed in each case.

E 200 Acceptance criteria based on Engineering Critical Assessment (ECA)

201 Whenever acceptance criteria for NDT are established by an ECA, the ECA shall be performed in accordance with the requirements given in 202 through 206.

202 The ECA shall be performed as required in Section 5D 1100. If acceptance criteria for weld defects are based on an ECA, ultrasonic testing or automated ultrasonic testing shall be performed.

204 The ultrasonic testing uncertainty data used in the ECA shall be appropriate for the applied ultrasonic testing equipment and procedures used for the detection and assessment of flaws of concern in the material and weld geometries in question.

205 If automated ultrasonic testing (AUT) is used for testing of or pipeline girth welds, the data used in the ECA shall be derived from the qualification testing of the automated ultrasonic testing system required in Appendix E.

The uncertainty data from this qualification testing shall be statistically treated to establish the flaw sizing error that gives a 95% confidence level against undersizing of flaws.

The maximum allowable flaw sizes from the ECA shall be reduced in length and height with a flaw sizing error, that based on the data from the qualification testing will give a 95% confidence against under sizing of flaws.

206 For manual ultrasonic testing the data used in the ECA for quantitative estimates of ultrasonic testing uncertainty, performance and reliability are preferably be of the "measured response versus actual flaw size" type. The estimates shall be based on published results from comprehensive studies into the reliability of manual ultrasonic testing.

207 The approach outlined above may also be used to justify exceeding the acceptance criteria referred to in 101.

F. Non-Destructive Testing of Plate and Strip at Mill

F 100 General

101 The type and extent of non-destructive testing during manufacture of plate and strip shall be:

— 100% ultrasonic testing of plate and strip for laminar imperfections,
— 100% ultrasonic testing of clad plate for laminar imperfections and lack of bonding.

102 The ultrasonic testing shall include testing of the four edges of plate/strip over a width extending at least 50mm inside the location of future welding preparations. A suitable allowance in the area width shall be made to cover possible oversized plates and later edge milling and end bevelling.

103 If NDT of the body of line pipe is performed at the pipe mill, ultrasonic testing of plate and strip for laminar imperfections may, subject to agreement, be omitted at the plate and strip mill.

104 The acceptance criteria given in this subsection are generally valid unless other acceptance criteria are specified in accordance with relevant clauses of subsection E.

105 Equipment and procedures used for the ultrasonic testing shall comply with the requirements of subsection D. The requirements for automated NDT processes given in subsection D are additional to the requirements of any code or standard referred to in this subsection where automated NDT methods are prescribed or optional.

F 200 Ultrasonic testing of C-Mn and duplex steel plate and strip

201 Ultrasonic testing of the plate or strip body for laminar imperfections shall be in accordance with ISO 12094 amended as follows:

— the distance between adjacent scanning tracks shall ensure 100% coverage of the plate body and all four edges and be sufficiently small to ensure detection of the minimum allowed imperfection size, and
— for plate nominal thicknesses ≥ 40 mm the recess depth in the reference standard/test piece shall be increased in order to place the bottom of the recess between ¼ and ½ of the nominal plate thickness.

202 Acceptance criteria for ultrasonic testing of C-Mn and duplex steel plate and strip are given in Table D-2.

203 Subject to agreement the acceptance criteria for the body of plate and strip can limited to an allowed permitted area of 100 mm² and a population density of 5 with the minimum imperfection size area 30 mm², length and width 5mm. All other requirements in Table D-2 shall apply.

<table>
<thead>
<tr>
<th>Table D-2 Ultrasonic testing of C-Mn and duplex steel plate and strip, acceptance criteria</th>
<th>Acceptance criteria plate and strip body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service</td>
<td>Maximumal lowed imperfection</td>
</tr>
<tr>
<td>Non-sour</td>
<td>Area: 1000mm²</td>
</tr>
<tr>
<td>Sour</td>
<td>Area: 500mm²</td>
</tr>
</tbody>
</table>

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### Table D-2 Ultrasonic testing of C-Mn and duplex steel plate and strip, acceptance criteria

<table>
<thead>
<tr>
<th>Service</th>
<th>Acceptance criteria for plate and strip edges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimal allowance imperfection</td>
</tr>
<tr>
<td>All</td>
<td>Area: 100mm²</td>
</tr>
<tr>
<td></td>
<td>Width: 6mm</td>
</tr>
</tbody>
</table>

### Notes:
1. Two or more adjacent imperfections shall be considered as one imperfection if they are separated by less than the largest dimension of the smallest indication.
2. The population density shall be the number of imperfections smaller than the maximum and greater than the minimum imperfection size.
3. The reference area shall be:
   - 1000mm x 1000mm for non-sour service
   - 500mm x 500mm for sour service
   - The reference area for plate/strip when the plate/strip width is less than the maximum and greater than the minimum imperfection size
   - 0.25m² for sour service
   - 1000mm length for the edge areas
4. The width of an imperfection is the dimension transverse to the edge of the plate/strip

### F 300 Ultrasonic testing of clad plate and strip

#### 301
For ultrasonic testing of the base material the requirements of F 100 and F 200 shall apply.

#### 302
Ultrasonic testing for the detection of lack of bond between the base material and cladding material in the body of plate and strip, shall be performed in accordance with ASTM A578, S7.

#### 303
Acceptance criteria are:
- ASTM A578, S7. In addition, no areas with laminations or lack of bond are allowed in the plate edge areas.

### F 400 Visual examination of plate and strip

#### 401
Visual examination and acceptance criteria shall be according to Section 6 E 504.

### G. Non-Destructive Testing of Linepipe at Pipe Mills

#### G 100 General

#### 101
The extent of non-destructive testing during manufacture of linepipe shall be as required in Section 6, Table 6-13.

#### 102
The types of testing required in Section 6, Table 6-13 are defined as:
- Ultrasonic testing
- Surface imperfection testing
- Radiographic testing

Whenever the choice of methods for non-destructive testing is optional, this is indicated in this subsection.

#### 103
The requirements for automated NDT processes given in subsection D are additional to the requirements of any code or standard referred to in this subsection where automated NDT methods are prescribed or optional.

#### 104
The acceptance criteria given in this subsection are valid unless other acceptance criteria are specified in accordance with relevant clauses of subsection E.

### G 200 Untested pipe ends

#### 201
When automated non-destructive testing equipment is used, a short area at both pipe ends cannot normally be tested. The untested ends may either be cut off or the ends subjected to manual or semi-automatic NDT by the same or alternative method with an appropriate technique and using test parameters that will achieve at least the same sensitivity.

### G 300 Suspect pipe

#### 301
In all cases when a pipe inspection results in automated non-destructive testing equipment signals equal to or greater than the trigger or alarm level, the pipe shall be deemed suspect.

Suspect pipe can be dealt with according to one of the following options:
- the pipe can be scrapped,
- the suspect area can be cropped off.

If the suspect area is cropped, then all NDT requirements pertaining to pipe ends shall be performed on the new pipe end.

#### 302
Alternatively, the suspect area of the pipe may be re-tested by a different and appropriate test method supplemented by the original method, with a different technique using test parameters which give the same sensitivity as used during the original test, and using the same acceptance level.

Pipes passing these tests are deemed acceptable.

#### 303
Pipes may be repaired provided the provisions of Section 6 E 1000 are fulfilled.

#### 304
Re-inspection of repair welds shall be 100% visual examination and 100% manual radiographic and ultrasonic testing.

Testing shall be performed in accordance with G 800. Acceptance criteria shall be in accordance with G 800.

### G 400 Non-destructive testing applicable to all pipe

#### 401
Ultrasonic testing of the ultimate 50 mm from each pipe end for detection of laminar imperfections in C-Mn and duplex steel shall be in accordance with ISO 11496. The 50mm band shall be measured from the future weld preparation and an allowance shall be made for later end bevelling. Manual ultrasonic testing, semi-automated or automated equipment may be used. For welded pipe the reinforcement of the longitudinal weld shall be removed so that it does not interfere with the testing.

The acceptance criterion is:
- According to requirements to plate and strip edges in Table D-2 for non-sour or sour service.

#### 402
Ultrasonic testing of the ultimate 50 mm from each pipe end for detection of laminar imperfections in of clad/lined pipe shall be in accordance with ASTM A578/578M, S7. The 50mm shall be measured from the future weld preparation and an allowance shall be made for later end bevelling.

The acceptance criterion is:
- no areas with laminations or lack of bond are allowed in the plate edge areas.
Guidance note:
The ultimate length from each pipe end may, subject to agree-
ment be increased to 100mm to allow field re-bevelling of pipe.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

403 Magnetic particle testing or eddy current testing of the end face or bevel of each pipe in ferromagnetic steel for the de-
tection of laminar imperfections shall be performed in accordance with:
— ISO 13664 and B 400 for magnetic particle testing
— B 600 for eddy current testing

The acceptance criterion is:
— imperfections longer than 6 mm in the circumferential di-
rection are not permitted.

404 Liquid penetrant or eddy current testing of the end face
or bevel of each pipe in non-ferromagnetic steel for the detec-
tion of laminar imperfections shall be performed in accordance with
— ISO 12095 and B500 for liquid penetrant testing
— B 600 for eddy current testing

The acceptance criterion is:
— imperfections longer than 6 mm in the circumferential di-
rection are not permitted.

405 Residual magnetism at pipe ends in the direction parallel
to the pipe axis shall be measured with a calibrated Hall effect
gauss meter or equivalent equipment. The residual magnetism
is not to exceed 3mT (30 Gauss). Some welding methods may
require a more stringent acceptance criterion.

G 500 Non-destructive testing of seamless pipe

501 The extent of NDT shall be according to Section 6, Ta-
ble 6-13.

502 For pipes in duplex steel, it shall be demonstrated that
the presence of any possible coarse, anisotropic zones will not
impede the testing.

Ultrasonic testing for laminar imperfections in pipe body

503 Ultrasonic testing for the detection of laminar imperfec-
tions in pipe body shall be performed in accordance with ISO
10124 amended as follows:
— the distance between adjacent scanning tracks shall ensure
100% coverage of the pipe body and be sufficiently small
to ensure detection of the minimum allowed imperfection
size;
— a sample pipe shall be fitted with one 3.0 mm Ø through
drilled hole at each end. The distance from the pipe end to
the hole shall be equal to the length not covered by the ul-
trasonic testing equipment during production testing. Prior
to start of production the pipe shall be passed through the
ultrasonic testing equipment at the operational scanning
velocity. For acceptance of the equipment both holes need
to be detected by all probes. At the manufactures option
these holes may be included in the reference block.

The acceptance criteria are:
— According to requirements to plate and strip body in Table
D-2 for non-sour or sour service.

Guidance note:
Acceptance criteria for laminations in the pipe body according to
F.203 may apply, subject to agreement

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Ultrasonic thickness testing

504 Full peripheral ultrasonic thickness testing shall be per-
formed in accordance with ISO 10543. The minimum area
coverage shall be not less than 25% of the pipe surface.

The acceptance criterion is:
— The specified minimum and maximum thickness shall be
met.

Ultrasonic testing for longitudinal imperfections in pipe body

505 Ultrasonic testing for the detection of longitudinal im-
perfections in the pipe body shall be performed in accordance with ISO 9303.

The acceptance criterion is:
— Acceptance level L2/C.

Ultrasonic testing for transverse imperfections in pipe body

506 Ultrasonic testing for the detection of transverse imper-
fecions in pipe body shall be performed in accordance with ISO 9305

The acceptance criterion is:
— Acceptance level L2/C.

Surface testing for longitudinal and transverse indications in pipe body

507 Testing of ferromagnetic seamless pipe for the detection
of longitudinal and transverse surface imperfections shall be performed in accordance with one of the following standards:
— ISO 9304 (eddy current testing)
— ISO 9402 (flux leakage testing)
— ISO 9598 (flux leakage testing)
— ISO 13665 (magnetic particle testing)

Guidance note:
If detection of defects on the internal surface of the pipe is
deemed important, ISO 9402 or ISO 9598 should be preferred.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The acceptance criteria are:
— ISO 9304 : Acceptance level L2
— ISO 9402: Acceptance level L2
— ISO 9598: Acceptance level L2
— ISO 13665: Acceptance level M1

508 Testing of non-ferromagnetic seamless pipe for the de-
tection of longitudinal and transverse surface imperfections
shall be performed in accordance with one of the following standards:
— ISO 9304 (eddy current testing)
— ISO 12095 (dye penetrant testing)

The acceptance criteria are:
— ISO 9304 : Acceptance level L2
— ISO 12095: Acceptance level P1

G 600 Non-destructive testing of HFW, LBW and EBW pipe

601 The extent of NDT shall be according to Section 6, Ta-
ble 6-13.

602 For pipes in duplex steel, it shall be demonstrated that
the presence of any possible coarse, anisotropic zones will not
impede the ultrasonic testing.

Ultrasonic testing for longitudinal imperfections in the weld
seam

603 Ultrasonic testing of the full length of the weld seam of
HFW, LBW and EBW pipe for the detection of longitudinal
The acceptance criteria are:

Equipment

— Dedicated probes, either tandem or sender/receiver for detection of imperfections located on the fusion face shall be used. Additionally, TOFD probes may be used, subject to agreement.

— The equipment shall include devices for weld tracking/centring and provide checking of adequate coupling for all probes.

Reference block

The reference block shall contain

— side drilled 1.6 mm Ø holes drilled parallel to the weld longitudinal axis at the weld centreline. The holes shall be located at mid thickness and 2 mm below each surface for detection of imperfections located on the fusion face, (for use with tandem or sender/receiver probes); and

— N5 notches on the inside and outside surfaces immediately adjacent to the weld and on both sides of the weld. The length of the notches shall be 1.5 x the probe element size or 20 mm, whichever is the shorter.

For use with TOFD probes, the reference block shall contain two equal radially spark eroded slits at the weld centreline with the width maximum 1.0 mm and located on the inside and outside surfaces. The length and depth of the slits shall be chosen such that the acceptance criterion when using TOFD probes will be the same as when using N5 notches and 1.6 mm Ø side drilled holes.

A sample pipe shall be fitted with one 3.0 mm Ø through drilled hole at the weld centreline at each end. The distance from the pipe end to the hole shall be equal to the length not covered by the ultrasonic testing equipment during production testing. Prior to start of production, the pipe shall be passed through the ultrasonic testing equipment at the operational scanning velocity. For acceptance of the equipment, both holes need to be detected by all probes. At the Manufacturer’s option, these holes may be included in the reference block.

Guidance note:

Provided equal coverage and sensitivity is obtained other equipment configurations, reference reflectors and calibration methods may be used, subject to agreement.

---end-of---Guidance---note---

604 The equipment shall be calibrated as follows:

— The response from the N5 shall be maximised according to ISO 9303.

— The response from the mid thickness 1.6 mm Ø side drilled hole with the dedicated tandem or sender or receiver probes shall be maximised while keeping the response from the near surface 1.6 mm Ø side drilled holes as equal as possible.

The TOFD probes shall not undersize the length or depth of the either one of the slits in the reference block. After calibration, all settings, gate positions and offsets from the weld centreline to the probe index point shall be reported for each probe.

605 The alarm/recording levels shall for the N5 notches and the 1.6mm holes shall be set separately for each type of reference reflector used. The level shall be the lesser of the responses obtained from either reflector type.

For TOFD probes, all indications exceeding the length or the depth of the reference slits shall be reported in a written format or by a corresponding alarm level setting.

606 The acceptance criteria are:

--- indications exceeding the alarm level set for N5 notches and 1.6 mm Ø holes are not acceptable; and

— for TOFD probes, indications exceeding the length or the depth of the reference slits are not acceptable.

607 Alternative arrangements of the equipment may be agreed provided it is demonstrated that equal coverage and sensitivity in detection of imperfections is obtained.

Ultrasonic testing of the pipe body for detection of laminar imperfections

608 Ultrasonic testing of the pipe body for detection of laminar imperfections need not be performed at the pipemill if testing according to subsection F is performed at the plate/strip mill.

609 The testing if performed at the pipemill shall be in accordance with ISO 12094 amended as follows:

— the distance between adjacent scanning tracks shall ensure 100% coverage of the plate body and all four edges and be sufficiently small to ensure detection of the minimum allowed imperfection size, and

— for plate nominal thicknesses ≥40mm the recess depth in the reference standard/test piece shall be increased in order to place the bottom of the recess between ¼ and ½ of the nominal plate thickness.

The acceptance criteria are:

— According to requirements to plate and strip body in Table D-2 for non-sour or sour service.

Guidance note:

Acceptance criteria for laminations in the pipe body according to F203 may apply, subject to agreement.

---end-of---Guidance---note---

Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections

610 Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections need not be performed at the pipemill if testing according to subsection F has been performed at the plate/strip mill.

611 The testing if performed at the pipemill shall be in accordance with ISO 112094 amended as follows:

— The width of the tested band shall be 50 mm;

— the distance between adjacent scanning tracks shall ensure 100% coverage of the area adjacent to the weld and shall be sufficiently small to ensure detection of the minimum allowed imperfection size; and

— for plate nominal thicknesses ≥40 mm, the recess depth in the reference standard/test piece shall be increased in order to place the bottom of the recess between 1/4 and 1/2 of the nominal pipe wall thickness.

The acceptance criterion is:

— According to requirements to plate and strip edges in Table D-2 for non-sour or sour service.

Testing of ferromagnetic pipe for the detection of surface imperfections in the weld area

612 Testing of ferromagnetic HFW, LBW and EBW pipe for the detection of surface imperfections in the weld area shall be performed in accordance with one of the following standards:

— ISO 9304 (eddy current)

— ISO 13665 (magnetic particle)

Eddy current testing performed in accordance with ISO 9304 shall use the segment coil technique, reference hole diameter of maximum 3.20 mm and the lowest possible excitation fre-
The equipment shall include devices for weld tracking and provide checks of adequate coupling for each individual probe.

709 The total automated ultrasonic system shall have a documentation of calibration not older than 6 months at the start of production.

710 The reference block shall contain:

- **A** 1.6 mm Ø through drilled holes at the weld centreline.
- **B** 1.6 mm Ø through drilled holes in the base material at both sides at the weld toe edge, or drilled to half thickness from the outside and inside.
- **C** N5 notches in the base material and parallel to the weld at both sides of the weld toe edge externally.
- **D** N5 notches in the base material and parallel to the weld at both sides of the weld toe edge internally.
- **E** N5 notches in the weld, centred on and transverse to the weld externally.
- **F** N5 notches in the weld, centred on and transverse to the weld internally.
- **G** 3.0 mm Ø through drilled holes in the pipe material 10 mm outside the weld toe edge.

The length of the N5 notches shall be 1.5 times the probe (crystal) element size or 20 mm, whichever is the shorter. The length does not include any rounded corners. The width of the N5 notches shall not exceed 1 mm.

The number of notches and holes may be increased above the numbers given above at the Manufacturer's option.

Pipe wall thickness in excess of approximately 20 mm may require that specific probes are used to detect longitudinal imperfections in the mid thickness area of the weld. In such cases the reference block shall contain a reflector to indicate the target position for these probes in order to verify correct positioning of the probes. The reflector may be used for setting of the alarm/recording level if it provides a return signal equal to a N5 notch. The Manufacturer shall propose a type of reflector suitable for the purpose, and the type of reflector used is subject to agreement.

711 A sample pipe shall be fitted with one 3.0 mm Ø through drilled hole at the weld centreline at each end. The distance from the pipe end to the hole shall be equal to the length not covered by the ultrasonic testing equipment during production testing. Prior to start of production the pipe shall be passed through the ultrasonic testing equipment at the operational scanning velocity. For acceptance of the equipment, both holes need to be detected by all probes. At the Manufacturer's option, these holes may be included in the reference block.

712 The initial calibration shall be performed in the static mode.

A separate calibration shall be performed for each probe against the reference reflectors located in the area of the weld that shall be covered by that probe.

For detection of transverse imperfections, readily distinguishable signals shall be obtained from the (A) 1.6 mm Ø hole. The response from the opposite side (B) 1.6 mm Ø hole and the (E) and (F) transverse N5 notches shall be recorded.

For detection of longitudinal imperfections, the probe shall be targeted at the (A) 1.6 Ø hole. The response from the (C) or (D) N5 notch that is applicable for the specific probe shall be recorded.

713 If the wall thickness require specific probes to cover the mid thickness area of the weld, they shall be adjusted to obtain a peak signal from the mid thickness reflector.

714 The calibration shall be optimised until each primary reflector (A), (B), (C) and (D) is detected by at least two different probes with different angles and/or sound paths and/or sensitivities.
The signal amplitude percentage of full screen height from reflectors (A) through (F) shall be recorded without any alterations to the amplification, position and angle relative to the weld axis or sound path length used to optimise the calibration of the probes.

The detection gates shall be set using the (G) 3mm Ø holes. Gates shall start at the (G) reflector on the near side and end at the (G) reflector at the opposite side. Only if geometrical echoes from the weld reinforcement can exceed the echo from the opposite (G) reflectors, may the gates end immediately before the appropriate (C) or (D) reflector. The gate start and end shall be set reflecting the tolerances of the weld tracking device.

After completing the static calibration all settings, gate positions, angle relative to the weld axis and offsets from the weld centre line to the probe index point shall be recorded for each probe.

The alarm/recording level for each probe shall set as follows:
- For transverse imperfections: 80% of the signal amplitude from the opposite side (B) 1.6mm hole, but not less than the lowest signal amplitude from the either of the (E) or (F) transverse N5 notches.
- For longitudinal imperfections: 100% of the signal amplitude from the applicable (C) or (D) N5 notch giving the lowest signal amplitude.
- If the use of a mid thickness notch has been agreed for setting of the alarm/recording level (signal response equal to a N5 notch): 100% of the signal amplitude.

Guidance note:
Provided equal coverage and sensitivity is obtained other equipment configurations, reference reflectors and calibration methods may be used, subject to agreement.

---end---of---Guidance---note---

A check on the calibration shall be performed in the dynamic mode. The change in gain required to maintain the recorded percentage of full screen height for each probe shall be recorded as an average of the 3 dynamic check results. All probes shall be verified as indicating the recorded signal amplitude from the probes dedicated to the respective holes and notches. Gate settings shall not deviate more than 2.5 mm from the reference position.

The dynamic check shall be performed at time intervals according to ISO 9765.

The equipment shall be deemed to be out of calibration if:
- the response from any reflector during the dynamic check falls below – 3dB of the recorded value from the dynamic checks, see 719.
- the gate settings during the dynamic check varies more than ± 2.5 mm from the recorded value from the static calibration.
- any of the parameter used when optimising the initial static calibration are changed.

If the equipment is deemed out of calibration it shall be re-calibrated as required in 712 to 719 and all pipes tested since the last successful dynamic check shall be re-tested.

Insufficient coupling shall be deemed to occur if the transmission signal from any probe is more than 10dB lower than lowest the alarm/recording level for the probe pair.

For production testing the total gain shall be increased with a minimum of + 3dB. This increased gain shall be removed during the dynamic check.

Indications exceeding the alarm/recording level or recorded shall be investigated by radiographic testing according to 803. If the presence of a defect is not confirmed by radiography, manual ultrasonic testing according to 809 and 810 shall be performed. If this additional NDT does not confirm the presence of defects, the pipe shall be re-scanned by the automatic ultrasonic equipment. If the rescanning the first 5 times the alarm system has been triggered does confirm the absence of defects, further re-scanning may be omitted.

Ultrasonic testing of the pipe body for detection of laminar imperfections

Ultrasonic testing of the pipe body for detection of laminar imperfections need not be performed at the pipemill if testing according to subsection F is performed at the plate/strip mill.

The testing, if performed at the pipemill, shall be in accordance with ISO 12094 amended as follows:
- the distance between adjacent scanning tracks shall ensure 100% coverage of the plate body and all four edges and be sufficiently small to ensure detection of the minimum allowed imperfection size, and
- for plate nominal thicknesses ≥ 40 mm the recess depth in the reference standard/test piece shall be increased in order to place the bottom of the recess between ¼and ½ of the nominal plate thickness.

The acceptance criteria are:
- According to requirements to plate and strip body in Table D-2 for non-sour or sour service.

Guidance note:
Acceptance criteria for laminations in the pipe body according to F.203 may apply, subject to agreement.

---end---of---Guidance---note---

Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections

Ultrasonic testing of the area adjacent to the weld seam body for detection of laminar imperfections need not be performed at the pipemill if testing according to subsection F has been performed at the plate/strip mill.

The testing if performed at the pipemill shall be in accordance with ISO 12094 amended as follows:
- The width of the tested band shall be 50 mm;
- the distance between adjacent scanning tracks shall ensure 100% coverage of the area adjacent to the weld and be sufficiently small to ensure detection of the minimum allowed imperfection size; and
- for plate nominal thicknesses ≥40mm the recess depth in the reference standard/test piece shall be increased in order to place the bottom of the recess between ¼ and ½ of the nominal pipe wall thickness.

The acceptance criterion is:
- The requirements to plate and strip edges in Table D-2 for non-sour or sour service.

Testing of ferromagnetic pipe for the detection of surface imperfections in the weld area
Testing of ferromagnetic SAW pipe for the detection of surface imperfections in the weld area shall be performed in accordance with one of the following standards:

- ISO 9304 (eddy current)
- ISO 13665 (magnetic particle)

Eddy current testing performed in accordance with ISO 9304 shall use the segment coil technique, reference hole diameter of maximum 3.20 mm and the lowest possible excitation frequency.

The acceptance criteria are:

- ISO 9304: Acceptance level L2
- ISO 13665: Acceptance level M1

Manual ultrasonic testing of SAW welds shall be performed at each pipe end and shall include the area not covered by the automatic ultrasonic testing. Scanning for transverse defects shall be performed at an angle of 45° to the weld with 100% overlap on scan lines. The scanning shall include a check along the weld with a 0° probe for laminar defects that may interfere with the testing. Scanning for transverse defects shall be included as detailed in 810.

Indications exceeding 20% of DAC shall be further investigated and the amplitude maximised using probes with a smaller and larger angle. All maximised indications exceeding 50% of DAC shall be reported.

Acceptance criteria is:

- no maximised indications between 50% and 100% of DAC are acceptable unless the presence of a defect is confirmed and found acceptable with radiographic testing and no maximised indications exceeding 100% of DAC are acceptable.

808 Ultrasonic testing for laminations over a 50mm wide band at each pipe end of clad/lined pipe shall be performed manually unless performed with automated equipment. The provisions of ASTM A578/578M, S7 shall apply.

Acceptance criterion is:

- ASTM A578, S7. In addition, no areas with laminations or lack of bond are allowed in the plate edge areas. Manual ultrasonic testing of seamless pipe

Manual ultrasonic testing of SAW welds

809 Manual ultrasonic testing of SAW welds shall be performed in general accordance with B 300.

Probes with beam angles of 0°, 35°, 45°, 60° and 70° shall be available. Use of 4 MHz probes shall be preferred.

Calibration shall be against a reference block with a 1.6 mm Ø through drilled hole using a 45° probe. A DAC curve consisting of 3 points shall be established.

Scanning for longitudinal defects shall be performed transverse to the longitudinal axis of the weld with 100% overlap on scan lines. The scanning shall also include a check along the weld with a 0° probe for laminar defects that may interfere with the testing. Scanning for transverse defects shall be included as detailed in 810.

Indications exceeding 20% of DAC shall be further investigated and the amplitude maximised using probes with a smaller and larger angle. All maximised indications exceeding 50% of DAC shall be reported.

Acceptance criterion is:

- no maximised indications between 50% and 100% of DAC are acceptable unless the presence of a defect is confirmed and found acceptable with radiographic testing and no maximised indications exceeding 100% of DAC are acceptable.

810 Scanning for transverse defects shall be performed at an angle to the weld and "on bead".

Probes with beam angles of 45°, 60° and 70° and frequencies of 2 and 4 MHz shall be available. Use of 4 MHz probes shall be preferred.

The reference block shall contain 1.0 mm Ø through drilled holes at the weld centreline.

For "on bead" scanning a DAC curve shall be established against the 1.6 mm Ø weld centreline hole using 3 points (e.g. 1/2, full and 11/2 skip).

For scanning at an angle of 45° to the weld a DAC curve shall be established against the 1.6mm Ø weld centreline hole using 3 points (e.g. ¼, full and 1½ skip).

"On bead" scanning shall be performed in both directions and a number of 100% overlapping scans shall be performed.

Scanning at an angle of 45° to the weld shall be performed from both sides and in both directions with 100% overlap on scan lines.

Indications found to be acceptable with radiographic testing, and where their dimension and type are confirmed by ultrasonic testing, are acceptable. Other indications are not acceptable if their maximised amplitude exceeds 50% of DAC.
Indications exceeding 20% of DAC shall be further investigated and the amplitude maximised using probes with a larger and smaller angle. All maximised indications exceeding 50% of DAC shall be reported.

The acceptance criterion is:

— no maximised indications between 50% and 100% of DAC are acceptable unless the presence of a defect is confirmed and found acceptable with radiographic testing and no maximised indications exceeding 100% of DAC are acceptable.

*Magnetic particle testing.*

811 Magnetic particle testing shall be performed in general accordance with B 400.

Acceptance criteria shall be according to the applicable requirements of this subsection.

*Liquid penetrant testing*

812 Liquid penetrant testing shall be performed in general accordance with B 500.

Acceptance criteria shall be according to the applicable requirements of this subsection.

*Eddy current testing*

813 Eddy current testing shall be performed in general accordance with B 600.

Acceptance criteria shall be according to the applicable requirements of this subsection.

**G 900 Non-destructive testing of weld repairs in pipe**

901 Complete removal of the defects shall be confirmed by magnetic particle testing, or liquid penetrant testing for non-ferromagnetic materials, before re-welding.

902 A repaired weld shall be completely re-tested using applicable NDT methods in accordance with G 800 and with acceptance criteria in accordance with the requirements in this subsection. Manual ultrasonic testing shall be governing for embedded defects.

**G 1000 Visual examination of welds in linepipe**

1001 Each linepipe weld shall be subject to 100% visual examination. The internal weld at both pipe ends shall be 100% visually inspected for pipe with internal diameter (ID) < 610. The internal weld of pipe with D < 600 mm shall be inspected from both ends as far as access permits.

If necessary, the inspection of the internal weld shall be assisted by a boroscope, video endoscope or similar equipment.

1002 Out-of-line weld bead at pipe ends, judged on radiographs or by etching, shall not exceed 0.3 t or 3 mm, whichever is smaller.

1003 The external flash of HFW pipe shall be trimmed flush with the pipe surface. The internal flash shall be trimmed to a height not exceeding 0.05 t + 0.3 mm. The trimming shall not reduce the wall thickness to below the minimum specified and the groove resulting from the trimming shall not undercut the internal pipe contour more than 0.05 t.

1004 The height of the external and internal weld bead of SAW pipe is not to exceed 3 mm.

1005 The longitudinal/helical weld of SAW pipe shall meet the visual examination acceptance criteria given in Table D-3.

1006 Pipes shall meet the specified requirements for workmanship, dimensions, length and weight given in Section 6.

1007 End preparation such as bevelling, grinding of internal weld beads and grinding of external weld bead for automated ultrasonic girth weld testing purposes shall meet the specified requirements.

**H. Testing of Installation Girth Welds, Component Welds and other Pressure Containing Welds**

**H 100 General**

101 These requirements are applicable to NDT and visual examination of installation girth welds and welds in bends, risers, expansion loops, pipestrings for reeling and towing and any other pressure containing welds.

102 The extent of NDT and visual examination shall be in accordance with the relevant requirements given in the Standard.

**H 200 Non-destructive testing and visual examination**

201 Manual NDT and visual examination shall be performed in accordance with the requirements in subsection B. Automated NDT shall be performed in general compliance with the requirements in subsection D and Appendix E as applicable.

202 Specific requirements to automated ultrasonic testing of girth welds (AUT) are given in Appendix E.

203 For radiography the following additional requirements to B 200 shall apply for installation girth welds:

204 Panoramic (single wall single image) exposures shall be used whenever possible.

205 Fluorometallic screens may be used in combination with X-ray based on a satisfactory procedure qualification test where all requirements to sensitivity are met. Films used with fluorometallic screens shall be designed for use with this screen type.

206 For pipe with internal diameter < 250 mm gamma ray and panoramic (single wall single image) exposures may be used. The gamma ray source shall be Ir 192 and shall be used in combination with lead screens and ultra fine-grained film. Other types of radiation sources may be used for small wall thicknesses in combination with other film types based on a satisfactory procedure qualification test where all requirements to sensitivity are met.

207 Where no internal access is possible, a double wall technique shall be applied.

208 For the double wall double image technique x-ray shall be used. Fluorometallic screens may be used based on a satisfactory procedure qualification test where all requirements to sensitivity are met. Films for use with fluorometallic screens shall be suitable for this screen type.

209 For the double wall single image technique both X-ray and gamma ray may be used. The choice of radiation source, film and screen types shall be based on a satisfactory procedure qualification test where all requirements to sensitivity are met.

**H 300 Acceptance criteria**

301 The acceptance criteria given in Table D-3, Table D-4 and Table D-5 are applicable for welds in C-Mn steel where the accumulated plastic strain resulting from installation and operation will not exceed 0.3%.

302 For other welds the acceptance criteria shall be established or validated as required by E.102 or E.103 as relevant.

303 The acceptance criteria use the term defect to define an imperfection that has exceeded given dimensions and thus is deemed unacceptable.

304 The acceptance criteria given in Table D-4, Table D-5 assume that multi-pass welds are used and that the height of defects will not exceed the height of a welding pass or maximum 0.2 t. If welding methods e.g. SAW, “one-shot” welding etc. resulting in weld passes higher than 0.2 t are used, defect indications equal to the length limits given in the tables shall be height determined with ultrasonic testing. If the height ex-
ceeds 0.2 t or the height of a welding pass, whichever is smaller, the defect is not acceptable.

305 For welds in duplex steel, other stainless steels and clad steel, the requirements in 301 to 304 are applicable except that lack of fusion and lack of penetration are not permitted in the root of single sided welds.

**H 400 Repair of welds**

401 Welds that do not comply with the requirements shall be repaired locally or the whole weld zone shall be removed. Rewelding shall be performed with qualified repair welding procedures and by qualified welders, see Appendix C.

402 Complete removal of the defect shall be confirmed by magnetic particle testing, or liquid penetrant testing for non-ferromagnetic materials, before re-welding.

403 A repaired weld shall be subject to the same testing and inspection requirements as the original weld.

### Table D-3 Acceptance criteria for visual examination and surface method testing

<table>
<thead>
<tr>
<th>External profile</th>
<th>Cap reinforcement/root penetration</th>
<th>Cap concavity/root concavity</th>
<th>Misalignment of adjoining ends (High/low)</th>
<th>Cracks</th>
<th>Lack of penetration/lack of fusion</th>
<th>Undercut, if measured by mechanical means</th>
<th>Surface porosity</th>
<th>Burn through</th>
<th>Arc burns, gouges, notches</th>
<th>Dents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welds shall have a regular finish and merge smoothly into the base material and shall not extend beyond the original joint preparation by more than 3 mm (6 mm for SAW welds). Fillet welds shall be of specified dimensions and regular in form.</td>
<td>Cap reinforcement: Height less than 0.2 t, maximum 4 mm. Root penetration: height less than 0.2 t, maximum 3 mm.</td>
<td>Cap concavity: not permitted. Root concavity shall merge smoothly into base material and at no point shall the weld thickness be less than t.</td>
<td>Less than 0.15 t and maximum 3 mm.</td>
<td>Not acceptable.</td>
<td>Individual length: ≤ t, maximum 25 mm. Accumulated length in any 300 mm length of weld: ≤ t, maximum 50 mm.</td>
<td>Depth d &gt; 1.0 mm 1.0 mm ≥ d ≥ 0.5 mm 0.5 mm ≥ d ≥ 0.2 mm &lt; 0.2 mm</td>
<td>Not permitted on one off or &lt; 12 2 t, maximum 50</td>
<td>Individual length: ≤ t/4, maximum 6 mm in any dimension. Accumulated length in any 300 mm length of weld: 2 t, maximum 12 mm. Acceptable if weld thickness at no point is less than t.</td>
<td>Not permitted.</td>
<td>Depth: &lt;3 mm, length 1/4 x OD.</td>
</tr>
</tbody>
</table>

### Table D-4 Acceptance criteria for radiographic testing

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Acceptance criteria 1) 2) 3) 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity 1) 2)</td>
<td>Individual defects (all dimensions in mm) Maximum accumulated size in any 300 mm weld length (all dimensions in mm)</td>
</tr>
<tr>
<td>Scattered</td>
<td>Diameter ≤ t/4, maximum 3 2, cluster diameter maximum 12 Length: t/2, maximum 12, Width: t/10, maximum 3 Length: t, maximum 25, Width: maximum 1.5 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Wormhole</td>
<td>Diameter ≤ t/4, maximum 3 2, cluster diameter maximum 12 Length: t/2, maximum 12, Width: t/10, maximum 3 Length: t, maximum 25, Width: maximum 1.5 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Hollow bead</td>
<td>Diameter ≤ t/4, maximum 3 2, cluster diameter maximum 12 Length: t/2, maximum 12, Width: t/10, maximum 3 Length: t, maximum 25, Width: maximum 1.5 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Isolated 5)</td>
<td>Diameter ≤ t/4, maximum 3 2, cluster diameter maximum 12 Length: t/2, maximum 12, Width: t/10, maximum 3 Length: t, maximum 25, Width: maximum 1.5 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>On-line 6)</td>
<td>Diameter ≤ t/4, maximum 3 2, cluster diameter maximum 12 Length: t/2, maximum 12, Width: t/10, maximum 3 Length: t, maximum 25, Width: maximum 1.5 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Slag</td>
<td>Diameter ≤ t/3, maximum 12 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Isolated</td>
<td>Diameter ≤ t/3, maximum 12 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Single lines</td>
<td>Diameter ≤ t/3, maximum 12 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Parallel lines</td>
<td>Diameter ≤ t/3, maximum 12 Diameter ≤ t/4, maximum 3 Diameter ≤ t/4, group length: 2t, maximum 50</td>
</tr>
<tr>
<td>Inclusions</td>
<td>Diameter ≤ 0.5 t, maximum 3 Diameter ≤ 0.5 t, group length: maximum 50</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Not permitted, if detected</td>
</tr>
<tr>
<td>Copper, wire</td>
<td>Diameter ≤ 0.5 t, maximum 3 Diameter ≤ 0.5 t, group length: maximum 50</td>
</tr>
<tr>
<td>Lack of penetration 1) 2) 3) 7)</td>
<td>Root Embedded 8)</td>
</tr>
<tr>
<td>Embedded 8)</td>
<td>Length: t, maximum 25 Length: 2t, maximum 50</td>
</tr>
<tr>
<td>Lack of fusion 1) 2) 3) 7)</td>
<td>Surface Embedded</td>
</tr>
<tr>
<td>Embedded</td>
<td>Length: t, maximum 25 Length: 2t, maximum 50</td>
</tr>
<tr>
<td>Cracks</td>
<td>Not permitted</td>
</tr>
</tbody>
</table>
I. Acceptance Criteria for Pipeline Components, Equipment, Structural Items, Base Materials and Weld Overlay

I 100 General

101 NDT and visual examination of pipeline components and equipment shall be performed in accordance with and meeting the acceptance criteria of the code or standard used for the design of the item in question, see Section 7.

102 For forgings and castings used in pipeline components and equipment, the acceptance criteria given in this subsection shall apply.

103 For pressure containing girth welds connecting the equipment or component to the pipeline or for pup-pieces welded to the equipment, the acceptance criteria for girth welds in the relevant pipeline section shall apply.

104 NDT and visual examination of structural items shall meet the requirements of the applied design code.

Table D-4 Acceptance criteria for radiographic testing

<table>
<thead>
<tr>
<th>Root concavity</th>
<th>See Table D-3</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root undercut</td>
<td>Depth: t/10, maximum 1</td>
<td>t, maximum 25</td>
</tr>
<tr>
<td>Excess penetration</td>
<td>0.2 t, maximum 3, Length: t, maximum 25</td>
<td>2 t, maximum 50</td>
</tr>
<tr>
<td>Burn through</td>
<td>See Table D-3</td>
<td>See Table D-3</td>
</tr>
</tbody>
</table>

Total accumulation of discontinuities

Excluding porosity, maximum accumulation in any 300 mm weld length 3 t, maximum 100

Maximum 12% of total weld length.

Any accumulation of defects in any cross sections of weld that may constitute a leak path or may reduce the effective weld thickness with more than t/3 is not acceptable.

Notes:

1) Volumetric defects separated by less than the length of the smallest defect or defect group shall be considered as one defect.
2) Elongated defects situated on line and separated by less than the length of the shortest defect shall be considered as one defect.
3) Refer to the additional requirements in 303 for welding methods that produce welding passes exceeding 0.2 t.
4) Maximum 10% porosity in cluster area.
5) "Isolated" pores are separated by more than 5 times the diameter of the largest pore.
6) Pores are "On-line" if not "Isolated" and if 4 or more pores are touched by a line drawn through the outer pores and parallel to the weld. "On-line" pores shall be checked by ultrasonic testing. If ultrasonic testing indicates a continuous defect, the criteria for lack of fusion defect shall apply.
7) Detectable imperfections are not permitted in any intersection of welds.
8) Applicable to double sided welding where the root is within the middle t/3 only.
9) Acceptance criteria of Table D-3 shall also be satisfied.

Table D-5 Acceptance criteria for ultrasonic testing

<table>
<thead>
<tr>
<th>Indication length, L</th>
<th>Maximum echo amplitude permitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>L ≤ t/2, maximum 12.5 mm</td>
<td>Reference level + 4 dB</td>
</tr>
<tr>
<td>t/2, maximum 12.5 mm &lt; L &lt; t, maximum 25 mm</td>
<td>Reference level - 2 dB</td>
</tr>
<tr>
<td>L ≥ t, maximum 25 mm (indications in both outer t/3)</td>
<td>Reference level - 6 dB</td>
</tr>
<tr>
<td>Accumulated length in any 300 mm of weld: t, maximum 50 mm</td>
<td></td>
</tr>
<tr>
<td>L ≥ t, maximum 50 mm (indications in middle t/3)</td>
<td>Reference level - 6 dB</td>
</tr>
<tr>
<td>Accumulated length in any 300 mm of weld: 2 t, maximum 50 mm</td>
<td></td>
</tr>
</tbody>
</table>

Cracks are not permitted.

Transverse indications: Indications shall be considered as transverse if the echo amplitude transversely exceeds the echo amplitude from the same indication longitudinally with more than 2 dB. Transverse indications are unacceptable unless proven not to be planar, in which case the acceptance criteria for longitudinal indications apply.

For indications approaching the maximum permitted length it shall be confirmed that the indication height is less than 0.2 t or maximum 3 mm (see 303).

Total accumulation of discontinuities: The total length of acceptable indications with echo amplitude of reference level – 6 dB and above shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm nor more than 12% of total weld length. Any accumulation of defects in any cross section of weld that may constitute a leak path or reduce the effective thickness of weld more than t/3 is not acceptable.

If only one side of the weld is accessible for testing 6 dB shall be subtracted from the maximum echo permitted above.

Notes:

a) Reference level is defined as the echo amplitude corresponding to the echo from the side drilled hole in the reference block described in Fig. D-2 of this appendix, or equivalent reflector.
b) All indications exceeding 20% of the reference level shall be investigated to the extent that the operator determines the shape, length and location of the imperfection.
c) Indications that cannot be established with certainty shall whenever possible be tested with radiography. Indications that are type determined in this way shall meet the acceptance criteria of Table D-4.
d) Longitudinal imperfections where the echo height intermittently is below and above the acceptance level, shall if possible be investigated with radiography. Indications that are determined in this way shall meet the acceptance criteria of Table D-4. If radiography cannot be performed, the length shall not exceed 3 t, maximum 100 mm in any weld length of 300 mm.
e) Length, height and depth shall be determined by an appropriate method, see B.315.
f) Detectable imperfections are not permitted in any intersection of welds.
The method of NDT and acceptance criteria shall be detailed in the material and manufacturing specification for:

- items of proprietary design,
- items where the NDT requirements are not part of the design code or standard, and
- items where the NDT requirements and acceptance criteria are subject to specific requirements.

### I 200  Manual Non-destructive Testing Acceptance criteria for Plate and Pipe

#### 201  For manual ultrasonic thickness measurements done on accordance with ASTM E797 or equivalent standard acceptance criteria shall be according to applicable specification or product standard

#### 202  Manual ultrasonic testing acceptance criteria for laminar flaws in C-Mn, duplex, other stainless steels and nickel based corrosion resistant alloys (CRA) performed according to ISO 12094 are given in Table D-2.

#### 203  Acceptance criteria for manual ultrasonic testing for detection of laminar flaws in clad/lined steel performed according to ASTM A578/578M, S7 shall be ASTM A578, S7. In addition, no areas with laminations or lack of bond are allowed over a width extending at least 50 mm inside the location of future weld preparations.

#### 204  For manual ultrasonic testing for detection of flaws other than laminar, performed according to ASTM A577/577M or equivalent standard, the acceptance criteria shall be that no indications exceed the DAC curve established against the rectangular notch with depth 3% of the thickness.

#### 205  Acceptance criteria for manual magnetic particle testing of plate and pipe edges performed according to ASTM E709, ASTM E1444 or equivalent standard shall be:

- No indications longer than 6mm in the circumferential/longitudinal direction are permitted

#### 206  Acceptance criteria for manual liquid penetrant testing of plate and pipe edges performed according to ASTM E1417 or equivalent standard shall be:

- No indications longer than 6mm in the longitudinal direction are permitted

#### 207  Acceptance criteria for manual eddy current testing of pipe and pipe edges performed according to ASTM E309 or equivalent standard shall be:

- No indications longer than 6mm in the circumferential/longitudinal direction are permitted

### I 300  Acceptance criteria for forgings

#### 301  Acceptance criteria for manual ultrasonic testing of forgings performed according to ASTM A 388/ASTM A 388/M or equivalent standard shall be:

- **Straight beam examination**
  - No indication shall be larger than the indication received from the 3mm Ø flat bottom holes in the reference block.

- **Angle beam examination**
  - No indication shall exceed a DAC curve established using N3 (3% of thickness) notches.

#### 302  Acceptance criteria for manual magnetic particle testing of forgings done in accordance with ASTM E709, ASTM E1444 or equivalent standard shall be according to Table D-6.

### Table D-6  Acceptance criteria for manual magnetic particle and liquid penetrant testing of forgings and castings

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Crack-like defects</td>
<td>not permitted</td>
</tr>
<tr>
<td>B Linear indications with length more than three times the width</td>
<td>not permitted</td>
</tr>
<tr>
<td>C Rounded indications: Diameter &lt;3 mm, accumulated diameters in any 100 x 150 mm area &lt;8 mm.</td>
<td></td>
</tr>
</tbody>
</table>

### I 400  Acceptance criteria for castings

#### 401  Acceptance criteria for manual ultrasonic testing of castings done according to ASTM A609 or equivalent standard shall be according to ASTM A606, Table 2. No crack-like indications are acceptable.

#### 402  Acceptance criteria for manual radiographic testing of castings done according to ASME V, section 5, article 2 or equivalent standard shall be according to Table D-7

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracks</td>
<td>ASTM E 186, E280, E446</td>
</tr>
<tr>
<td>Gas porosity</td>
<td>ASTM E 186, E280, E446</td>
</tr>
<tr>
<td>Inclusions</td>
<td>ASTM E 186, E280, E446</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>ASTM E 186, E280, E446</td>
</tr>
</tbody>
</table>

#### 403  Acceptance criteria for manual magnetic particle testing of castings done in accordance with ASTM E709, ASTM E1444 or equivalent standard shall be according to Table D-6.

### I 500  Acceptance criteria for weld overlay

#### 501  Acceptance criteria for as-welded surfaces of magnetic and non magnetic weld overlay for visual examination, magnetic particle testing and liquid penetrant testing are:

- No round indications with diameter above 2 mm and no elongated indications with length above 3 mm,
- indications separated by a distance less than the diameter or length of the smallest indication, shall be considered as one indication, and
- accumulated diameters of round indications and the length of elongated indications in any 100 x 100 mm shall not to exceed 10 mm.

For machined surfaces acceptance criteria shall be especially agreed upon.
APPENDIX E

AUTOMATED ULTRASONIC GIRTH WELD TESTING

A. General

A 100 Scope

101 This Appendix details the examination requirements for the automated ultrasonic testing of pipeline girth welds.

102 The Appendix applies when automated ultrasonic testing (AUT) is performed on pipeline girth welds.

103 Relevant parts of Appendix D apply and supplement this Appendix.

A 200 References


c) Electricity Supply Industry - Standard 98-2: Ultrasonic Probes: Medium Frequency Miniature Shear Wave Angle Probes

d) EN12668-1 Non destructive testing - Characterisation and verification of ultrasonic examination equipment- Part 1: Instruments

e) EN12668-2 Non destructive testing - Characterisation and verification of ultrasonic examination equipment- Part 2: Probes

f) EN12668-3 Non destructive testing - Characterisation and verification of ultrasonic examination equipment- Part 3: Combined equipment

g) EN583-6 Non destructive testing - Ultrasonic examination Part 6 - Time-of-flight diffraction as a method for defect detection and sizing

Until final approval of the ENs, reference is made to the corresponding prENs.

B. Basic Requirements

B 100 General

101 The ultrasonic system to be used shall be accepted through qualification, see subsection H.

102 The ultrasonic system may use pulse echo, tandem, time-of-flight diffraction (ToFD) and/or through transmission techniques. It shall have a fully automatic recording system to indicate the location of defects and integrity of acoustic coupling. The system shall be configured such that the weld volume is divided into primary examination zones of a height not exceeding 3 mm. Higher zones may be used for heavy wall thickness, if agreed.

103 The ultrasonic system shall include scanner heads specifically configured for testing of repairs. Due to the wide variation in repair weld groove shapes that may limit the detection capabilities of the system, manual UT should support the AUT on weld repairs unless the groove shape is controlled to be within given tolerances and the scanner head is configured accordingly.

Manual UT support is not required if weld repair grooves are made with mechanical equipment that consistently prepares the same groove geometry.

104 If specifically required, the ultrasonic system shall incorporate facilities for detection of transverse defects.

105 An operating Quality Assurance system shall be used covering the development of ultrasonic examination systems, testing, verification and documentation of the system and its components and software against given requirements, qualification of personnel and operation of ultrasonic examination systems. ISO 9001 and ASTM E 1212 shall apply.

B 200 Documentation

201 The configuration of the ultrasonic system shall for evaluation purposes be described and documented with regard to:

- brief functional description of the system,
- reference to the code, standard or guideline used for design and operation of the system,
- description of the Quality Assurance system,
- equipment description,
- limitations of the system with regard to material or weld features including sound velocity variations, geometry, size, surface finish, material composition, etc.
- number and type of transducers with description of characteristics and set-up,
- number of and height of examination zones, where relevant,
- gate settings,
- function of scanning device,
- ultrasonic instrument, number of channels and data acquisition system,
- recording and processing of data,
- calibration blocks,
- couplant monitoring method,
- temperature range for testing and limitations,
- coverage achieved,
- maximum scanning speed and direction,
- reporting of indications and documentation of calibration and sensitivity settings.

B 300 Qualification

301 Automated ultrasonic systems shall be qualified and the performance of the system shall be documented.

Further guidance is given in subsection H.

B 400 Ultrasonic system equipment and components

General requirements

401 The system shall be capable of examining a complete weld including the heat affected zone in one circumferential scan.

402 There shall be recordable signal outputs for at least each 2 mm of weld length.

403 Distance markers shall be provided on the recording at intervals not exceeding 100 mm of circumferential weld length.

404 The scanning direction (clockwise or anti-clockwise) shall be clearly described and referred to an identifiable datum, and shall be maintained throughout the duration of the field weld examination.

Specific requirements for ultrasonic instruments using multiple channels, pulse echo, tandem and/or through transmission techniques.
The instrument shall provide a linear A-scan presentation. The instrument linearity shall have been determined according to the procedures detailed in ASTM-317-79 or EN12668. Instrument linearity shall not deviate by more than 5% from ideal. The assessment of instrument linearity shall have been performed within 6 months of the intended end use date. For production AUT with an expected duration exceeding 6 months, but less than one year, the assessment of instrument linearity may be performed immediately before the start of work. A calibration certificate shall be made available upon request.

Specific requirements to ultrasonic instruments using the ToFD technique

The recording system

The recording or marking system shall clearly indicate the location of imperfections relative to the 12 o’clock position of the weld, with a ±1% accuracy. The system resolution shall be such that each segment of recorded data from an individual inspection channel does not represent more than 2 mm of circumferential weld distance.

Acoustic coupling

Acoustic coupling shall be achieved by contact or water column using a liquid medium suitable for the purpose. An environmentally safe agent may be required to promote wetting, however, no residue shall remain on the pipe surface after the liquid has evaporated.

The method used for acoustic coupling monitoring and the loss in signal strength defining a “loss of return signal” (loss of coupling) shall be described.

Transducers

Prior to the start of field weld examination details of the types and numbers of transducers shall be specified. Once agreed, there shall not be any transducer or design changes made without prior agreement.

All transducers used in the ultrasonic system shall meet the performance requirements detailed in Annex A. This Annex is not necessarily complete for all possible configurations that may be used. When the relevant requirements are not fully covered in the Annex, acceptance specific requirements to transducers shall be identified. All transducers shall be evaluated according to this Annex, and the test results recorded. The test result data sheets shall be available for review. When required, all transducers shall be contoured to match the curvature of the pipe.

Calibration blocks

Calibration blocks shall be used to qualify the inspection system for field inspection and to monitor the ongoing system performance. Calibration blocks shall be manufactured from a section of pipeline specific linepipe.

Acoustic velocity and attenuation measurements shall be performed on material from all sources of pipe material supply to be used. These measurements shall be performed according to Annex B unless an equivalent method is agreed. If differences in acoustic velocity for the same nominal wall thickness from any source of supply results in a beam angle variation of more than 1.5°, specific calibration blocks shall be made for material from each source of supply showing such variations.

Details of the specific weld geometries shall be provided in order to determine the particulars and numbers of calibration blocks required, including the calibration reflectors required and their relative positions.

The preferred principal calibration reflectors are normally 3 mm Ø flat bottom holes (FBH) and 1 mm deep surface notches. Other reflector dimensions and types may, however, be used, if it is demonstrated during the system qualification that the defect detection and sizing capabilities of the system is acceptable.

The calibration blocks shall be designed with sufficient surface area so that the complete transducer array will traverse the target areas in a single pass.

The calibration block shall be identified with a hard stamped unique serial number providing traceability to the examination work and the material source of supply for which the standard was manufactured. Records of the serial number, wall thickness, bevel design, diameter, and ultrasound velocity shall be kept and be available.

The machining tolerances for calibration reflectors are:

- Hole diameters ± 0.2 mm
- Flatness of FBH ± 0.1 mm
- All pertinent angles ± 1°
- Notch depth ± 0.1 mm
- Notch length ± 0.5 mm
- Central position of reference reflectors ± 0.1 mm
- Hole depth ± 0.2 mm

The lateral position of all calibration reflectors shall be such that there will be no interference from adjacent reflectors, or from the edges of the blocks.

All holes and notches shall be protected from degradation by filling or covering the hole or notch with a suitable sealant.

Dimensional verification of all calibration reflectors and their position shall be performed and recorded.

A calibration block register shall be established. The register shall include all calibration blocks to be used identified with the unique serial number and include the dimensional verification records, ultrasound velocity, name of the plate/pipe manufacturer and the heat number. The register shall be available for review.

Operators

Details of each AUT operator shall be provided for prior to start of field weld examination.

Operators performing interpretation are to possess a valid certificate of proficiency to Level 2 in the ultrasonic method according to a certification scheme meeting the requirements of EN473, ASNT or equivalent. In addition they are to document adequate training with the equipment in question, by passing a specific and practical examination. If requested, they shall be able to demonstrate their capabilities with regard to calibrating the equipment, performing an operational test un-
der field conditions and evaluating size, nature and location of imperfections.

425 Operators whom are not accepted shall not be used, and operators shall not be substituted without prior approval. In case additional operators are required, details of these shall be accepted before they start to work.

426 One individual shall be designated to be responsible for the conduct of the ultrasonic personnel, the performance of equipment, spare part availability, and inspection work, including reports and records.

427 The operators shall have access to technical support from one individual qualified to Level 3 at any time during execution of the examination work.

B 500 Recorder set-up

501 Channel output signals shall be arranged on the recording media in an agreed order. The function of each channel shall be clearly identified. The hard copy recording shall be corrected to account for any difference introduced due to different circumferential positions of the transducers.

B 600 Circumferential scanning velocity

601 The maximum allowable circumferential scanning velocity \( V_C \), shall be determined according to

\[
V_C \leq W_C \cdot \text{PRF} / 3
\]

where \( W_C \) is the narrowest -6 dB beam width at the appropriate operating distance of all transducers within the array, and PRF is the effective pulse repetition frequency per transducer.

B 700 Gate settings

Pulse echo, tandem and through transmission techniques

701 With each transducer positioned for the peak signal response from the calibration reflector the detection gates are to be set. The gate shall start before the theoretical weld preparation and a suitable allowance shall be included to allow for the width of the heat affected zone, so that complete coverage of the heat affected zone is achieved. The gate ends shall be after the theoretical weld centreline, including a suitable allowance for offset of the weld centreline after welding. For porosity mapping channels the gates shall also be set to cover the total weld volume dedicated to the transducer.

ToFD technique

702 Ideally the time gate start should be at least 1 \( \mu \)s prior to the time of arrival of the lateral wave, and should at least extend up to the first back wall echo. Because mode converted echoes can be of use in identifying defects, it is recommended that the time gate also includes the time of arrival of the first mode converted back wall echo.

703 As a minimum requirement the time gate shall at least cover the depth region of interest.

704 Where a smaller time gate is appropriate, it will be necessary to demonstrate that the defect detection capabilities are not impaired.

B 800 Recording Threshold

Pulse echo, tandem and through transmission techniques

801 The recording threshold for planar detection channels shall be at least 6 dB more sensitive than the reference reflector, and shall be such that the smallest non-allowable imperfections are detected.

802 The recording threshold for porosity detection channels shall be at least 14 dB more sensitive than the reference reflector.

ToFD technique

803 The recording threshold for ToFD is normally not recommended to be changed from the calibration threshold. However, a change of threshold may be prescribed in the procedure.

Threshold level

804 It shall be verified that the threshold level is set low enough to detect the minimum height critical defect identified in the acceptance criteria.

B 900 Power supply

901 The ultrasonic system shall have a dedicated power supply. There shall be provisions for alternative power supply in case of failure in the main power supply. There shall be no loss of inspection data as a result of a possible power failure.

B 1000 Software

1001 All recording, data handling and presenting software shall be covered by the Quality Assurance system and all software versions be identifiable by a unique version number.

1002 This version number shall be clearly observable on all display and printout presentations of examination results.

B 1100 System Log Book

1101 The operator shall keep a Log Book detailing the performance/characteristics data and identification for instruments and transducers. The Log Book shall be updated as changes are made, or, as additional information is gathered. The Log Book shall be kept at the place of inspection, and be made available for review upon request.

B 1200 Spares

1201 There shall be a sufficient number of spare parts available at the place of examination to ensure that the work can proceed without interruptions. The type and number of spares shall be agreed.

B 1300 Slave monitors

1301 The system shall include the possibility to provide slave monitors for use by supervising personnel, if agreed.

C. Procedure

C 100 General

101 A detailed Automated Ultrasonic Examination Procedure shall be prepared for each wall thickness and joint geometry to be examined prior to the start of any welding. The procedure is as a minimum to include

— functional description of equipment;
— reference standards and guidelines controlling equipment maintenance;
— instructions for scanning device, ultrasonic instrument, ultrasonic electronics, hard- and software for recording, processing, display, presentation and storage of inspection data;
— transducer configuration(s), characteristics, types, coverage;
— number of examination zones for each wall thickness to be examined;
— gate settings;
— equipment settings;
— description of calibration block(s), including type, size and location of all calibration reflectors;
— calibration intervals;
— calibration records;
— identification of inspection starting point, scanning direction, and indication of length inspected;
— method for scanner alignment and maintenance of alignment;

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Offshore Standard DNV-OS-F101, 2000
App.E – Page 153

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— allowed temperature range;
— couplant, coupling and coupling control;
— transducer and overall functional checks;
— height and length sizing methodology;
— surface condition and preparation;
— description of inspection work;
— acceptance criteria; and
— instructions for reporting including example of recorder chart and forms to be used.

D. Calibration

D 100 Initial static calibration

Transducer positioning and Primary Reference Sensitivity

101 The system shall be optimised for field inspection using the relevant calibration block(s).

102 Pulse echo and tandem transducers shall in turn be positioned at its operating (stand-off) position and adjusted to provide a peak signal from its calibration reflector, this signal shall be adjusted to the specified percentage of full screen height (FSH).

103 The gain level required to produce this peak signal response is the Primary Reference Level (PRE). The PRE, the signal to noise (SNR) ratio, and the transducers stand-off distance shall be recorded.

Gate settings

104 With each transducer positioned for a peak signal response from the calibration reflector the detection gates shall be set as detailed in the agreed Automated Ultrasonic Examination Procedure and according to B.701.

105 The settings for gate start and gate length for each channel shall be recorded.

D 200 Dynamic calibration

Detection channels

201 With the system optimised, the calibration block shall be scanned. The position accuracy of the recorded reflectors relative to each other shall be within ±2 mm and with respect to the zero start within ±10 mm. Gate settings shall not deviate more than 0.26 mm from the reference positions.

202 For all transducers the recording media shall indicate the required percentage of FSH and locate signals from each calibration reflector in its correctly assigned position.

203 A calibration qualification chart shall be used as the inspection quality standard to which subsequently produced calibration charts may be judged for acceptability. This recording shall be kept with the system Log Book.

Coupling monitor channels

204 The coupling monitor channels shall indicate no loss of return signal, see also F.103.

E. Field Inspection

E 100 Inspection requirements

General requirements

101 The ultrasonic system used for examination during production shall in all essential aspects be in compliance with the set-up and configuration of the system used for system qualification (H).

102 Before the ultrasonic system is used for examination of production welds the system shall be tested. After calibration of the complete system, a weld shall be scanned followed by re-calibration with the inspection band removed between each scan. If any of the echo amplitudes from the reflectors of the calibration block deviate more than 2 dB from the initial calibration, the system shall not be used until acceptable corrections have been made. For an acceptable test, 3 satisfactory scans and re-calibrations are required. In addition, a power failure shall be simulated and operation of the system on the alternative power source with no loss of examination data shall be verified.

Reference line

103 Prior to welding a reference line shall be scribed on the pipe surface at a distance from the centreline of the weld preparation on the inspection band side. This reference line shall be used to ensure that the band is adjusted to the same distance from the weld centreline as to that of the calibration block.

Guiding band positioning

104 The tolerance for inspection band positioning is ±1 mm relative to the weld centreline. The template used to align the scanning band to the reference line shall be adjusted to account for weld shrinkage. Shrinkage is determined by marking the reference line on both pipe ends for the first 25 welds, then measuring the distance between them after welding.

Surface condition

105 The scanning area shall be free of spatter and other irregularities which may interfere with the movement of the transducers, the coupling or the transmission of acoustic energy into the material. The longitudinal seam welds shall be ground flush and smooth for a specified distance, normally in the range of 150 mm from the factory bevel face to ensure that no transducers are lifted from the pipe surface. The pipe coating shall be cut back from the original factory bevel face for a specified distance, normally around 350 mm for concrete coating and 150 mm for corrosion coating.

106 The actual cut back dimension requirements shall be advised and confirmed by the inspection body conducting the testing.

Transducer wear baseline measurements

107 Transducer case height measurements shall be provided for prior to the start of field weld examinations. An accurate (±0.1 mm) measurement shall be made of the case height at each corner of each transducer. These measurements shall be recorded and provide a comparison for the periodic measurements taken throughout the examination period to assess for transducer wear.

Calibration frequency

108 The system shall be calibrated by scanning the calibration block before and after inspection of each weld:

— for the first 20 welds,
— at any change of calibration block
— at any change of nominal wall thickness
— at any change of components
— before and after examination of repairs

109 If agreed, the frequency of calibration scans may be reduced to a minimum of 1 scan for each 10 consecutive welds.

110 The peak signal responses from each calibration scan shall be recorded. Any gain changes required to maintain proper sensitivity shall also be recorded.

111 Hard copy recordings for each calibration scan shall be included sequentially with the weld inspection charts. The last weld number examined before calibration and the time at which the calibration was performed shall appear on each calibration chart.

Weld identification

112 Each weld shall be numbered in the sequence used in the pipe tracking system.
Appendix E, subsection D.

producer a new calibration shall be performed as described in Appendix E. Following either replacement or resurfacing of a transducer, wearface which may cause local imperfections shall be evaluated. Their nature shall be clearly identified on the examination report.

Replacement of components

114 Following replacement of any component, the system shall be re-calibrated according to D.

E 200 Operational checks

Circumferential position accuracy

201 As a minimum the position accuracy of the chart distance markers shall be validated twice during each shift. Chart accuracy shall be ±1 cm or better. The result shall be recorded.

Transducer performance

202 Transducers shall be examined for wear against the baseline measurements performed according to 107 whenever a change in gain of more than 6 dB is necessary to maintain the required percentage of FSH (PRE). The transducer shall be replaced or the contact face shall be re-surfaced to correct any of the following:

— Beam angle changes of ± 1.0° for angles less than 45° or ± 1.5° for angles greater than 45°.
— Squint angles exceeding 1.5° for single crystal transducers and 2° for twin crystal transducers.
— For all transducers except creeping wave transducers the noise shall be at least 20 dB weaker than the signal from the reference reflector at the target distance.
— For creeping wave transducers the noise shall be at least 16 dB weaker than the signal from the reference reflector at the target distance.
— Scores in the transducer wearface which may cause local loss of contact or which exceed 0.5 mm.

203 Following either replacement or resurfacing of a transducer a new calibration shall be performed as described in Appendix E, subsection D.

F. Re-examination

F 100 General

101 Welds shall be re-examined whenever any of the following occur:

Sensitivity

102 Welds examined at a sensitivity lower than 3 dB from the PRE shall be re-examined.

Coupling loss

103 Welds exhibiting a loss of acoustic coupling, i.e. a drop in echo amplitude of more than 10 dB from the level through a clean weld for a circumferential distance which exceeds the minimum allowable defect length for the affected channel shall be re-examined.

Out of calibration

104 If a calibration scan shows that the system is in any way "out of calibration", all welds examined since the last successful calibration shall be re-examined.

G. Evaluation and Reporting

G 100 Evaluation of indications

101 Indications from weld imperfections shall be evaluated according to the defect acceptance criteria provided.

102 Indications recorded from sources other than weld imperfections shall be evaluated. Their nature shall be clearly identified on the examination report.

103 All evaluations shall be completed immediately after examination of the weld.

G 200 Examination reports

201 The examination results shall be recorded on a standard ultrasonic report form. The reports shall be made available on a daily basis or on demand.

G 300 Inspection records

301 The following inspection records shall be provided:

— a hard copy record of each weld examined,
— an assessment of the weld quality according to the acceptance criteria,
— hard copy records of all calibration scans, and
— examination data in electronic form.

302 In lieu of hard copy records an alternative recording media is acceptable. Where weld interpretation has been performed using digitally processed signals, the data files shall be stored and backed up immediately following the examination of each weld. The stored data shall be in the same format as used by the operator to assess the acceptability of welds at the time of examination.

303 It agreed, a software package and one set of compatible hardware shall be provided in order to allow the weld data file to be retrieved in the same manner as the operator viewed the data at the time of inspection.

H. Qualification

H 100 General

101 Ultrasonic systems shall be qualified and the performance of the system shall be documented.

102 A qualification is AUT system, weld method and groove geometry specific. Qualification done for one type of welds or an earlier version of the AUT system will not automatically qualify the system for a new application. This does, however not mean, that earlier experience and qualification shall be disregarded, but be actively used for qualification for related applications.

103 Qualification involves a technical evaluation of the AUT system and application in question combined with any required practical tests.

104 The qualification shall be based on a detailed and agreed qualification programme.

H 200 Scope

201 A qualification programme shall document the following:

— Fulfilment of the requirements to AUT systems according to this Appendix
— The ability of the AUT system to detect defects of relevant types and sizes in relevant locations
— The accuracy in sizing and locating defects.

H 300 Requirements

Detection

301 The detection ability of an AUT system shall be deemed sufficient if the probability of detecting a defect of the smallest allowable height determined during an Engineering Critical Assessment (see Appendix D, E 200) is 90% at a 95% confidence level. This requirement will, after technical justification, in most cases be regarded fulfilled, when the smallest allowable defect height is 3 mm or more and the AUT sensitivity level is set at 50% of the echo from a 3 mm Ø flatbottom hole.
An alternative route to showing sufficient sensitivity and detection ability is to show that detection rates are higher, with 95% confidence, than those for an accepted workmanship NDT technique, as given in Appendix D.

**Sizing accuracy**

No specific requirements apply to defect sizing accuracy. However, if the determined accuracy is to be used for determination of acceptable defect sizes based on the allowable sizes calculated according to an Engineering Critical Assessment (see Appendix D E 200), then high inaccuracies in sizing (especially undersizing) can cause problems in defining the acceptance criteria. The requirements are thus indirectly set.

**General**

A full qualification programme for a specific application of an AUT system will in general comprise the following stages:

1. Collection of available background material, including technical description of the AUT system and its performance.
2. Initial evaluation and conclusions based on available information.
3. Identification and evaluation of significant parameters and their variability.
4. Planning and execution of a capability test programme.
5. Planning and execution of a reliability test programme.
6. Reference investigations.
7. Evaluation of results from capability and reliability trials.

The extent of each of these stages will be dependent on the prior available information and documentation, and may be totally omitted if the prior knowledge is sufficient.

As a minimum a qualification will involve an assessment of the AUT system technical documentation, including the quality assurance system, and available information on detection abilities and defect sizing accuracy. Limited practical tests, must, however, in many cases be executed, on which information is given below.

**Variables**

Variables, which must be taken into account during a qualification, include, but are not necessarily limited to:

- Welding method and groove geometry;
- Root and cap probe set-up;
- Probe set-up for other channels (the number of these channels may be increased or decreased provided there are no set-up changes);
- Reference reflectors;
- System, data acquisition and data treatment;
- Software version (except changes affecting viewing or display only).

**Test welds**

Qualification testing shall be performed using test welds containing intentionally induced defects typical of those expected to be present in welds produced with the welding methods to be used.

The material and the weld geometry shall be as for the actual use of the equipment, including a sufficient number of repair welds with a representative variations in groove shape.

The intentionally introduced defects shall vary in length, height and location. Too close spacing of the defects shall be avoided. The number of defects in simulated production welds shall be minimum 10 for each welding method/joint geometry to be used. For small diameter pipelines a number of test welds may be required.

In order to show sufficient detection ability at a required confidence level, it will be necessary to increase the number of included defects.

The presence and sizes of the induced defects in the test welds shall be confirmed. For this purpose the test welds shall subject to radiography, manual ultrasonic testing and magnetic particle or eddy current testing. The reference point for all testing shall be the same and shall be indicated by hardstamping on the test welds. The techniques used for this testing shall be optimised for the weld geometries in question. The interpretation of radiographs and other test results should at least be performed two individuals, initially working independently of each other and later reporting their findings jointly.

The report shall identify the identified defects in the test welds with respect to circumferential position, length, height and depth. The report shall be kept confidential.

**Qualification testing**

The test welds shall be subjected to testing by the AUT system.

For the testing a low echo amplitude recording threshold shall be used. This threshold should be selected somewhat above the noise level and the recording of echo amplitudes may be used for possible later determination of the examination threshold setting to achieve sufficient detectability.

The reference point for circumferential positioning shall be a hardstamped reference point on the test welds.

The testing shall include repeatability tests with several scans with guiding band removed and re-attached between scans.

At least one test shall be done at the elevated temperature expected during field work.

The AUT test results shall be reported. The report shall give the identified defects in the test welds with respect to circumferential position, length, height and depth. In addition the defect height and amplitude around the highest and lowest part of the defects shall be reported for each 2 mm circumferential length over a length of 15 to 20 mm.

**Validation testing**

The reports from the AUT qualification testing shall be validated for accuracy in the determination of defect circumferential position, length, height and depth.

The validation testing shall be by cross-sectioning ("salami method"). The defects as reported in the AUT reports shall be used when selecting the areas for cross sectioning. The extent of cross sectioning shall be sufficient to ensure that the defect height sizing accuracy determination will be based on a minimum of 29 measurements on different defects and/or 'ultrasonically independent' parts of defects (i.e. at locations many beam widths apart) for each welding method and joint configuration.

The cross sections shall be referenced to and validated against the recording chart positions.

For determination of defect height sizing accuracy two parts of each defect, 10 - 20 mm long and corresponding to the highest and lowest part of the defect recorded by AUT, see 706, shall be selected and the "salami method" applied on these parts to determine its height and location.

The weld sections containing defects shall be machined in increments of 2.0 mm. Each machined cross section of the weld shall be etched and the defect location, height and depth measured with an accuracy better than ± 0.1 mm. Each cross section shall be documented by a photograph with 5 - 10x magnification.

In addition a few randomly selected defect parts shall be
subject to such cross-sectioning. For determination of detection abilities and adjustment of required threshold levels additional cross-sectioning, or detailed ultrasonic mapping of specimens cut out from the test weld pipes, is required. These cross-section should be selected randomly, at locations where one or more of the applied NDT techniques have found indications.

H 900 Analysis

901 The data recorded during the tests and reference investigations shall be analysed with respect to:

— Accuracy in height sizing (random and systematic deviation);
— Accuracy in length sizing;
— Accuracy in circumferential positioning / location;
— AUT defect characterisation abilities compared to the results of the destructive tests and the other NDT performed;
— Repeatability when repositioning guide band and at elevated temperature;
— If relevant, determination of probability of detection values or curves for different assumed echo amplitude threshold settings to determine the threshold to be used during examination, or, alternatively or supplementary, an analysis of the relationship between echo amplitude and defect height.

H 1000 Reporting

1001 A qualification report shall as a minimum contain:

— Outcome of the technical evaluation of the AUT system according to this Appendix;
— Description of the specimens and tests performed, including sensitivities used;
— Definitions of the essential variables (see E 200) for the welds and equipment used during qualification testing;
— Data recorded for each defect and each defect cross-section (sizes, locations, types, measured and determined during reference investigation, echo amplitudes);
— Outcome of the analysis of data (H 900);
— Conclusion of the qualification.

I. Validity of Qualification

I 100 Validity

101 A qualification is AUT system, weld method and groove geometry specific.

A qualification of an AUT system will remain valid on the condition that no changes are made in the essential variables defined in I 200.

I 200 Essential variables

201 The following essential variables apply:

— Welding method and groove geometry (including repair welds);
— Root and cap probe set-up;
— Probe set-up for other channels (the number of these channels may be increased or decreased to accommodate changes in wall thickness provided there are no set-up changes);
— Reference reflectors;
— System, data acquisition and data treatment;
— Software version (except changes affecting viewing or display only).

202 Changes in the essential variables for an existing qualified system will require a demonstration of the ability of the new or modified system to detect and accurately size and position weld imperfections.

Annex A. Transducer requirements

A.1 Identification

The transducer shall be identified with the following: the manufacturer, type, beam angle, nominal frequency, crystal size and shape, and a unique identification number.

A.2 Beam angle

For beam angles less than 45° the measured angle shall not differ by more than 1.0°.

For beam angles greater than 45° the measured angle shall not differ by more than 1.5°.

Evaluation shall be made according to BS 4331, Clause 5. The beam angles shall be determined using the same homogeneous material for all probes.

A.3 Beam size

The vertical dimension of the beam at the target shall be within 20% of the design height specified. The horizontal dimension of the beam at the target shall not be greater than two times the vertical dimension of the beam. The target is defined as the point along the beam axis where the inspection is to be performed. In the case of a focused element the target shall fall within the -6 dB working range distributed across the focus. Beam height measurements shall be taken at 5 points along the -6 dB working range.

Evaluation shall be according to BS 4331 Clause 6.

A.4 Overall gain

The gain in hand shall be at least 50 dB.

Evaluation shall be according to ESI Clause 8.4.

A.5 Index point

Evaluation shall be according to ESI Clause 8.6.

A.6 Squint

The squint angle shall not exceed 1.5° for single crystal transducers or 2° for twin crystal transducers.

Evaluation shall be according to ESI Clause 8.8.

A.7 Longitudinal angle beam

The longitudinal angle beam shall be at least 35 dB weaker than the shear wave beam measured at a range of 100 mm.

Evaluation shall be according to ESI Clause 8.10.

A.8 Surface waves

Surface waves shall be at least 34 dB weaker than the shear wave, for beam angles less than 64°. For angles greater than 64° they shall be at least 24 dB weaker measured at 100 mm range.

Evaluation shall be according to ESI Clause 8.11.

A.9 Side lobes

Side lobes shall be at least 20 dB weaker than the main beam, except for angles greater than 64° where they shall be at least 15 dB weaker.

Evaluation shall be according to ESI Clause 8.13.

A.10 Subsidiary maxima

Any fluctuations in the echo amplitude shall not exceed that caused by interference caused with grass.

Evaluation shall be according to ESI Clause 8.14.

A.11 Pulse shape

The pulse shape shall be single peaked with any secondary peaks in the tail of the pulse at least 20 dB less than the peak.

Evaluation shall be according to ESI Clause 8.16.
A.12 Frequency
The operating frequency shall be within ±10% of the nominal frequency.
Evaluation shall be according to ESI Clause 8.18.

A.13 Pulse length
The pulse length shall not exceed 2.5 microseconds between points on the rectified pulse at 10% of peak amplitude.
Evaluation shall be according to ESI Clause 8.19.

A.14 Signal to noise
For all transducers except creeping wave transducers the noise shall be at least 20 dB weaker than the signal from the reference reflector at the target distance.
For creeping wave transducers the noise shall be at least 16 dB weaker than the signal from the reference reflector at the target distance.
Evaluation shall be according to BS 4331, Clause 11. Note: This evaluation shall be performed using the system instrumentation in multiplex mode with all cabling in place, and all relevant electrical systems operating.

Annex B. Determination of shear wave velocity in pipe steels

B.1 General
The procedure defined in this Annex covers methods that may be used to determine acoustic velocity of shear waves in linepipe steels. Equivalent methods may be used subject to agreement.
Linepipe used in oil and natural gas transmission exhibit varying degrees of anisotropy with varying acoustic velocities depending on the propagation direction with resultant changes in the refracted angle of the sound in the steel. This is especially critical where focused beams are used for zonal discrimination. It is thus required to determine the ultrasonic shear wave velocity for propagation in different directions.

B.2 Equipment
To determine the shear wave velocity directional dependency an ultrasonic shear wave transducer of 5 MHz frequency with a crystal diameter of 6 - 10 mm should be used in combination with an ultrasonic apparatus with bandwidth at least up to 10 MHz and a recommended capability of measuring ultrasonic pulse transit times with a resolution of 10 ns and an accuracy of ±25 ns. Devices for measuring mechanical dimension of the specimens should have a recommended accuracy of ±0.1 mm. As couplant an easily removable glue or special high viscosity shear wave couplant is recommended.

B.3 Specimens
A specimen is cut from a section of pipe to be tested and the corresponding results are specific for a particular pipe diameter, wall thickness and manufacturer. Specimen dimensions should be a minimum of 50 mm x 50 mm.
A similar arrangement can also be used for measuring velocities in a plane normal to pipe axis.

A minimum of two parallel surfaces are machined for the plane to be evaluated; one pair of surfaces is made in the radial direction (perpendicular to the OD surface) and the other pair made 20° from the perpendicular to the OD surface. See Figure 1. Additional pairs of parallel surfaces may be machined at other angles in the plane to be evaluated if more data points are desired.
The machined surfaces should be smooth to a 20 µm finish or better. Minimum width of the specimen surface to be measured should be 20 mm and the minimum thickness between the parallel surfaces to be measured should be 10 mm. Vertical extent of the test surface will be limited by the pipe wall thickness.

B.4 Test method
Using the machined slots as reflectors for the shear wave pulses with the transducer in the appropriate positions and measuring the pulse transit times determines together with the mechanically measured pulse travelling distances the shear wave velocities in the axial and 20° direction (Figure 1).
A similar measurement in the through thickness direction determines the radial velocity. Pulse transit times shall be measured between the forefront parts of 1st and 2nd backwall echo, or, alternatively, using more multiple echoes.
A minimum of three readings shall be made for each plane in which testing shall be done.

B.5 Accuracy
Errors in velocity determination shall not be greater than ±20 m/s.

B.6 Recording
Values for the velocities determined can be tabulated and graphed. By plotting velocities on a two dimensional polar graph for a single plane, velocities at angles other than those made directly can be estimated.
The effect of temperature on velocity can be significant under extreme test conditions, therefore the temperature at which these readings have been made should also be recorded.