INTERNATIONAL STANDARD

ISO 13628-5

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Petroleum and natural gas industries — Design and operation of subsea production systems —

Part 5: **Subsea umbilicals**

Industries du pétrole et du gaz naturel — Conception et exploitation des systèmes de production immergés —

Partie 5: Faisceaux de câbles immergés

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13628-5 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

This second edition cancels and replaces the first edition (ISO 13628-5:2002), which has been technically revised.

ISO 13628 consists of the following parts, under the general title *Petroleum and natural gas industries — Design and operation of subsea production systems*:

— *Part 1: General requirements and recommendations*

— *Part 2: Unbonded flexible pipe systems for subsea and marine applications*

— *Part 3: Through flowline (TFL) systems*

— *Part 4: Subsea wellhead and tree equipment*

— *Part 5: Subsea umbilicals*

— *Part 6: Subsea production control systems*

— *Part 7: Completion/workover riser systems*

— *Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems*

— *Part 9: Remotely Operated Tool (ROT) intervention systems*

— *Part 10: Specification for bonded flexible pipe*

— *Part 11: Flexible pipe systems for subsea and marine applications*

A Part 12, dealing with dynamic production risers, a Part 13, dealing with remotely operated tool and interfaces on subsea production systems, a Part 15, dealing with subsea structures and manifolds, a Part 16, dealing with specification for flexible pipe ancillary equipment, and a Part 17, dealing with recommended practice for flexible pipe ancillary equipment, are under development.

Introduction

This part of ISO 13628 is based on the first edition of ISO 13628-5, which was based on API Spec 17E, second edition and API RP 17I, first edition. The first edition of ISO 13628-5 was adopted by API as API Spec 17E, third edition. It is intended that API Spec 17E, fourth edition, will be identical to this International Standard.

It is important that users of this part of ISO 13628 be aware that further or differing requirements can be needed for individual applications. This part of ISO 13628 is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment engineering solutions for the individual application. This can be particularly applicable if there is innovative or developing technology. If an alternative is offered, it is the responsibility of the vendor to identify any variations from this part of ISO 13628 and provide details.

In this part of ISO 13628, where practical, US Customary (USC) and other units are included in parentheses for information.

Petroleum and natural gas industries — Design and operation of subsea production systems —

Part 5: Subsea umbilicals

1 Scope

This part of ISO 13628 specifies requirements and gives recommendations for the design, material selection, manufacture, design verification, testing, installation and operation of umbilicals and associated ancillary equipment for the petroleum and natural gas industries. Ancillary equipment does not include topside hardware. Topside hardware refers to any hardware that is not permanently attached to the umbilical, above the topside hang-off termination.

This part of ISO 13628 applies to umbilicals containing components, such as electrical cables, optical fibres, thermoplastic hoses and metallic tubes, either alone or in combination.

This part of ISO 13628 applies to umbilicals for static or dynamic service, with surface-surface, surface-subsea and subsea-subsea routings.

This part of ISO 13628 does not apply to the associated component connectors, unless they affect the performance of the umbilical or that of its ancillary equipment.

This part of ISO 13628 applies only to tubes with the following dimensions: wall thickness, $t < 6$ mm, internal diameter, ID < 50,8 mm (2 in). Tubular products greater than these dimensions can be regarded as pipe/linepipe and it is expected that they be designed and manufactured according to a recognised pipeline/linepipe standard.

This part of ISO 13628 does not apply to a tube or hose rated lower than 7 MPa (1 015 psi).

This part of ISO 13628 does not apply to electric cable voltage ratings above standard rated voltages $U_0 / U(U_m) = 3{,}6/6(7{,}2)$ kV rms, where U_0, U and U_m are as defined in IEC 60502-1 and IEC 60502-2.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 527 (all parts), *Plastics — Determination of tensile properties*

ISO 1402, *Rubber and plastics hoses and hose assemblies — Hydrostatic testing*

ISO 4080, *Rubber and plastics hoses and hose assemblies — Determination of permeability to gas*

ISO 4406, *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles*

ISO 4672:1997, *Rubber and plastics hoses — Sub-ambient temperature flexibility tests*

ISO 6801, *Rubber or plastics hoses — Determination of volumetric expansion*

ISO 6803:2008, *Rubber or plastics hoses and hose assemblies — Hydraulic-pressure impulse test without flexing*

ISO 7751, *Rubber and plastics hoses and hose assemblies — Ratios of proof and burst pressure to design working pressure*

ISO 13628-8, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems*

ISO 8308, *Rubber and plastics hoses and tubing — Determination of transmission of liquids through hose and tubing walls*

IEC 60228, *Conductors of insulated cables*

IEC 60502-1, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) — Part 1: Cables for rated voltages of 1 kV (U_m = 1,2 kV) and 3 kV (U_m = 3,6 kV)*

IEC 60502-2, *Power cables with extruded insulation and their accessories for rated voltages from 1 kV (U_m = 1,2 kV) up to 30 kV (U_m = 36 kV) — Part 2: Cables for rated voltages from 6 kV (U_m = 7,2 kV) up to 30 kV (U_m = 36 kV)*

IEC 60793-1-1, *Optical fibres — Part 1-1: Measurement methods and test procedures — General and guidance*

IEC 60793-2, *Optical fibres — Part 2: Product specifications — General*

IEC 60794-1-1, *Optical fibre cables — Part 1-1: Generic specification — General*

IEC 60794-1-2, *Optical fibre cables — Part 1-2: Generic specification — Basic optical cable test procedures*

EN 10204:2004, *Metallic products — Types of inspection documents*

ASTM A240, *Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications*

ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A480, *Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip*

ASTM A789/A789M, *Standard Specification for Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service*

ASTM A1016/A1016M-04A, *Standard Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel and Stainless Steel Tubes*

ASTM E8/E8M, *Standard Test Methods for Tension Testing of Metallic Materials*

ASTM E92, *Standard Test Method for Vickers Hardness of Metallic Materials*

ASTM E213, *Standard Practice for Ultrasonic Examination of Metal Pipe And Tubing*

ASTM E273, *Standard Practice for Ultrasonic Examination of the Weld Zone of Welded Pipe and Tubing*

ASTM E309, *Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation*

ASTM E384, *Standard Test Method for Microindentation Hardness of Materials*

ASTM E426, *Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys*

ASTM E562, *Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count*

ASTM E1001, *Standard Practice for Detection and Evaluation of Discontinuities by the Immersed Pulse-Echo Ultrasonic Method Using Longitudinal Waves*

ASTM E1245, *Standard Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis*

ASTM G48-03, *Standard Test Methods for Pitting And Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferritic Chloride Solution*

BS 5099, *Electric cables. Voltage levels for spark testing*

ITU-T G.976, *Test methods applicable to optical fibre submarine cable systems*

3 Terms, abbreviated terms and definitions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
allowable bend radius
minimum radius to which an umbilical, at a given tension, may be bent to without infringing design criteria or suffering loss of performance

See Figure 1.

NOTE 1 The bend radius is measured to the centreline of the umbilical.

NOTE 2 Allowable bend radius increases with increasing tensile load and varies depending on internal pressure and condition, i.e. safety level.

3.1.2
allowable tensile load
maximum tensile load that an umbilical, at a given bend radius, can be loaded to without infringing design criteria or suffering loss of performance

See Figure 1.

NOTE Allowable tensile load decreases with decreasing bend radius and will vary depending on internal pressure and condition, i.e. safety level.

3.1.3
ancillary equipment
accessory to the umbilical system that does not form part of the main functional purpose

EXAMPLES Weak link, buoyancy attachments, I-tube or J-tube seals, VIV strakes, centralizers, anchors external clamps.

3.1.4
bend restrictor
device for limiting the bend radius of the umbilical by mechanical means

NOTE A bend restrictor typically is comprised of a series of interlocking metallic or moulded rings, applied over the umbilical. It is sometimes referred to as a bend strain reliever (BSR).

3.1.5
bend stiffener
device for providing a localized increase in bending stiffness, preserving the minimum bend radius of the umbilical under defined bending moment conditions

NOTE The stiffener is usually a moulded device, sometimes reinforced, depending on the required duty, applied over the umbilical. It is sometimes referred to as a bend strain reliever (BSR).

3.1.6
bird-caging
phenomenon whereby armour wires locally rearrange with an increase and/or decrease in pitch-circle diameter as a result of accumulated axial and radial stresses in the armour layer(s)

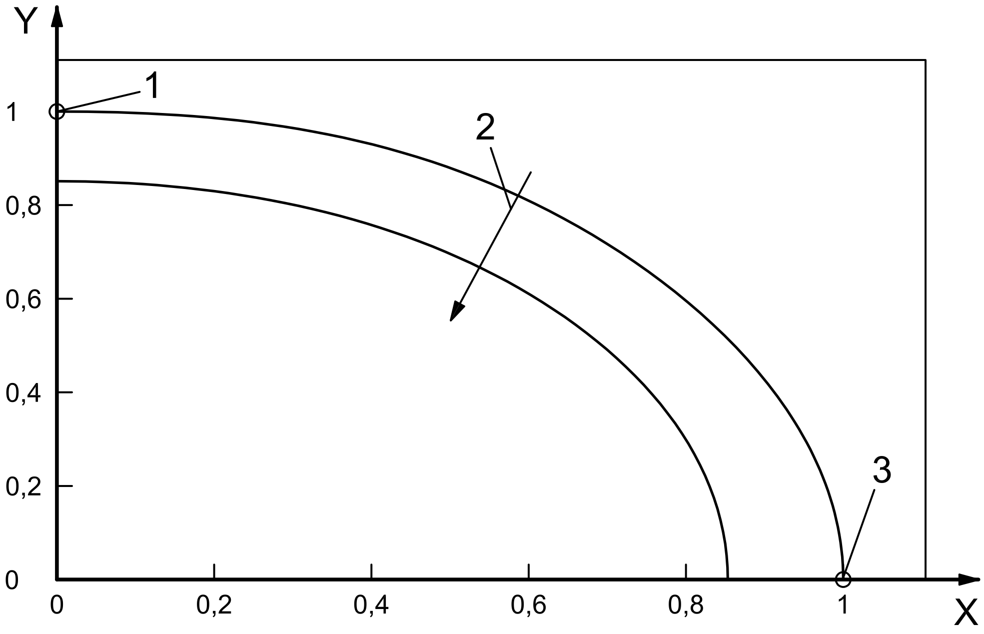
3.1.7
bundle
laid-up functional components and associated fillers in the umbilical prior to further processing

NOTE Typical functional components in a bundle include hoses, tubes, electric cables, optical fibre cables.

3.1.8
capacity curve
curve that defines the relationship between the allowable bend radius and allowable tension for an internal pressure condition

See Figure 1.

NOTE Curves can, therefore, differ for storage, testing, installation and operation scenarios.



Key

X inverse of the normalized bend radius, MBR per radius

Y normalized allowable tensile load, tension per MTL

1 maximum tensile load (MTL) with no bending

2 increasing pressure and/or increasing safety level

3 inverse of minimum bend radius (MBR) with no tension

NOTE 1 Increasing the level of safety generally increases the allowable bend radius and decreases the allowable tensile load, i.e. moves the capacity curves towards origin.

NOTE 2 Increasing the internal pressure generally increases the allowable bend radius and decreases the allowable tensile load, i.e. moves the capacity curves towards origin.

Figure 1 — Capacity curves

3.1.9
carousel
storage container that can be rotated by a drive about a vertical axis

3.1.10
caterpillar
device that holds the umbilical between belts or pads and which transfers axial linear motive power to the umbilical

NOTE A caterpillar is also known as an in-line cable engine, or haul off, or tensioner.

3.1.11
characterization data
data relating to a component or an umbilical giving an indication of performance but not giving specific acceptance/rejection criteria

3.1.12
chinese finger
type of gripper used to hold the umbilical via its outer diameter, comprised of a number of spirally interwoven wires or synthetic rope attached to a built-in anchorage arrangement

3.1.13
core
generic term used to describe an individual electrically insulated conductor

3.1.14
crab lay
installation deployment activity whereby the installation vessel moves sideways along, or at the end of, the installation route

3.1.15
crushing load
load that acts in the radial direction that might not be evenly distributed along the circumference and that is limited in length along the umbilical

NOTE A crushing load is typically induced during installation.

3.1.16
deep water
water depth generally ranging from 610 m (2 000 ft) to 1 830 m (6 000 ft)

3.1.17
design life
service life multiplied by an appropriate factor that is equal to, or greater than, one

3.1.18
design working pressure
DWP
maximum working pressure at which a hose or tube is rated for continuous operation

3.1.19
design tensile load
maximum tensile load multiplied by an appropriate factor that is equal to, or less than, one

3.1.20
end termination
mechanical fitting that is attached to the end of an umbilical and that provides a means of transferring installation and operating loads, fluid and electrical services to a mating assembly mounted on the subsea facility or surface facility

3.1.21
factory acceptance test
series of tests carried out on the completed umbilical component or complete umbilical to demonstrate the integrity of the item under test

3.1.22
filler
item wholly or partially filling the voids between the **functional components** (3.1.23) with the purpose(s) of maintaining the relative location of the components, maintaining the shape of the cross-section, influencing the weight-to-diameter ratio, separating components for wear considerations, or providing a certain radial stiffness

3.1.23
functional component
hoses, tubes, electric/optical fibre cables included within an umbilical which are required to fulfil the operational service needs

3.1.24
functional specification
document that specifies the totality of needs expressed by features, characteristics, process conditions, boundaries and exclusions defining the performance of a product or service including quality assurance requirements

3.1.25
host facility
fixed or floating facility to which the umbilical is mechanically and functionally connected and that provides the functions and services transmitted through the umbilical

EXAMPLES Platform, buoy, floating production system.

3.1.26
hydrogen scavenger
gel material applied inside the tube (metal or polymer) holding the optical fibre to absorb hydrogen ions that prevent fibre from “darkening” and from reducing transmission capabilities

3.1.27
independent verification agent
party or group independent from the manufacturer and the purchaser

3.1.28
lay-up
operation of helically assembling (SZ where appropriate) electrical cores or optical fibres into a cable*,* or hoses, tubes, electric cables, optical fibre cables into a bundle or sub-bundle

NOTE Sometimes referred to as “cabling”.

3.1.29
lay angle
angle between the axis of a spiral-wound element (e.g. armour wires) and a line parallel to the longitudinal axis of the umbilical

3.1.30
load-out
transfer of an umbilical or umbilical system from a storage facility onto an installation/shipping vessel, either by transfer spooling or by lifting the product stored on its installation/shipping reel

3.1.31
manufacturer's written specification
specification for the umbilical, the umbilical components and their manufacture, generated by the manufacturer in compliance with requirements specified by the purchaser and this part of ISO 13628

NOTE The specification may be comprised of a multiplicity of documents (design plan, inspection and test plan, test procedures, etc.).

3.1.32
maximum tensile load
maximum tensile load that an umbilical, with zero curvature, can withstand without infringing the stress criterion or suffering loss of performance

See Figure 1, and 3.1.8.

3.1.33
messenger wire
device installed or pre-fitted into an I-tube or J-tube for transferring the primary pulling device, usually a wire rope, into the tube to provide means of pulling an umbilical through the tube

3.1.34
minimum bend radius
minimum radius to which an umbilical, at zero tensile load, can be bent to without infringing the stress criterion or suffering loss of performance

See Figure 1 and 3.1.8.

3.1.35
multi-coupler
multi-way connector arrangement comprised of two mating stabplate sub-assemblies, one of which is made of a number of hydraulic and/or electric and/or optical coupler halves, each carrying a separate service, that mate simultaneously with corresponding coupler halves on the other sub-assembly when the two sub-assemblies are brought together

3.1.36
pull-in head
device used for terminating the end of an umbilical so that it can be loaded/offloaded from a vessel and pulled along the seabed and/or through an I-tube or J-tube

NOTE In some designs, the terminated armours can be used to anchor the umbilical at the top of the I-tube or J-tube. It normally is comprised of a streamlined cylindrical housing into which the umbilical armouring is terminated and within which the ends of the functional components are contained. It is usually capable of rapid disassembly to access the components for post-pull-in tests and monitoring. A form of pull-in head may also be used at the subsea end of the umbilical.

3.1.37
reel
device for storing, transporting, or installing umbilicals or components comprised of two flanges, separated by a barrel, with the barrel axis normally being horizontal

NOTE Reels are designed for the intended use.

3.1.38
service life
specified time during which the umbilical system shall be capable of meeting the functional requirements

3.1.39
S-N data
data obtained by plotting cyclic stress level versus number of cycles to failure

3.1.40
splice
join together component lengths or sub-components to achieve the required production length

3.1.41
static application
application for which the load effect(s) due to dynamic loads (e.g. wave action, induced vibrations, etc.) when installed can be neglected

NOTE Free spans, in an otherwise static umbilical, should be considered as a dynamic application.

3.1.42
subsea termination interface
mechanism that forms the transition between the umbilical and the subsea termination

NOTE The interface is comprised typically of an umbilical armour termination and/or a mechanical anchoring device for the tubes, bend stiffener/limiter, and tube or hose-end fittings. If the umbilical contains electric cables/fibre optics, then penetrator(s) and/or connectors may also be incorporated.

3.1.43
subsea umbilical termination
mechanism for mechanically, electrically, optically and/or hydraulically connecting an umbilical or jumper bundle to a subsea system

3.1.44
tensile armour
structural layer consisting of e.g. steel wires, fibre reinforced plastic rods, etc. that is used to sustain tensile loads in the umbilical

NOTE For some applications, the tensile armour may also have the additional function of providing additional weight and/or impact protection.

3.1.45
ultimate tensile load
load at which the weakest component of the umbilical bundle fails when the load is applied with the umbilical in a straight condition

3.1.46
ultra-deep water
term used to imply depths exceeding 1 830 m (6 000 ft), which can necessitate the consideration of design and/or technology alternatives

3.1.47
umbilical
group of functional components, such as electric cables, optical fibre cables, hoses, and tubes, laid up or bundled together or in combination with each other, that generally provides hydraulics, fluid injection, power and/or communication services

NOTE Other elements or armouring may be included for strength, protection, or weight considerations.

3.1.48
umbilical joint
means of joining together two lengths of umbilical to effect a repair or to achieve the required production length

3.1.49
umbilical system
umbilical, complete with end terminations and other ancillary equipment

3.1.50
unaged representative sample
non-degraded sample of umbilical, or component that has not previously been subjected to operational or installation loadings, stresses, elevated temperature, and/or other conditions that can degrade the sample

EXAMPLES Electric cables, hoses, tubes and optical fibres.

3.1.51
verification test
test performed to qualify the design and manufacture of the item for its use in service as well as to provide characterization data

3.1.52
weak link
device that is used to ensure that the umbilical parts or severs at a specified load and location

3.2 Abbreviated terms

AC alternating current

AVE apparent volumetric expansion

CP corrosion protection

DC direct current

DWP design working pressure (mathematical symbol: p_{DW})

FAT factory acceptance test

FD frequency domain

FE finite element

FEM finite element modelling

ID inside diameter (mathematical symbol: d)

LTD linearized time domain

MBR minimum bending radius at zero tensile load

MTL maximum tensile load

NDE non-destructive examination

NTD nonlinear time domain

OD outside diameter (mathematical symbol: D)

OTDR optical time-domain reflectometer

PMI portable metal identification

PRE pitting resistance equivalent

RAO response amplitude operator

ROV remotely operated vehicle

SF safety factor

SMYS specified minimum yield strength (mathematical symbol: σ_{SMY})

TDR time-domain reflectometry

TVE true volumetric expansion

UT ultrasonic testing

UV ultra-violet

VIV vortex-induced vibration

WT wall thickness (mathematical symbol: t)

4 Functional requirements

4.1 General requirements

4.1.1 Umbilical

The umbilical, and its constituent components, shall have the following characteristics:

a) be capable of withstanding specified design loads and load combinations and perform its function for the specified design life;

b) be capable of storage and operation at the specified temperatures during the design life;

c) be composed of materials compatible with the environment to which they are exposed, including permeating fluids, and in conformance with the corrosion control and compatibility requirements;

d) have electric cables capable of transmitting power and signals with the required characteristics;

e) have optical fibres capable of transmitting signals at the required wavelengths within the attenuation specified;

f) have hoses and/or tubes capable of conveying fluids at the required flow rate, pressure, temperature and cleanliness levels;

g) be capable of venting, in a controlled manner, if permeation through components can occur;

h) be capable of being installed, recovered and reinstalled as defined in the manufacturer's written specification.

4.1.2 End terminations and ancillary equipment

End-termination interfaces with the umbilical components are a critical area and should be addressed during the design review stage.

End terminations and ancillary equipment shall, as a minimum, meet the same functional requirements as the umbilical. If applicable, the following shall be demonstrated.

a) The end termination shall provide a structural interface between the umbilical and the support structure.

b) The end termination can provide a structural interface between the umbilical and bend restrictor/bend stiffener device.

c) The end termination shall not downgrade the service life of the umbilical or the system performance below the functional requirements.

d) CP shall meet the design life requirement.

e) Contingency or planned recovery of the end termination to the surface during installation shall not downgrade the service life or system performance of the umbilical.

f) The materials in the end terminations shall be compatible with any specified fluids with which they come into contact (including potential permeation).

4.2 Project-specific requirements

The purchaser shall specify the functional requirements for the umbilical.

Functional requirements neither specifically required nor specified by the purchaser but which can affect the design, materials, manufacturing, testing, installation and operation of the umbilical shall be specified by the manufacturer. If the purchaser does not specify a requirement and its absence does not affect any of these activities, the manufacturer may assume there is no requirement.

NOTE Annex A provides a basis for such specifications.

5 Safety, design and testing philosophy

5.1 Application

Clause 5 applies to umbilical systems, including umbilicals, terminations and auxiliary equipment that are built in accordance with this part of ISO 13628.

5.2 Safety objective

An overall safety objective shall be established, planned and implemented covering all phases from conceptual development until retrieval or abandonment.

All companies have policy regarding human aspects and environment issues. These are typically on an overall level, but more detailed objectives and requirements in specific areas can follow them. These policies should be used as a basis for defining the safety objective for a specified umbilical system.

5.3 Systematic review

A systematic review or analysis shall be carried out for all phases (e.g. manufacture, load-out, installation and operation) in order to identify and evaluate the consequences of single failures and series of failures in the umbilical, such that necessary remedial measures can be taken. The consequences include consequences of such events for people, for the environment and for the entire subsea system and financial interests.

The operator shall determine the extent of risk assessments and the risk assessment methods, and it should be the operator's responsibility to perform the systematic review.

5.4 Fundamental requirements

5.4.1 General

The following fundamental requirements apply.

- The materials and products shall be used as specified in this part of ISO 13628 or in the relevant material or product specification.
- Adequate supervision and quality control shall be provided during manufacture and fabrication.
- Manufacture, fabrication, handling, transportation and operation shall be carried out by personnel having the appropriate skill and experience. Reference is made to recognized standards for personnel qualifications.
- The umbilical shall be adequately maintained including inspection and preservation when applicable.
- The umbilical shall be operated in accordance with the design basis and the installation and operating manuals.

— Design reviews shall be carried out where all contributing and affected disciplines (professional sectors) are included to identify and solve any problems.

— Verification shall be performed to check compliance with provisions contained herein in addition to purchaser requirements and national and international regulations. The extent of the verification and the verification method in the various phases, including design and fabrication, shall be agreed with the purchaser. As a minimum, the manufacturer shall issue an inspection and test plan with planned surveillance and QC and shall issue this to the purchaser. The inspection and test plan shall include plans for sub-supplier and sub-contractor activities when applicable.

— Relevant information between personnel involved in the design, manufacture, fabrication, installation and operation shall be communicated in a clear manner to avoid misunderstandings.

5.4.2 Quality assurance

Equipment manufactured in accordance with this part of ISO 13628 shall conform to a certified quality assurance program. The manufacturer shall develop written specifications that describe how the quality assurance program will be implemented.

5.5 Design philosophy

5.5.1 Design principles

The umbilical system shall be designed according to the following basic principles.

— The umbilical system shall satisfy functional and operational requirements as given in the design basis.

— The umbilical system shall be designed such that an unintended event does not escalate into an accident of significantly greater extent than the original event.

— The umbilical system shall permit simple and reliable installation, retrieval and be robust with respect to use.

— The umbilical system shall provide adequate access for replacement and repair.

— Design of structural details and selection of materials shall address the effects of corrosion, ageing, erosion and wear.

— A conservative design approach shall be applied for the umbilical mechanical components. Redundancy may be considered for essential components.

5.5.2 Design basis

A design basis document shall be established in the initial stages of the design process. The design basis should contain or reference all relevant information required for design of the umbilical system. The design basis normally includes

— specifications supplied by the purchaser as specified in Annex A (e.g. functional requirements, field data, host data);

— procedures for load-effect analyses for the umbilical and associated components; see Annex F; and

— load-case matrices, as specified in Annex A (e.g. temporary conditions, installation, extreme conditions, fatigue conditions).

5.5.3 Design methodology

5.5.3.1 General

The design methodology shall include, as a minimum, the following.

a) A description of the theoretical basis, including calculation procedures and methods for evaluating the umbilical design parameters and the criteria that it is necessary to satisfy in order to meet the functional requirements shall be included.

b) Documentation of the fatigue life and extreme stress assessment methodology shall be provided.

c) Verification shall be provided of the theoretical basis via verification or qualification tests on component samples and on samples of the complete umbilical as specified in 5.6 and Annex B. The testing or documentation shall include the capacity of all umbilical structural components.

d) Simplified conservative analysis methods for checking of non-critical components, such as anti-wear layers, shall be acceptable if the method does not influence the reliability of the calculation of stresses in the other components.

e) The documented basis for the effect of internal friction on stresses and the basis for stress concentration factors to account for the geometry of metallic structural components, including stress concentrations at and within the end-termination interface, clamped accessories, contact with rigid surfaces, manufacturing tolerances, and load-induced gaps shall be documented.

f) Manufacturing and design tolerances, manufacturing-induced stresses, internal friction, welds and other effects that influence structural capacity shall be provided.

g) The design methodology shall clearly state the range and application limits to which it applies.

The design methodology shall account for the effects of wear, corrosion, fretting, manufacturing processes, installation loads, dimensional changes, creep and ageing (due to mechanical, chemical and thermal degradation) in all layers, unless the umbilical design is documented to not suffer from such effects.

If the umbilical design is outside the envelope of previously qualified designs, then the manufacturer shall perform qualification tests to test the design methodology for this new design. The qualification tests shall validate fitness-for-purpose for those design parameters that are outside the previously validated envelope. the requirements on when qualification testing shall be performed are stated in 5.6.

For steel structural parts of the end termination, recognized standards, such as BS 5950, EN 10027 and EN 10025, or equivalent shall apply.

5.5.3.2 Independent agent verification

If required by purchaser, an independent verification party should review, evaluate, and report on the design methodology to establish the range of applications for which it is suitable.

5.6 Testing

5.6.1 General

All tests specified in this part of ISO 13628 can be sorted into three categories: qualification, verification and acceptance testing. The selection of test methodology shall be agreed between the purchaser and manufacturer and shall account for the risks involved in the intended application and the practicality of the test programme in relation to the project schedule.

Guidance on the responsibility of identifying the need for qualification testing is given in A.2.9.

5.6.2 Qualification testing

Qualification testing are tests performed on a prototype component or prototype umbilical to prove that it can withstand the environment and/or loads for which it is designed and that it has the properties that it is predicted to have. It is not necessarily performed only on new designs or components, but a testing philosophy is chosen based on the purchaser's risk profile and the manufacturer's design/testing statistics. Choosing this testing philosophy reflects high project risk or low purchaser risk willingness. See also A.2.9.

For umbilicals and/or components which represent new technology or high risk, qualification testing should be performed according to a structured methodology as defined in the manufacturer's written specification, DNV RP-A203 or equivalent.

NOTE DNV RP-A203 (September 2001) defines proven and new technology as follows. Proven technology (definition): in the field, proven technology has a documented track record for a defined environment. Such documentation shall provide confidence in the technology from practical operations, with respect to the ability of the technology to meet the specified requirements. New technology (definition): new technology is technology that is not proven. This implies that the application of proven technology in a new environment or an unproven technology in a known environment, are both new technology. The degree of new technology can be classified in categories to be used as input to risk assessments (see DNV RP-A203).

It is the responsibility of the manufacturer to document the track record for, and to identify the need for, qualification testing. The evaluation of existing data and the extent of qualification testing shall be approved by the purchaser.

The above implies that qualification testing should be carried out in cases where no relevant track record or test data exist for the umbilical design, component and/or environment in question.

Whenever a new component is used and the properties of this component affect the global properties of the umbilical, qualification testing of the umbilical, and not only the individual component, shall be carried out.

Analysis may be used to compare umbilical and component designs and to judge the relevance of data from previous testing and operation experience. Such analysis shall be carried out according to the requirements of this part of ISO 13628; see Clause 6.

Unless otherwise agreed, all qualification testing shall be performed prior to manufacture of the umbilical.

Qualification testing should also be considered for the end terminations and midline connectors and ancillary equipment, if applicable.

5.6.3 Verification testing

Verification tests performed on an umbilical component, or a production length of umbilical, are designed to determine conformance with specified design requirements, or predicted properties.

Verification tests shall include end terminations and midline connectors and ancillary equipment.

5.6.4 Acceptance testing

Acceptance testing is testing performed to ensure that the umbilical or components meet the design values/criteria specified by the purchaser and stated in the design basis, i.e. to ensure that the sample subjected to verification testing is representative for the manufactured components. Acceptance testing includes testing performed on the actual delivery component or umbilical, e.g. tests that are performed to document that a welded tube string can withstand the test pressure over a defined time period, or to verify that an electrical/optical signal element has the characteristics it is designed to have. These tests are normally performed several times per product. Required acceptance tests for common components are outlined in Annex B.

Acceptance tests shall also be carried out for the end terminations and midline connectors and ancillary equipment.

6 Design requirements

6.1 General

The umbilical and its constituent components shall be designed to meet the functional and technical requirements of this part of ISO 13628. The requirement for analysis shall result from a risk evaluation for the umbilical. The factors that shall be considered are, amongst others, the environmental and service conditions for the umbilical and the consequences of non-performance.

Fatigue analyses shall include fatigue at operating temperature, a prediction of load cycles and translation of load cycles into nominal stress or strain cycles. The load cycles shall include reeling, handling, construction, installation, unplanned events such as partial recovery and reinstallation, as stated in the design basis.

The effect of mean stresses, internal (service) and external (environmental) plastic pre-strain and rate of cyclic loading shall be considered when determining fatigue resistance.

Assessment of fatigue resistance may be based on either S-N data obtained on representative components or a fracture mechanics fatigue-life assessment. The selection of safety factors shall take into account the inherent sensitivity in fatigue-resistance predictions for such designs.

Account shall be taken of the effect of the strain accumulated during manufacturing, handling and installation on the umbilical fatigue performance.

Guidance on fatigue testing is given in Annex E.

6.2 Loads

6.2.1 Load classification

Loads are classified as functional, environmental (external) or accidental, and defined as follows.

a) Functional loads are all loads acting on the umbilical during manufacture, installation and operation, including those loads that can act on the umbilical in still water, with the exception of wind, wave or current loads.

b) Environmental loads are those loads induced by external forces caused directly or indirectly by all environmental parameters acting on the umbilical, including those induced by waves, currents and vessel motion.

c) Accidental loads are those loads caused directly or indirectly by unplanned activities. Accidental loads shall be understood as loads to which the umbilical can be subjected in case of abnormal conditions, incorrect operation or technical failure as defined by purchaser.

6.2.2 Functional loads

The functional loads of relevance for the actual umbilical system shall be identified. Examples of functional loads are

a) loads due to weight and buoyancy of the umbilical, its contents and attachments, both temporary and permanent;

b) marine growth based on information for the actual geographical location;

c) pressure within hoses and tubes;

d) thermal loads resulting from radiant heat, hot injected gas/fluids, or from adjacent hot riser(s);

e) external hydrostatic pressure;

f) testing pressures, including installation, commissioning and storage pressures;

g) external soil or rock reaction forces for trenched, buried or rock-dumped umbilicals;

h) static reaction and deformation loads from supports and protection structures;

i) temporary installation or recovery loads, including applied tension and crushing loads, impact loads and guidance induced loads;

j) displacements due to pressure- and tension-induced rotation;

k) interaction effects of clamping the umbilical;

l) loads due to rigid or flexible pipe crossings, or spans;

m) loads due to positioning tolerances during installation;

n) loads from inspection and maintenance tools.

6.2.3 Environmental loads

The environmental loads of relevance for the actual geographical location shall be identified. Examples of environmental loads are

a) waves;

b) current;

c) wave-frequency host motions;

d) low-frequency host motions due to wave drift and wind loading and station-keeping system characteristics;

e) vortex-induced host motions due to current loading;

f) host offset from nominal position due to environmental loading;

g) ice;

h) earthquake;

i) subsea landslides.

6.2.4 Accidental loads

The accidental-load scenarios of relevance for the actual umbilical system shall be identified. Examples of accidental loads are

a) dropped objects;

b) trawl-board impact;

c) anchor-line failure;

d) fire and explosion;

e) compartment damage or unintended flooding of support vessel or other buoyancy device (e.g. subsea arch structure);

f) loss of buoyancy modules in lazy-wave umbilical configuration;

g) failure of thrusters;

h) dynamic-positioning failure

i) net external pressure (due to flooding, crushing, incorrect installation rate, etc.);

j) net internal pressure;

k) failure of turret drive system.

6.2.5 Load combinations and conditions

6.2.5.1 General

The umbilical shall be designed to withstand the most onerous load combinations of functional, environmental and accidental loads selected from the extreme design and fatigue environment specified by the purchaser. The load combination selection shall cover all relevant loading conditions that can be applied to the umbilical during factory-acceptance testing, installation, operation and any temporary condition specified by the purchaser as defined in Annex A. Variation of the loads with respect to time shall be addressed.

6.2.5.2 Extreme load combinations

The extreme load combinations shall reflect the most probable extreme combined load effect over a specified design time period. Extreme load combinations shall be defined for permanent as well as temporary design conditions as follows.

a) Normal operation: This applies to the permanent operational state of the umbilical, considering functional and environmental loads. Design conditions with a 10^{-2} annual exceedence probability (i.e. 100 year return period) shall be applied.

b) Abnormal operation: This applies to the permanent operational state of the umbilical considering functional, environmental and accidental loads. Combined design conditions with an annual exceedence probability between 10^{-2} and 10^{-4} shall be considered.

c) Temporary conditions: This applies to temporary conditions, such as installation, retrieval, pressure testing and other intermediate conditions prior to permanent operation, e.g. temporary in-field configurations prior to platform tie-in of umbilicals in dynamic service or burial of static umbilicals. The applicable return period for the design conditions depends on the seasonal timing and duration of the temporary period. The return periods shall be defined such that the probability of exceedence in the temporary state is no greater than that of the permanent normal operational state.

Accidental loads in terms of frequency of occurrence and magnitude should be determined based on risk analyses and relevant accumulated experiences. Account shall be taken of other loads that can reasonably be present at the time of the accidental event. Further, accidental loads shall be determined with due account of the factors of influence. Such factors may be personnel qualifications, operational procedures, the arrangement of the installation, equipment, safety systems and control procedures. Combined design conditions with an annual exceedence probability higher than 10^{-2} should be considered as normal operation. Load combinations with an annual exceedence probability lower than 10^{-4} may normally be ignored.

Recommended load combinations for assessment of the extreme-load effect are summarized in Table 1.

Table 1 — Load combinations

Load type	Temporary conditions	Normal operation	Abnormal operation
Functional	Expected, specified or extreme	Expected, specified or extreme	Expected, specified or extreme
Environmental	Probability of exceedence according to season and duration of the temporary period. If more information is not available, the following return period values may be applied for temporary conditions: a 100 year return period if duration in excess of 6 months; a 10 year return period for the actual seasonal environmental condition if duration is in excess of 3 days but less than 6 months. For temporary conditions with a duration less than 3 days or operations that can be terminated within a 3 day window, an extreme load condition may be specified and start-up /shut down of the operation is then based on reliable weather forecasts.	Annual exceedence probability of 10^{-2}	Annual exceedence probability of 10^{-2} to 10^{-4} If combined with accidental loads, the environmental load may be established so that the combined annual exceedence probability is 10^{-4}.
Accidental	As appropriate to the actual temporary condition	Not applicable	Individual considerations. Annual exceedence probability $\geqslant 10^{-4}$.

6.2.5.3 Fatigue load conditions

Fatigue damage shall be calculated considering all relevant cyclic loading imposed on the umbilical over its design life covering fabrication, temporary conditions including installation as well as in-place operation. Consideration shall be given to the long-term probabilistic nature of the fatigue loading. The following principal sources of fatigue damage shall be evaluated:

a) wave-frequency response of the umbilical due to direct wave loading as well as wave induced (first-order) host motions;

b) slow drift (second-order) host motions including variation of mean position;

c) VIV response of the umbilical under steady current conditions;

d) possible VIV motions of the host hull where applicable (typically spar platforms);

e) cyclic loading during fabrication and installation, e.g. reeling/unreeling;

f) cyclic loading due to operation of the umbilical, e.g. variation in temperature and pressure.

The interfaces to the supporting rigid structures are normally the most critical locations for fatigue loading on in-place dynamic umbilicals operated from a floating host. The fatigue performance of the umbilical is in most situations governed by the bend limiting devices installed at the rigid supports, e.g. bend stiffener or bellmouth.

Consideration shall be given to the long-term operation/performance of the host/station-keeping system, e.g. variation of loading conditions/draft, change in mooring pretension, change in restoring due to additional riser tie-ins, re-location, connected/disconnected operational mode for loading systems, etc. Conservative assumptions shall be made in case of lack of precise information.

Average values may be applied for functional loading unless more precise information is available regarding the long-term variation of functional loading.

Calculation of fatigue stresses shall address wear/corrosion.

Calculation of fatigue stresses should, unless more precise information is available, be based on nominal component dimensions minus half the corrosion/wear allowance. In a uniform thickness degradation environment, this corresponds to the average wall thickness over the umbilical service life.

6.3 Load effect analysis

6.3.1 General

The manufacturer shall, as part of the design evaluations, consider the results of any installation, dynamic service and structural analysis that might have been carried out in relation to the umbilical design. The output of the analyses shall be used to demonstrate that the umbilical is suitable for installation and will remain fit for service during its design life.

The analysis results shall be verified either during qualification or verification testing. In lieu of physical testing of the components/umbilical, representative historical data may be offered by the manufacturer to verify the models or calculations used; see Clause 5.

All load-effect analyses shall be based on accepted physical/numerical principles for modelling of the umbilical response in all relevant static- and dynamic-loading scenarios. All of the software tools used for the umbilical global and local analysis should be

— verified against closed-form analytical solutions;

— verified by a range of simulations or by an independent verification agent that the generic model/software tool is internally consistent and that it does not contain detectable flaws; and

— calibrated against full-scale tests by means of manipulating the independent variables of the software model to obtain a match between the observed and simulated distributions of the dependent variables.

The validity range of the calibration shall be documented.

The accuracy/validity range of the software should be specified based on a correlation to observed values from the physical testing (full scale/model tests).

The manufacturer shall demonstrate to the purchaser supporting verification, validation and confirmation documentation for all global and local analysis tools, including those developed in-house, used for the umbilical analysis and design.

The main types of load-effect analyses in Table 2 may be required, depending on the actual concept.

Table 2 — Load-effect analysis

Type of analysis	Description	Main application
Global analysis	Static- and dynamic-load effect analysis due to static and dynamic environmental loading (current, waves and host offset/motions)	Extreme-load analyses of umbilicals in dynamic service Fatigue-load analyses of umbilicals in dynamic service Analyses of installation scenarios to establish limiting criteria for the operations
On-bottom stability analyses	Analyses to assess the displacement of on-bottom umbilicals exposed to functional and environmental loading	Stability analysis of umbilicals in static service Stability analysis of laying operations Stability analysis of on-bottom part of umbilicals in dynamic service
VIV analyses	Analysis of VIV in steady current	Fatigue analyses of umbilicals in dynamic service Fatigue analyses of umbilicals during installation operations Assessment of requirement for VIV suppression devices Considered as a sensitivity assessment of the effect on drag coefficients for application to global analyses and interference analyses where these analyses are critical
Interference analyses	Analysis to determine minimum distance or contact loads/forces between adjacent structures exposed to static and dynamic environmental loading	Assessment of minimum distance to neighbouring risers, umbilicals and mooring lines; applies to in-place analyses of umbilicals in dynamic service as well as installation scenarios
Free-spanning analyses	Analysis of VIV of free spans in steady current and establish product curvature	Fatigue analyses of free spans of umbilicals in static service
Pull-in analyses	Analysis of pull-in installation operations	Analysis of I/J tube pull-in operations of umbilicals in dynamic/static service
Installation analysis	Analyses to establish the lay limits of installation operations and to assess and compare the variables for all planned and contingency operations	Assessment of allowable environmental criteria for first-end initiation, initial lay, normal lay, curve lay, second-end approach, second-end installation; either end may be a subsea termination, an I/J tube pull-in operation or a landfall approach Assessment that planned handling routes and loads are within manufacturer's recommendations or limitations (combinations of bend radius, contact force, tension, squeeze load from caterpillar, internal pressure) Analysis of the installation scenario and comparison with assumptions used for the calculation of fatigue damage
Structural analyses	Establish loads and/or load sharing between the components of the umbilical cross-section	Establish combined tension/curvature capacity for the umbilical cross-section (basis for global capacity checks) Establish stress/strain in individual components of the umbilical cross-section for a given tension/curvature combination (basis for, e.g., fatigue analyses) Establish cross-sectional stiffness (bending, axial, torsional) for application to global analyses Analyses of installation scenarios to establish limiting criteria for the operations (e.g., assessment of load effects due to crushing loads from caterpillars)

6.3.2 Global load-effect analysis

The purpose of global load-effect analyses is to describe the overall static and dynamic structural response of the umbilical. The global analyses shall be based on accepted principles of static and dynamics analysis, with the use of discrete modelling, strength of materials, environmental loading and soil mechanics to determine reliable load effects on the umbilical system. Global load-effect analyses should be based on numerical simulations by means of FE, or similar, analyses with due regard to the following issues.

— The global response model shall include the complete umbilical system considering accurate modelling of stiffness, mass, damping and hydrodynamic load effects along the umbilical in addition to top and bottom boundary conditions.

— Appropriate drag and inertia coefficients for the selected method shall be applied. Effects of marine growth shall be considered. Recognized principles shall be applied to assess possible drag magnification due to VIV.

— The global cross-sectional properties shall be representative of the stiffness and damping properties of the actual umbilical cross-section.

— The umbilical shall be modelled with a sufficient number of elements to represent environmental loading and structural response and to resolve load effects in all critical areas. Time and/or frequency discretization shall be verified to ensure that the desired accuracy is obtained. The principles for model validation as outlined in Annex F, Appendix F of DNV OS-F201, or equivalent may be applied.

— Sensitivity studies should be considered to investigate the influence of uncertain system parameters (e.g. soil data, hydrodynamic coefficients, marine growth, structural damping and stiffness, host draft, current modelling in fatigue analysis, etc.). The main purpose is to quantify model uncertainties, support rational conservative assumptions and identify areas where a more thorough investigation is needed.

— Any use of simplified modelling and/or analysis techniques shall be verified by more advanced modelling and/or analyses for representative (critical) load cases.

For further details, reference can be made to Annex F.

6.3.3 On bottom stability analysis

The umbilical shall be designed to be sufficiently stable, when laid on the seabed, to meet the requirements of Clause 4. The need for additional ballast and impact on other installation activities shall be evaluated, if required.

DNV RP-F109 is an example of a standard suitable for assessing the lateral stability of umbilicals exposed to current and wave loading.

6.3.4 Pull-out analysis

Routing of the umbilicals on the seabed often requires that static service umbilicals are arranged in a predefined, curved configuration. Pull-out analyses shall be performed to document that the geometry of curved on-bottom sections of the umbilical remains stable for the maximum apparent effective tension in the umbilical. It shall be documented that the axial and sideways soil resistance is sufficient to support the tension in a curved, on-bottom configuration. Static analyses using analytical expressions for the holding capacity of straight and curved umbilical sections as given in DNV RP-F109 should be applied. Sensitivity studies shall be performed to support rational, conservative assumptions for the governing parameters (e.g. soil friction coefficients and submerged weight).

Pull-out analyses shall be performed to assess the capacity of the seabed portion of an in-place dynamic service umbilical system, in terms of its ability to absorb the bottom tension generated by the dynamic part of the umbilical system. Pull-out analyses shall also be conducted to document the stability of curved sections during lay installations.

6.3.5 Vortex-induced vibration analysis

The effect of vortex-induced vibration (VIV) shall be considered for all umbilicals exposed to current and/or waves. For cases where VIV is likely to represent a design problem, refined assessment according to the methods outlined in this subclause is required. The requirement for qualification testing shall be assessed in accordance with 5.6.

In most cases the focus of this assessment is to evaluate whether the fatigue capacity is sufficient. Accordingly, a simplified conservative VIV analysis suffices if the resulting fatigue damage is within the tolerated limit. If the simplified analysis indicates insufficient fatigue capacity, more sophisticated methods should be chosen. The method should be chosen according to the specific case investigated.

Important parameters for VIV response are cross-sectional diameter, mass, damping, bending stiffness and effective tension. Mass ratio, reduced damping and number of natural frequencies within the bandwidth of the vortex shedding frequency can be important for a determination of lock-in behaviour and VIV amplitude.

Methodology for the prediction of fatigue damage due to VIV on other slender elements such as pipelines and risers may be applied with special attention to umbilical-specific properties. In particular, cross-sectional stiffness and damping properties shall be selected to represent the umbilical VIV (typically small amplitude) response. VIV analyses are in most cases carried out using a modal approach. The eigenmodes/ eigenfrequencies applied in such analyses shall reflect the physical umbilical configuration (i.e. geometrical configuration, tension, boundary conditions, etc.). The number of modes shall be sufficient to determine the umbilical response at the highest VIV frequency. For further guidance on VIV analysis methodology, reference can be made to ANSI/API RP 2RD, DNV RP-F204, or other recognized industry standards.

The increase in the drag coefficient due to cross-flow VIV for application in global response analyses may be estimated in accordance with DNV RP-F203.

If vortex-suppression devices are used for the mitigation of VIV, their efficiency shall be qualified. In most cases, vortex-suppression devices increase the in-line drag of the umbilical. This shall be accounted for in other design analyses, such as global load-effect analyses.

6.3.6 Interference analysis

The system design shall include a check of possible interference with other adjacent structures (e.g. host hull, mooring lines, risers, umbilicals or any other obstacles). Critical loading conditions are normally governed by extreme current events. The interference assessment shall include relevant installation scenarios. Normal operation as well as accidental scenarios shall be considered for the in-place condition.

Interference analysis requires information on the entire host/umbilical/riser/mooring system and it is the purchaser's responsibility to provide the required information; the responsibility to carry out the analysis is defined in Annex A; see Table A.2.

The basic design strategy should be that no impact with other structures is allowed. In this case, interference analyses shall document sufficient spacing between the umbilical and adjacent structures for all critical-load cases. Due regard shall be given to hydrodynamic interaction in terms of wake effects on the downstream configuration (i.e. reduced drag force and non-zero lift force as function of distance from upstream configuration). Effects from possible VIV on the drag coefficients for the upstream and downstream configurations shall be evaluated and implemented in a conservative way supported by sensitivity studies.

The minimum clearance between two adjacent slender structures should be greater than $D_1 + D_2$, where D_1 and D_2 are the outer diameters of the slender structures.

Umbilicals in dynamic service operated from hosts are normally placed close to other dynamic structures such as risers. The static and dynamic response characteristics of the adjacent slender structures should be as similar as possible to avoid interference. This may be accomplished, to some extent, by assigning a common target value for the weight-diameter ratio for the adjacent slender structures. The weight-diameter ratio is defined as $\gamma = W/D$, where W is the submerged weight per unit length and D is the outer diameter. It should be noted that the weight-diameter ratio can be significantly influenced by variable functional loading due to, for example, marine growth and the internal fluid content of risers. Sensitivity studies shall be performed to support assumptions regarding functional loading for application in interference analyses.

Account shall be taken of installation tolerances and length manufacturing tolerances.

The same basis for selection of drag coefficients shall be applied for umbilicals and neighbouring risers that can interfere with each other. It is the responsibility of the purchaser to ensure that there is sufficient distance in instances where neighbouring risers are delivered by different manufacturers.

The interference analyses are essentially global load-effect analyses with due regard to the modelling of hydrodynamic interaction. Industry standards, such as outlined in DNV RP-F203 or equivalent should be adhered to. Hydrodynamic interaction models for new applications (e.g. different diameters of the adjacent structures, VIV-suppression devices, etc.) shall be validated on the basis of physical testing.

An alternative design strategy that may be applied is to allow for structural impact in the most extreme load conditions. In this case, it shall be documented that the structural integrity is not endangered due to impact loads. Wear fatigue and extreme impact load shall be considered.

The engineering efforts required to qualify an umbilical system for structural impact is hence substantially more demanding compared to that for a no-impact design criterion. Load-effect models to account for structural impact should be validated with basis in physical testing.

Structural impact should be avoided in the buoyancy section of wave-type configurations.

6.3.7 Free spanning analysis

As-laid umbilicals on the seabed can suffer VIV in a steady bottom current under span-length and tension combinations. For umbilicals at the seabed, reference is made to DNV RP F-105 or equivalent. Due consideration shall be made to the specific properties of the umbilical. In particular, empirical equations for natural frequencies and unit amplitude stress levels are not directly applicable to umbilicals. FE analysis should be applied for determination of eigen modes with due regard to boundary conditions and multi-span scenarios.

Umbilicals are normally more tension-dominated than pipelines due to the low bending stiffness. Effective as-laid tension is, hence, important for the prediction of participating modes. The uncertainty in the tension can be large, causing large uncertainties in the VIV fatigue-damage prediction. Sensitivity studies shall be performed to support rational, conservative assumptions.

6.3.8 Pull-in analyses

The purpose of a pull-in analysis is to provide an estimate of the required pulling force for the installation of the umbilical in I- and J-tubes or other supporting structures. The pull-in analysis should in general be comprised of

— an estimation of the friction force due to the weight of the umbilical;

— an estimation of the friction force due to the bends around corners, if relevant;

— an estimation of the required pulling force due to bending of the umbilical, if relevant;

— an estimation of reverse pull-in analysis for contingency scenarios or for future removal and/or abandonment.

Pull-in analyses may be conducted by means of conservative analytical formulas or by FE-based computer analyses.

Analytical expressions can be found in literature for the friction force due to weight, due to pulling around corners and due to bending (e.g. the equation for bending around corners is given in DNV RP-E305). The contributions from friction forces and bending of the umbilical should be added together in a conservative manner.

Computer analyses by use of general purpose FE code should be applied in the case of complex pull-in scenarios. Such analyses should be performed as non-linear static analyses. The load application shall represent the actual pull-in scenario. Due regard shall be given to the modelling of constraints and contact forces from the supporting structure (e.g. bend geometry with appropriate friction-force modelling). A contact formulation is required in order to estimate the friction force and, accordingly, the required pulling force.

6.3.9 Structural analysis

6.3.9.1 General

The purpose of the structural analysis is to establish a design for the umbilical and its constituent components that shall be capable of withstanding the design loads and conditions envisaged during manufacture, load-out, recovery, repair, installation and also for the operational conditions throughout the design life.

Details relating to structural analyses of umbilical components are provided within 7.2 to 7.5 for individual component design.

The structural analysis includes a description of the load-sharing between components in the cross-section to determine the stresses and strains in each component and to establish the stiffness parameters required for global analyses. The results from structural analyses can be grouped into the following main categories:

— capacity curves in terms of tension versus curvature at a specific pressure, if applicable;

— assessment of maximum allowable crushing loads;

— stresses and strains used for fatigue calculations;

— cross-sectional stiffness parameters for application as input to global load effect analyses.

The structural analysis should be based on accepted principles of structural mechanics and strength of materials and may be based on empirical, analytical or numerical (FE) methods that are qualified by structural testing. See Clause F.3 for an overview of the fatigue-analysis strategies.

Maximum allowable stress/strain and usage factor for each component (tube, electric cable, strength member, sheath, etc.) in the installation, in the in-place pressure test and in the operation phase shall be clearly indicated and justified by the manufacturer.

6.3.9.2 Modelling and analysis requirements

The analysis shall demonstrate and justify that the structural and functional materials used within the umbilical system are designed to satisfy the application requirements of the material throughout the umbilical design life. This shall be performed using recognized standards and applicable factors of safety if they are available.

The following shall be considered:

a) deterioration of material properties and degradation as a result of ageing throughout the service life;

b) materials selection, including corrosion of metallic elements, cathodic attack and delamination of bonded elements;

c) fatigue of structural and functional components (e.g. metallic tubes, armour wires, copper conductor, fillers, bend stiffeners, polymers);

d) contact pressure and friction among different umbilical components;

e) effects of environmental conditions, (for example UV radiation, temperature, ozone and long-term exposure to seawater and permeated fluids);

f) cumulative effects of strain of copper conductors, armour wires, metallic tubes and fibres throughout the manufacturing processes, handling, and installation operations;

g) strain of optical fibres;

h) assessment of lateral deformations and stress/strain of the individual components due to crushing loads during storage and installation.

The load effects in the umbilical cross-section may be documented by qualification or verification testing. Numerical methods may also be used to predict local stresses. If numerical analysis is used, the analysis results may be qualified as described in Clause 5 and F.3.

Design formulas are related to the specific umbilical design and may be validated for those specific designs by strain-gauge results from prototype tests. Justification for extrapolation of results shall be documented. When considering the use of analytical methods, the actual load situation in the umbilical shall be considered, especially with regard to combined loading.

Models for structural analysis should be capable of describing the load sharing between each component of the cross-section based on evaluating the stiffness contribution from each component.

The load-sharing analysis shall be based on nominal dimensions. It is necessary to take dimensional tolerances, including effects from corrosion and wear, into account in the stress and fatigue analysis.

Tolerances shall be considered in wall-thickness sizing of steel tubes.

The internal frictional resistance resulting from internal contact forces shall be applied to calculate the friction stresses that are added to the elastic axial and bending stresses in fatigue and extreme stress calculations. Sensitivity studies should be conducted on the internal friction factor as part of the fatigue analysis.

NOTE 1 Friction can influence the global damping and stiffness behaviour and it is, therefore, necessary to consider it in global dynamic analyses.

In cases where fretting and wear due to a combination of internal contact forces, metal-to-metal contact and relative deformations can occur, it is necessary to take this into account as part of the fatigue calculation.

It is necessary to give special attention to the terminations of dynamic umbilicals in operation. Due to high bending gradients, end effects can occur due to the helically layered umbilical structure. It is necessary to evaluate or document by testing (qualification or verification testing according to Clause 5) the stress amplification due to this effect. This governs for both extreme stress and fatigue evaluations.

NOTE 2 For standard service-life tests of dynamic umbilicals, the umbilical components are normally terminated by end fittings providing axial fixation. Provided that the length of the specimen is shorter than the real length from the dynamically curved section to the end termination, such tests are normally conservative with respect to end effects. To avoid such conservatism, validated 3D structural analysis models can be used to adjust the test program to simulate the real loading conditions.

6.4 Installation analysis

All transport, load transfer, lifting, subsea operations shall be performed according to company requirements, DNV Rules for Planning and Execution of Marine Operations or other equivalent standard.

Installation analysis shall demonstrate that suitable installation equipment (tensioners, pads, chutes, etc.) and procedures will be used to install the umbilical without risk of damage. In particular, load transfer, friction between umbilical components, crushing resistance and friction between umbilical and pads shall be evaluated and accounted for in the installation analysis.

In addition, a recovery analysis shall be performed. Conditions of recovery shall be identified. The analysis shall be conducted in the same way as for the installation analysis. The utilization factors identical to those for the installation case shall be taken.

6.5 Fatigue life

The umbilical shall be designed with fatigue life that is equal to, or greater than 10 times the service life. The service life is determined on a project-specific basis.

Qualification or verification testing can be considered necessary to confirm that the manufacturer's design methodology, analysis methodologies and software tools are mature and accurate for the prediction of fatigue damage and fatigue life.

7 Component design, manufacture and test

7.1 General

7.1.1 Design verification

The umbilical components shall be designed and manufactured to meet the umbilical functional and technical requirements. Conformance shall be demonstrated by verification and acceptance testing.

For new component designs that are similar to previously verified designs and whose performance can be predicted with a high level of confidence, design verification tests may be included with some or all of the component FATs. For unusual designs or designs significantly different from previously verified designs, design verification testing shall be undertaken as a separate program.

If the component design is similar to a previously validated design and the umbilical is being installed under similar environmental and service conditions, design verification may be substituted by previous historical design verification data.

The performance of verification and acceptance tests shall also be considered for the end terminations and midline connectors and ancillary equipment, if applicable.

NOTE Verification and acceptance tests that it is necessary to perform during and on completion of component manufacture specified in this subclause are summarized in Annex B.

7.1.2 Quality plan

Before production commences, the manufacturer shall prepare a quality plan. The quality plan shall demonstrate how the specified properties can be achieved and verified through the proposed manufacturing route. The quality plan shall address all factors that influence the quality and reliability of production. All main manufacturing steps from control of received raw material to shipment of the finished product, including all examination and check points, should be covered in detail. References to the procedures established for the execution of all steps shall be included. The quality plan shall be approved by the purchaser and shall, as a minimum, contain the following information:

— plan(s) and process flow description/diagram;

— project-specific quality plan;

— manufacturing process;

— manufacturer(s) of functional components and any supplier quality plans;

— handling, loading and shipping procedures.

7.1.3 Materials selection

The choice of the materials shall be made with a consideration of the following:

a) installed environment;

b) installed duty;

c) processability;

d) in-service repair;

e) degradation related to the seawater environment and service fluids.

NOTE The EEMUA publication No. 194 includes guidance on materials selection for umbilicals and subsea equipment.

7.2 Electric cables

7.2.1 General

Electric cables shall be capable of continuous operation with the insulated conductors operating in a fully flooded seawater environment.

The design of the electric cables shall recognize that the cables may be terminated in some form of water blocking arrangement(s), which shall function throughout the design life.

7.2.2 Operating voltages

The following definitions shall be used.

a) U_0 is the rated power-frequency voltage between conductor and earth or metallic screen, for which the cable is designed;

b) U is the rated power-frequency voltage between conductors, for which the cable is designed;

c) U_m is the maximum value of the “highest system voltage” for which the equipment may be used; see IEC 60038.

The standard voltage ratings shall be as described in IEC 60502-1 and IEC 60502-2, such as 0,6/1 (1,2) kV, 1,8/3 (3,6) kV and 3,6/6 (7,2) kV.

Whether a cable is intended for a power or signal application shall be defined in the purchaser's functional specification.

This definition shall be used to identify which type of tests and conditions normally apply as described.

In the event cables are used for “Signal on Power”, then both sets of conditions apply.

7.2.3 Power cables

Power-cable voltage ratings shall be selected up to the standard rated voltages $U_0 / U(U_m) = 3{,}6/6\ (7{,}2)$ KV rms, where U_0, U and U_m are as defined in IEC 60502-1 and IEC 60502-2.

7.2.4 Signal cables

Signal cables shall be designed to transmit electrical control and communication signals in the voltage range 0 V rms to $U_0 / U(U_m) = 0{,}6/1\,(1{,}2)$ kV rms, where U_0, U and U_m are as defined in IEC 60502-1 and IEC 60502-2.

7.2.5 Construction

7.2.5.1 General

Various cable constructions are acceptable for use in a subsea umbilical, however the chosen design shall be verified according to requirements defined in Clause 4.

Cables shall be manufactured in accordance with the manufacturer's written specification.

Some cables may include screening and/or armouring depending on intended service or for other reasons.

Electric cores and cables should be manufactured as continuous lengths.

If splices are necessary to achieve the final length requirements, these shall be carried out in accordance with the qualified procedures by qualified personnel specified in the manufacturer's written specification. Splices shall also be subject to the same qualification and acceptance criteria as the insulated conductors and cables.

In a multi-core cable, the construction shall ensure that the cores can be readily separated for termination purposes and do not adhere or do not bond to the sheath, fillers, binder tape or adjacent cores.

As cable cores are, in many cases, sealed by boot-seal methods, the surface of the insulation shall be round, smooth and free from marks, indentations and surface defects that can affect sealing.

On a design-specific basis, consideration shall be given to conductor-strain relief due to compressive and tensile forces and the potential for damaging crushing forces that can arise in the laid-up components, particularly for deepwater service.

Designs shall take into consideration the effects and mitigation of gas migration in electric cables.

7.2.5.2 Construction material

Electric-cable construction materials (such as insulation, fillers, sheathing, etc.) shall be oil/dielectric-fluid-resistant in order to avoid deterioration of their electrical and physical properties if terminations/connectors are of the pressure-compensated type that normally uses electrical or hydraulic oil/dielectric fluid as an equalizing fluid.

7.2.5.3 Conductor

The conductors shall be fabricated from high-conductivity copper wire and shall comply with the relevant conductivity and material requirements of IEC 60228. The conductors shall be manufactured from annealed circular copper wire.

If stranded, each conductor shall be comprised of a minimum of seven strands. The minimum nominal cross-sectional area shall be 2,5 mm^2 (0,004 in^2). The nominal cross-sectional area for the conductor shall meet the functional requirements of Clause 4. The relationship between conductor size, strand count and stiffness should be considered.

7.2.5.4 Insulation

The insulation material shall be suitable for immersion in seawater.

The chosen insulation material shall be of virgin stock applied as a continuous seamless circular single/multiple extrusion and shall meet the requirements of IEC 60502-1 and IEC 60502-2.

Materials that have been used successfully, e.g. thermoplastic polyethylene and various grades of ethylene propylene rubber, may be used. These materials shall keep their insulating properties for the full service life and be proven to keep the required mechanical properties under the actual temperature and pressure conditions. During the material selection process, consideration shall be given to the operating temperature.

The minimum allowable insulation thickness shall be stated in the manufacturer's written specification.

Depending on voltage rating, insulation material and thickness, non-metallic conductor and insulation screening may be required, as specified in IEC 60502-1 and IEC 60502-2.

7.2.5.5 Insulation coding

The insulated conductors shall be identified either by colour or by numbers. If numbers are employed, these shall be printed at regular intervals not exceeding 100 mm (4,0 in) along the length of each core. The numbers and/or colours employed shall be cited in the manufacturer's written specification.

Coding shall be stable under heat ageing and shall not cause a failure to satisfy the requirements of Clause 4.

Embossed printing is not permitted.

7.2.5.6 Core lay-up

The process of twisting individual cores shall be qualified for the specific application.

If an alternative lay-up technique is used, then it shall be qualified for the service.

For an intermediate lay-up operation, the cabled cores may be bound with a helically applied overlapping tape to ensure bundle stability and a circular cross-section.

The lay-up operation shall minimize compressive forces between the cores to minimize the extent of deformation of the insulation.

7.2.5.7 Fillers

To achieve a circular consolidated arrangement, fillers or extruded filling shall be included in the interstices. Any filler and binder tape materials shall be compatible with other materials in the cable. In particular, the effect on electrical insulation shall be considered. The materials shall be as stated in the manufacturer's written specification. The binder tape can be longitudinally applied or helically applied depending on whether or not a screen is applied.

7.2.5.8 Screening

If required, the cable shall be screened with a suitable metallic tape, or a two-component tape comprised of a thin metallic film, bonded to a polymer-based substrate. The thickness and number of layers shall be as stated in the manufacturer's written specification. The screen shall be electrically continuous throughout the cable length, and should be applied in such a manner that its electrical continuity shall not be broken throughout its design life.

Plain metal tape screens, for electric cables or individual power cores, shall provide 100 % coverage of the enclosed electrical cores. They shall be applied helically with an overlap. The screen shall not be applied directly over the twisted cores without due consideration for the cores beneath.

If present, a drain wire shall have a minimum of three strands and the total cross-sectional area shall not be less than 0,35 mm^2 (0,000 5 in^2). It shall be incorporated in such a way that the drain wire remains in contact with the metallic part of the screen.

7.2.5.9 Sheathing

The electric cable sheath shall be of a polymeric material incorporating protection against UV radiation and oxidation, and shall be as stated in the manufacturer's written specification. The chosen material shall be continuously and concentrically extruded over the laid-up cores to produce a uniform cross-section. The material shall be compatible with sea-water and the specified service fluids throughout manufacture, installation and service, and shall not degrade the quality of other materials with which it can be in contact in the lay-up.

The coefficient of friction between the sheath and the sheaths of other electric cables and/or other components shall be minimized.

As cable sheaths are, in many cases, sealed by boot-seal methods, the surface of the insulation shall be round, smooth and free from marks, indentations and surface defects that can affect the sealing.

7.2.5.10 Armour/reinforcement

In some cases, cables may incorporate additional layers for strength or mechanical protection. These are, typically, metallic armour, tapes or alternatively a non-metallic reinforcement.

Details of any required layers are included in the manufacturer's written specification.

7.2.5.11 Cable identification

The cables shall be marked along the complete length at regular intervals not exceeding 1 m (3,28 ft). As a minimum the marking shall include

a) the manufacturer;

b) a unique component reference, e.g. “Cable 3”;

c) the batch number;

d) the voltage rating.

7.2.6 Performance requirements

7.2.6.1 DC conductor resistance

The DC resistance for each conductor shall not exceed the value defined in IEC 60228.

7.2.6.2 Insulation resistance

The DC insulation resistivity for each electrical core shall not be less than the value defined in the manufacturer's written specification, which shall not be less than 500 MΩ km at 500 V DC.

7.2.6.3 Screen layer resistivity

For power cable incorporating non-metallic (semi-conducting) screening layers, the resistivities shall not exceed the following values:

a) conductor screen: 1 000 Ω m;

b) core screen: 500 Ω m.

7.2.6.4 Power-cable requirements

The power-cable design shall consider

a) the voltage rating,

b) the current rating,

c) the number of phases,

d) the maximum ambient temperature, and

e) the maximum voltage drop.

7.2.6.5 Signal-cable requirements

The following characteristics for each signal-conductor pair shall be defined between upper and lower limits at frequencies within the operating bandwidth of the proposed system:

a) attenuation;

b) characteristic impedance;

c) inductance;

d) capacitance;

e) resistance, if requested by subsea system supplier;

f) conductance, if requested by subsea system supplier.

These transmission characteristics and cross-talk limits between pairs of conductors shall be as stated in the manufacturer's written specification.

7.2.7 Structural analysis

Structural analysis, taking account of the data generated from the umbilical structural analysis specified in 6.3, shall be undertaken to verify the acceptability of the electric cable design for tensile, compressive and fatigue loadings upon the conductors.

7.2.8 Manufacturing

7.2.8.1 Conductor stranding

The stranding process shall ensure that individual strands and the stranded conductor shall not be subject to compressive and tensile loadings that can introduce kinks or a reduction in the conductor or strand cross-sectional area. This does not exclude the use of compacted conductors as defined in IEC 60228.

The tension applied to the strands during the stranding operation shall be uniformly controlled during the manufacturing process and checked at regular intervals in accordance with the manufacturer's written specification.

Multi-stranded conductors shall be of the concentric lay construction and planetary lay-up in a continuous helix. Other constructions shall not be employed. During the stranding operation, the stranded conductor shall show no propensity to corkscrew or exhibit any other out-of-balance effects.

Blocking compounds in stranded conductors may be incorporated to minimize/eliminate water/gas migration.

7.2.8.2 Insulation extrusion

During extrusion, the following process parameters shall be continuously measured and recorded:

a) extruder barrel/head temperatures;

b) melt pressure/temperature;

c) screw speed/power requirements;

d) haul-off speed.

The insulation shall be extruded as one continuous length without defects, and shall be subject to inspection and continuous spark-testing during the extrusion process, in accordance with the manufacturer's written specification. Repairs to the insulation shall not be permitted.

The insulation thickness shall be measured and the outside diameter (OD) shall be measured continuously at two positions 90° apart, and continuously recorded.

After extrusion, the insulated conductors shall be stored in a dedicated area under cover and protected against direct sunlight, dust and other potential contaminants.

7.2.8.3 Core lay-up

During the cabling operation, the conductors shall not be subject to tensile and compressive loadings that introduce kinks or reduction in conductor or strand cross-sectional area.

If necessary, filler material shall be incorporated to form a compact and reasonably circular bundle. These fillers may be included in the external interstices of the laid-up cores or, alternatively, remaining voids inside functional elements shall be filled with a compound to minimize water ingress.

During lay-up, the twisted cores shall be subject to continuous visual inspection to ensure consistent cabling of the cores and fillers.

If a binder tape is incorporated in the construction, it shall be applied at a uniform tension level that shall not prevent relative movement between individual cores when the cable is flexed.

On completion of lay-up, the cabled cores and/or cabled electric-cable elements shall be stored in a dedicated area under cover and protected against direct sunlight, dust and other potential contaminants.

7.2.8.4 Sheath extrusion

There shall be no discontinuities or holes observed or detected in the extruded sheath. Repairs to a sheath are permissible and shall be performed and documented in accordance with the manufacturer's written specification.

The sheath OD shall be measured continuously, at a minimum of two positions 90° apart. Eccentricity and wall thickness shall be measured from samples taken from each end of the extrusion.

7.2.8.5 Armouring/reinforcement

Where present, this shall be uniformly applied in accordance with the manufacturer's written specification.

7.2.9 Verification/qualification testing

7.2.9.1 General

Verification tests are performed on samples of the particular cable, and are intended to qualify the design as being fit for purpose, considering the characteristics and properties described in 7.2.9.2 to 7.2.9.14.

If a splice is being provided in the cable, then this shall also be subjected to the same qualification testing.

7.2.9.2 Visual and dimensional

Electrical cores shall be 100 % visually examined on samples of cores and shall be free from damage, conductor kinks or faults. This shall include examination of materials for possible contamination, verification of dimensions and construction. Conductors shall be examined in accordance with IEC 60228.

7.2.9.3 DC conductor resistance

A DC conductor resistance test shall be performed on two samples of each insulated conductor, each sample being at least 1 m (3,28 ft) long. One sample shall be taken from each end of a completed electric cable. The measured DC conductor resistance of each conductor, corrected to 20 °C (68 °F), shall not exceed the value specified in IEC 60228 by more than 2 % when corrected for lay-loss, i.e. assembly angle or twist.

7.2.9.4 DC insulation resistance

A DC insulation resistance test shall be performed on two samples of insulated conductors, each sample being at least 1 m (3,28 ft) long. One sample shall be taken from each end of a completed electric cable.

The individual insulated conductors shall be fully immersed in a tank filled with potable water. Insulation resistance shall be measured. The specimens shall then be subjected to a minimum hydrostatic pressure of 3,5 MPa (500 psi), or maximum hydrostatic pressure at service water depth, whichever is greater, for a minimum period of 22 h, and then insulation-resistance tested while still under pressure. The value of the insulation resistance shall not be less than the value defined in 7.2.6.2.

If an insulated conductor incorporates a metal screen over its entire length, this test may be undertaken by carrying it out under ambient conditions, without immersion in water.

7.2.9.5 High-voltage DC

A high-voltage DC test shall be performed on two samples of insulated conductor, each sample being at least 1 m (3,28 ft) long. One sample shall be taken from each end of a completed electric cable.

This test may be combined with the insulation-resistance test specified in 7.2.9.4, using the same samples, provided the insulation resistance test is performed first.

The individual insulated conductors shall be fully immersed in a tank filled with potable water. An initial insulation resistance test, shall be made. The specimens shall then be subjected to a minimum hydrostatic pressure of 3,5 MPa (500 psi), or maximum hydrostatic pressure at service water depth, whichever is greater, for a minimum period of 22 h and then high voltage tested while still under pressure.

Each insulated conductor shall withstand the DC voltage between conductor and water at each of the pressure levels, for a period of not less than 5 min, without breakdown. At the end of each period, the leakage current shall be measured and shall not exceed the value stated in the manufacturer's written specification.

The DC test voltage for conductors designated as “signal” and for conductors designated as “power” shall be 5 kV or three times U_0, whichever is greater.

If an insulated conductor incorporates a metal screen over its entire length (such as a single power core), this test may be undertaken by carrying it out under ambient conditions, without immersion in water.

7.2.9.6 High-voltage AC

On completion of the high-voltage DC test specified in 7.2.9.5, a high-voltage AC test shall be performed on the insulated conductors while subjected to the same hydrostatic pressure.

The test shall be performed with an alternating voltage of sine waveform having a frequency in the range 40 Hz to 62 Hz, unless otherwise stated in the manufacturer's written specification. The value of the applied test voltage shall be as shown in Table 3. The voltage shall be applied between conductor and water. It shall be increased at the rate defined in 7.2.9.10, and maintained at the full value for 5 min without breakdown of the insulation.

If an insulated conductor incorporates a metal screen over its entire length (such as a single power core), this test may be undertaken by carrying it out under ambient conditions, without immersion in water.

Table 3 — AC test voltages

Voltage designation of cable		Test voltage V (rms)
Signal cables	$U_0 / U(U_m) =$ 0,6/1,0 (1,2) kV[a]	1 500
Power cables $U_0 < 600$ V	$\leqslant 6$ mm^2 (0,009 3 in^2)	1 500
	> 6 mm^2 (0,009 3 in^2)	3 000
Power cables $U_0 \geqslant 600$ V	$U_0 / U(U_m) =$ 3,6/6 (7,2) kV	7 500

[a] See IEC 60502-1 and IEC 60502-2 for definition of U_0, U and U_m.

7.2.9.7 Complete breakdown

On completion of the high-voltage tests, four further samples at least 1 m (3,28 ft) in length shall be subjected to a complete DC breakdown test. Two samples shall be taken from each end of a completed electric cable.

Each of the samples shall be tested in a manner identical to that in 7.2.9.5, with two samples being tested at ambient hydrostatic pressure and two being tested at the higher pressure used in the test defined in 7.2.9.5. The DC voltage shall be increased at a rate of 0,1 kV/s until breakdown occurs. The test results shall be recorded for each sample. If no voltage breakdown occurs before application of $10 \times U_0$ the insulated conductor shall be considered suitable.

7.2.9.8 Partial discharge

For cables rated above $U_0 / U(U_m) = 1{,}8/3(3{,}6)$ kV, a partial discharge test in accordance with IEC 60502-2 shall be performed. The discharge magnitude shall not exceed 10 pC.

7.2.9.9 Screen resistivity

In cases where this is required, the resistivity of the non-metallic screening layers (semi-conducting) in the completed power core shall not exceed the values specified in 7.2.6.3.

7.2.9.10 Application of test voltages

Unless otherwise specified for all voltage tests, the rate of increase from the initially applied voltage to the specified test voltage shall be uniform and shall not be more than 100 % in 10 s, nor less than 100 % in 60 s. The initial applied voltage shall not be greater than 500 V.

7.2.9.11 Inductance

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be measured for inductance. The inductance of each conductor pair in the cable shall be measured at fixed frequencies as specified in the manufacturer's written specification. The measured values shall comply with the requirements specified in 7.2.6.5, which shall include limits for deviation between actual and specified values.

7.2.9.12 Capacitance

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be measured for capacitance. The capacitance of each conductor pair in the cable shall be measured at fixed frequencies as stated in the manufacturer's written specification.

The capacitance of each power unit (a single screened power core) shall be measured at the transmission frequency with respect to ground, unless stated otherwise in the manufacturer's written specification. The measured values shall comply with the requirements specified in 7.2.6.5, which shall include limits for deviation between actual and specified values.

7.2.9.13 Attenuation

The test shall be performed on signal cables and on power cables if signals are being superimposed on the power conductors.

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be evaluated for attenuation. The attenuation of each conductor pair shall be measured or derived at the frequencies specified in the manufacturer's written specification and a curve of attenuation versus frequency shall be produced. The measured values shall be in accordance with the requirements specified in 7.2.6.5, which shall include limits for deviation between actual and specified values.

7.2.9.14 Characteristic impedance

A sample of completed electric cable of 10 m (32,8 ft) minimum length shall be used for the determination of characteristic impedance.

Measurements shall be made on each pair, at the frequencies specified in the manufacturer's written specification, and the characteristic impedance derived from the values obtained.

A curve of impedance versus frequency shall be produced. The results shall be in accordance with the requirements specified in 7.2.6.5, which shall include limits for deviation between actual and specified values.

7.2.10 Acceptance testing

7.2.10.1 General

Acceptance tests shall be performed on 100 % of manufactured cable, cores and conductors, prior to their inclusion within an umbilical.

7.2.10.2 Visual and dimensional

Electrical cores shall be visually examined on samples of cores and shall be free from damage, conductor kinks or faults. This shall include examination of materials for possible contamination, verification of dimensions and construction. Conductors shall be examined in accordance with IEC 60228.

7.2.10.3 Spark testing

All cores shall be spark-tested during insulation extrusion and all sheathing extrusions should be tested if the extrudate is applied directly over a screen or metallic armour layer. There shall be no indication of faults during the extrusion process in order to pass this test. During the process of insulation and sheath extrusion, the minimum voltage levels shall be in accordance with BS 5099 for the insulation and sheath thicknesses.

NOTE It is not possible to spark-test cores incorporating non-metallic screening (semi-conducting) layers.

7.2.10.4 DC conductor resistance

This test shall be performed on the complete conductor lengths at the following manufacturing stages, as a minimum:

a) after insulation extrusion;

b) after lay-up of the cores;

c) after completion of the electric cable.

The measured DC conductor resistance of each conductor, corrected to 20 °C (68 °F), shall not exceed the value in IEC 60228 by more than + 2 % when corrected for lay-loss, i.e. assembly angle or twist.

7.2.10.5 Insulation resistance

This test shall be performed on the completed insulated conductor lengths in accordance with the procedure and acceptance value specified in 7.2.9.4 after having been immersed in potable water for a duration of 22 h. For acceptance testing of these insulated conductors, the hydrostatic pressure and duration shall be stated in the manufacturer's written specification. This may be different from the value used for qualification testing.

The test shall also be repeated without the requirement for immersion in town-mains water under pressure after lay-up and on completion of the manufacture of the electric cable.

7.2.10.6 High-voltage DC

This test shall be performed on the completed insulated conductor lengths in accordance with the procedure and acceptance value specified in 7.2.9.5. For acceptance testing of these insulated conductors, the hydrostatic pressure and duration shall be stated in the manufacturer's written specification. This may be different from the value used for qualification testing.

The test shall also be repeated without the requirement for immersion in town-mains water under pressure after lay-up and on completion of the manufacture of the electric cable.

7.2.10.7 Inductance

On completion of cable manufacture, the inductance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.2.9.11 as follows:

a) on a sample of minimum length 10 m (32,8 ft) removed from the completed length; or

b) on the completed length, provided the overall length does not introduce spurious results.

7.2.10.8 Capacitance

On completion of cable manufacture, the capacitance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.2.9.12 as follows:

a) on a sample of minimum length 10 m (32,8 ft) removed from the completed length;

b) on the completed length, provided the overall length does not introduce spurious results.

7.2.10.9 Attenuation

On completion of cable manufacture, the attenuation characteristics shall be measured or derived in accordance with the procedure and acceptance values specified in 7.2.9.13 as follows:

a) on a sample of minimum length 10 m (32,8 ft) removed from the completed length;

b) on the completed length, provided the overall length does not introduce spurious results.

7.2.10.10 Characteristic impedance

On completion of cable manufacture, the characteristic impedance shall be established in accordance with the procedure specified in 7.2.9.14 as follows:

a) on a sample of minimum length 10 m (32,8 ft) removed from the completed length;

b) on the completed length, provided the overall length does not introduce spurious results.

7.2.10.11 Cross-talk

For cables containing independent conductor pairs, if it is necessary to minimize cross-talk, the cross-talk between conductor pairs at the specified testing conditions shall be measured on the complete cable length for the appropriate mode.

The measured values shall not exceed the values stated in the manufacturer's written specification.

7.2.10.12 Time-domain reflectometry

A time-domain reflectometry (TDR) trace shall be obtained for each conductor from both ends. The width of the pulse shall be sufficient to allow a scan of the complete conductor length. The graphs produced shall detail all the major points, such as start and finish of the conductor, splices, if present, etc. The results of this test shall be used to characterize a conductor within an electric cable or electric cable element and do not constitute acceptance/rejection criteria.

7.2.10.13 Delivery testing

Should completed cables be transported from the cable manufacturer's facility to the umbilical manufacturer's facility, the following tests shall be performed on all electrical cores following delivery and prior to lay-up:

a) DC conductor resistance as specified in 7.2.10.4;

b) insulation resistance as specified in 7.2.10.5.

7.3 Hoses

7.3.1 General

Hoses shall be capable of continuous operation immersed in a seawater environment.

7.3.2 Hose sizing

All hoses shall be referenced by nominal bore and DWP.

NOTE Preferred hose bore sizes and DWP are tabulated in Annex C.

Tolerances on nominal bore shall not exceed the values given in Table 4, and the IDs and ODs of the hose shall be concentric within the limits in Table 5.

The completed hose OD, D, shall be within ± 4 % of the value specified in the manufacturer's written specification.

Table 4 — Nominal bore and wall thickness tolerances

Nominal bore		Tolerance	Liner wall thickness t	
mm	(in)	%	mm	(in)
6,0 to 10,0	(0,236 to 0,394)	$^{+5,0}_{-3,0}$	± 0,2	(0,008)
10,1 to 20,0	(0,395 to 0,787)	$^{+3,0}_{-2,0}$	± 0,2	(0,008)
20,1 to 38,1	(0,788 to 1,5)	$^{+2,0}_{-1,5}$	± 0,25	(0,010)

If the hose liner is specifically designed to withstand external hydrostatic pressure and this necessitates increasing the thickness of the liner to resist collapse, larger wall thickness and concentricity tolerances are permissible. Such tolerances shall be as stated in the manufacturer's written specification.

Table 5 — Concentricity

Nominal bore		Concentricity (full indicated reading)	
mm	(in)	mm	(in)
$\leqslant$ 25,4	(1,0)	1,0	(0,039)
> 25,4	(1,0)	1,5	(0,059)

7.3.3 Hose construction

7.3.3.1 General

The hose shall be comprised of three component parts: the liner, the reinforcement and the sheath. When subject to pressure in an unrestrained state, the hose construction shall show no significant propensity to loop, or rotate about its axis.

The hose, fittings and couplings shall be designed considering exposure to sunlight, UV radiations, temperatures of storage and operation, seawater, air and marine atmosphere according to the expected conditions of storage during manufacturing, storage, packing, handling and lay-up relative to the umbilical's characteristics for the specified service life.

7.3.3.2 Liner

The liner shall be a continuous, seamless, circular and concentric extrusion, manufactured from virgin thermoplastic material, and shall be compatible with the intended service fluids.

Multi-layer liners may be acceptable if application requirements cannot be satisfied by a single-layer construction. For instance in situations where there are high external pressures, then an internal support may be incorporated.

For collapse-resistant hoses, the liner may incorporate an internal structure, such as an interlocking carcass, to provide resistance to external hydrostatic pressure. The interlocked carcass shall be of CR material, compatible with both external environment and inner fluid, e.g. AISI 316L for control fluids.

The material in its extruded form shall not introduce particulate contamination of the hose bore, either by extraction or by reaction with the fluid being transported, to the extent that fluid cleanliness cannot be maintained.

7.3.3.3 Reinforcement

The reinforcement shall be comprised of one or more layers of synthetic fibre, applied around the liner.

7.3.3.4 Sheath

The sheath shall be comprised of a continuous, seamless, circular extrusion, manufactured from thermoplastic material incorporating protection against ozone and UV radiation.

The sheath shall provide for the venting of permeated fluids if the particular fluid/hose liner combination can give rise to permeation. The sheath material shall be compatible with the interstitial filler material and the sheathing material of other services within the umbilical throughout its design life. The sheath shall be designed to protect the reinforcement and liner from abrasion, erosion and mechanical damage.

The coefficient of friction between the sheath and the sheaths of other hoses and/or other components shall be minimized.

7.3.3.5 Identification

At least the following information shall be marked, along the complete length of a hose, on the external sheath at regular intervals not exceeding 1 m (3,28 ft):

a) manufacturer;

b) batch number;

c) nominal bore size;

d) DWP;

e) manufacturer's part number;

f) unique component reference, e.g. “Line 6”.

7.3.3.6 Termination interface

The long-term sealing and retention of couplings and/or end fittings shall not be impeded by the hose materials of construction. All materials used shall be suitable for long-term immersion in seawater and shall be in accordance with the manufacturer's written specification. If fittings are crimped or swaged onto the outer sheath of the hose, special attention should be given to ensuring that permeated fluids from the hose do not soften or otherwise degrade the sheath material, resulting in leakage of the end fitting or its detachment from the hose.

Couplings used to join two hose lengths within an umbilical shall be of the one-piece unthreaded type. Couplings used to join hose lengths within a rigid umbilical joint shall be of the threaded type and/or a one-piece design type eliminating the requirements for mechanical connection between the two abutment halves.

The attachment of the abutment part of the fitment shall be performed using a radial crimping or longitudinal swaging procedure. Each crimped or swaged connection should be checked with an appropriate gauging tool to ensure proper make-up.

In the design and assembly of an end fitting or coupling, consideration shall be given to the possibility of the formation of crevices with the potential for corrosion.

End fittings or couplings in a rigid joint shall either be protected by a water-blocking barrier, have the facility for linking to a cathodic protection system, or be fabricated from an inherently corrosion-resistant material.

If there is a risk of an end fitting or coupling nut unscrewing as a result of induced torque, vibration, etc., then an appropriate interlock feature shall be included to prevent rotation of the nut.

Fittings shall be made of CRA materials compatible with both the inner fluid and seawater.

7.3.4 Performance requirements

7.3.4.1 Design pressure ratios

Table 6 indicates the required ratio of proof and burst pressures to the DWP for thermoplastic hoses, in accordance with ISO 7751.

Table 6 — Ratios of test pressure to DWP

Proof pressure		Burst pressure
A[a]	B[b]	
2,0	1,5	4,0

[a] Applicable on completion of hose manufacture and normally used once.

[b] Applicable following shipment of individual hose lengths and inclusion of hoses into an umbilical.

For higher DWP ratings and/or larger bore sizes than those specified in Annex C, lower burst-pressure ratios, which shall be in accordance with the manufacturer's written specification, may be acceptable. These hoses for higher working pressures shall be design-verified in accordance with 7.3.7.

7.3.4.2 Collapse pressure

The hose assembly, if filled with installation/service fluid at zero internal pressure (gauge) and bent to the minimum bend radius, shall be capable of withstanding a minimum applied external pressure without collapsing. The minimum value of the external pressure shall be 150 % of the difference in static head due to external hydrostatic pressure at maximum design depth, less the static head at that depth due to the internal installation/service fluid.

If the environmental and/or service fluids can materially affect physical properties of the hose, these factors should be taken into account in the performance requirements.

7.3.4.3 Change in length

The hose shall be designed such that the change in length when the hose is pressurized from atmospheric pressure to its DWP shall be within the range − 1,5 % to + 2 %.

7.3.5 Structural analysis

Structural analysis, taking account of data generated from the umbilical structural analysis specified in Clause 6, shall be undertaken to confirm the acceptability of the hose design for the loadings it will experience during testing and service.

7.3.6 Manufacturing

7.3.6.1 Liner extrusion

Transfer of raw material into the extruder shall employ vacuum draw-off from an enclosed container system to prevent ingress of contamination.

During extrusion, the following process parameters shall be continuously measured and recorded:

a) extruder barrel/head temperatures;

b) melt pressure/temperature;

c) screw speed/power requirements;

d) haul-off speed.

The liner shall be extruded as one continuous length without joints or defects in a segregated, controlled entry area. The outside diameter shall be measured continuously at two positions 90° apart and the liner wall thickness shall be measured continuously at four positions 90° apart, and continuously recorded. Both wall thickness and diameter measurements shall be traceable to the length of hose produced.

The extruder head shall be visually inspected frequently during extrusion. Deposits that can build up on the extruder tooling shall be continuously monitored. If such deposits impact or are transferred onto the liner surface (external or internal), the effect of these shall be examined. The liner shall be rejected if it is outside the manufacturer's written specification.

During extrusion, the liner shall be subject to visual examination in accordance with the manufacturer's written specification for the detection of visible defects, such as colour changes, bubbles or inclusions. The extrusion process shall provide all-round visual observation of the extruded liner. The manufacturer's written specification shall include acceptance/rejection levels for such defects.

After extrusion, the ends shall be sealed against ingress of contamination. Liners awaiting application of reinforcement shall be stored in a controlled dry area under cover and protected against direct sunlight, dust and other potential contaminants, and UV radiation (if not UV-stabilized).

If a carcass is employed, consideration should be given to removal of the manufacturing lubrication. The requirement to perform welds to achieve production lengths shall also be considered with respect to weld quality and profile.

7.3.6.2 Reinforcement application

The reinforcement yarn shall be protected against dust and UV degradation during storage. Yarn bobbins affected by humidity and/or temperature shall be conditioned in accordance with the material supplier's recommendations before use.

Linear-density and breaking-strength tests shall be performed on samples from each batch of reinforcement yarn to confirm that the material properties are within the limits specified.

The reinforcement yarn shall be wound uniformly onto braiding bobbins, taking care to minimize fluff and exclude dirt, oil or other extraneous matter from the package. The tension in each yarn shall be controlled within the specified tension tolerance. Extraneous fibres and fluff shall be regularly removed from the braiding machine.

The tension applied to the reinforcement yarn during manufacture of the hose shall be checked for each bobbin at the commencement of each production run, and thereafter in accordance with the manufacturer's written specification, which shall ensure that all bobbins are checked at regular intervals.

The effect of high transient braiding tensions and resulting hoop forces shall be addressed to ensure bore size consistency.

Splices in the braided yarn are permitted, provided hose-performance requirements are still met, and shall be made in accordance with the manufacturer's written specification and qualified. The incidence of yarn splices shall be staggered within each braid and between braids, so that no two splices coincide. The distance between splices, measured along the axis of the hose, shall be stated in the manufacturer's written specification.

During application of the reinforcement, the braided liner shall be inspected during spooling to ensure that there are no visible defects.

On completion of braiding, the storage reel shall immediately be completely covered to protect the reinforcement from airborne contaminants and degradation from exposure to UV radiation. While awaiting completion, the braided liner shall be stored in a controlled dry area under cover and protected against direct sunlight, dust and other potential contaminants, and UV radiation.

Storage reels surfaces shall be smooth such that the fibre is not damaged.

7.3.6.3 Sheath extrusion

Extrusion of the hose sheath shall follow the same process requirements as those for the extrusion of the liner, with the exception of the measurement and recording of quench-tank vacuum and wall thickness, which are not applicable.

The reinforced hose liner shall be kept dry prior to and during passage through the extruder. Care shall be taken to ensure that the reinforced liner is not stretched and that the reinforcement is not disturbed during application of the outer sheath.

During sheath extrusion, the product shall be subject to visual inspection to ensure uninterrupted and uniform coverage and that no extraneous material is included under the sheath. Repairs to a sheath are allowable and shall be performed in accordance with the manufacturer's written specification.

If a hose is intended for use with a fluid that can permeate the liner (typically methane and methanol), the sheath shall be adequately vented to prevent pressure build-up between the liner and sheath. The requirement for venting shall be identified and the venting method shall be in accordance with the manufacturer's written specification.

7.3.7 Verification/qualification testing

7.3.7.1 General

The tests specified in 7.3.7.2 to 7.3.7.13 shall be performed to verify each hose design and provide characterization data.

If the hose design is intended for use where more than one length of hose is joined by a coupling, for tests specified in 7.3.7.5 to 7.3.7.7 at least one sample shall contain the coupling design constructed with its service material. If a coupling of the one-piece design is employed using the same abutment design and same method of attachment to the hose on the umbilical hose end fittings, there shall be a requirement only to perform a burst test as specified in 7.3.7.6 to verify the coupling for service. In addition, the test procedure specified in 7.3.7.11 shall be performed if threaded couplings are to be incorporated.

If a material is specified that is of higher strength than a design already verified, there shall be no requirement to undertake impulse testing. Verification shall be restricted to leakage and burst testing as specified in 7.3.7.5 and 7.3.7.6.

If no reference is made to an end-fitting design, for expediency this may be carbon steel of proprietary design provided the performance does not degrade the test performance requirements.

7.3.7.2 Test fluid

The test fluid shall be the manufacturer's standard test fluid as specified in the manufacturer's written specification. The fluid used for each test shall be recorded as part of the test report. Unless otherwise specified, all pressure measurements shall be made at the hose inlet.

7.3.7.3 Visual and dimensional

One unaged representative sample of 150 mm (5,91 in) minimum length shall be taken from each end of a manufactured hose length. During the dimensional tests, the hose shall be visually examined and shall be free from damage, irregularities and visual non-conformances in each part of the construction. Measurements of the following parameters of each sample shall be made in accordance with the manufacturer's written procedure:

— internal diameter;

— diameter over reinforcement;

— external diameter;

— hose concentricity;

— liner wall thickness.

The manufacturer's written specification shall include a dimensional specification for the hose, clearly stating the values and manufacturing tolerances for all the above parameters. The values and tolerances shall not exceed those specified in 7.3.2.

7.3.7.4 Change-in-length

One unaged representative sample shall be taken from each end of a manufactured hose length. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15,75 in). The test shall be performed on each sample in accordance with the change-in-length test for hydraulic hoses specified in ISO 1402 at a test pressure equal to the DWP.

The measured change-in-length shall be within the range specified in 7.3.4.3.

7.3.7.5 Leakage

One unaged representative sample shall be taken from each end of a manufactured hose length and assembled with the intended material and design of end fitting incorporated at each end of each sample. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15,75 in). The test shall be performed on each sample in accordance with the leakage test for hydraulic hoses specified in ISO 1402. There shall be no evidence of leakage during or on completion of the test.

7.3.7.6 Burst

One unaged representative sample shall be taken from each end of a manufactured hose length and assembled with the intended material and design of end fitting incorporated at each end of each sample. Two further samples shall be prepared with a minimum of one splice in the reinforcement of each sample made in accordance with the manufacturer's written specification. These particular samples shall be clearly marked showing the position of each splice. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15,75 in). Each sample shall be tested using the burst pressure test for hydraulic hoses specified in ISO 1402 at the standard laboratory/ambient temperature. Test results for samples with splices and samples without splices shall be recorded. The burst pressure shall not be less than the value specified in 7.3.4.1.

This test may be combined with the change-in-length test specified in 7.3.7.4 after having first performed the change-in-length test.

7.3.7.7 Impulse

Two unaged representative samples shall be taken from each end of a manufactured hose length (four samples in total). Two further samples shall be prepared with a minimum of one splice in the reinforcement made in accordance with the manufacturer's written specification. The splices shall be located nominally in the centre of the test sample and their location clearly identified.

End fittings shall be attached to each sample using the same procedure that is being used to attach the fittings being employed in service. At least four end fittings shall be of the same design and material of construction as those being employed in service. The sample length shall be calculated in accordance with ISO 6803:2008, Figure 1.

All hose assemblies shall be subjected to a proof pressure test as specified in ISO 1402 before commencing the impulse test. The test shall be conducted in accordance with the impulse test procedure specified in ISO 6803 at the reduced test-fluid temperature of 55 °C ± 3 °C (131 °F ± 5 °F). Compatibility of the test fluid with the hose liner shall be confirmed prior to commencement of the test. The test pressure shall be $1{,}33 \times p_{DW}$, and the hose shall withstand a minimum of 200 000 cycles without any signs of leakage or failure.

For hoses greater than 25,4 mm (1 in) nominal bore, or working pressures higher than those specified in Table C.1 or hoses constructed with an internal carcass to provide support against external hydrostatic pressure, alternative installed test configurations, pressure waveforms and/or number of cycles forming the acceptance/rejection criteria may be acceptable, as defined in the manufacturer's written specification.

7.3.7.8 Cold bend

One unaged representative sample shall be taken from the end of a manufactured hose length. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15,75 in). The test shall be carried out in accordance with the cold flexibility test in accordance with ISO 4672:1997, method B, where the test temperature is − 40 °C ± 3 °C (− 40 °F ± 5 °F). The sample shall fail the test if any signs of leakage, distortion or cracking are apparent.

7.3.7.9 Collapse

A sample of hose, with a length of not less than 500 mm (19,69 in) between end fittings, shall be installed in a pressure vessel and bent to its minimum bend radius. The hose shall be filled with water until the water reaches a burette on the end of the hose. The vessel shall be filled with water and the pressure gradually increased at a rate in accordance with the manufacturer's written specification.

As the pressure increases, there is an increase in fluid volume expelled into the burette at a small but discernible rate. The pressure at which this volume rapidly increases shall be noted. This is the pressure at which the hose has collapsed.

The pressure at which the hose collapses shall exceed the value specified in 7.3.4.2.

7.3.7.10 Volumetric expansion

One unaged representative hose sample shall be subject to volumetric expansion testing in accordance with the procedure described in Annex D. The results from this test shall be used to characterize a hose design and do not constitute acceptance/rejection criteria.

NOTE Volumetric expansion measurements made on sample lengths do not correlate directly with hoses in an installed umbilical system. Factors, such as frictional losses in long hydraulic lines, the presence of adjacent hoses, hydrostatic head due to vertical installed umbilical sections, seabed hydrostatic pressure, etc., can all contribute to the differences.

7.3.7.11 End-fitting rotation

Two unaged representative hose samples of length not less than 600 mm (23,62 in) shall have swivel female service-design fittings attached at one end only.

The other ends shall be terminated with any convenient end fitting that is not detrimental to the outcome of the test. The service-design female connections shall be mated using a male-male adapter manufactured from the same material and tightened to the manufacturer's recommended sealing torque. One end of the mated arrangement shall be clamped, the other end shall have a minimum of 90° twist imparted before being clamped. The direction of twist shall be in the direction required to unscrew the mated fittings at the centre of the test arrangement.

Hydrostatic pressure cycling between zero and $1,5 \times p_{\text{DW}}$ shall be applied 10 times consecutively, at a frequency of less than 1,5 cycles per minute. The time for the test pressure rise and decay shall be a minimum of 10 s. On completion of 10 cycles, the pressure shall be held constant at $1,5 \times p_{\text{DW}}$ for a minimum of 10 min. The sample shall be inspected for signs of leakage and distortion. Any such signs shall result in failure of the test.

7.3.7.12 Compatibility testing

7.3.7.12.1 General

Compatibility testing shall be performed to demonstrate that the specified service fluids are compatible with the materials of hose construction.

Unless the manufacturer is able to provide documentary evidence of previously conducted compatibility tests for identical fluid and material combinations, testing shall be required for each of the proposed fluid/material combinations. The fluid/material combinations and the applicable test procedure shall be as stated in the manufacturer's written specification.

Immersion testing that utilizes plaques or dumbbells may be used only to determine whether there is gross incompatibility between the hose liner and sheath material, and the fluid. This method may be used for predicting hose sheath compatibility, but for hose liners, such testing shall be supported by a program of pressure-cycle testing on complete hose samples from which the minimum design life shall be predicted**.**

Prediction of the minimum design life, determined by compatibility testing, shall be in accordance with the manufacturer's written specification.

The manufacturer shall also demonstrate that the reinforcement and outer sheath materials are compatible with seawater and permeated fluid throughout the minimum design life. If the manufacturer is able to produce documentary evidence of satisfactory compatibility based upon actual service experience, compatibility testing of the hose sheath might not be required.

7.3.7.12.2 Immersion tests

Specimens shall be stressed by means of dead-weight loads at strain levels in accordance with the manufacturer's written specification.

Measurement of specimen material properties shall include volume swell, ultimate tensile stress and elongation at break in accordance with ISO 527.

7.3.7.12.3 Pressure cycling

Pressure cycling tests shall be performed on a minimum of six representative hose samples, terminated with the same abutment design features as the service end fittings, each approximately 1 m (3,28 ft) long; the six representative hose samples may be joined in a series for convenience. Prior to testing, the hose assemblies shall be subject to a change-in-length test as described in 7.3.7.4, followed by a proof test in accordance with ISO 1402. The hose string shall be immersed in town-mains water, held at a temperature of 40 °C ± 1 °C

(104 °F ± 1,8 °F) for a period of 12 months. In the event that scheduling does not permit a 12 month program, a higher temperature for a shorter duration and a lower number of test samples may be acceptable. In this event, the duration and temperature shall be as stated in the manufacturer's written specification. If elevated temperatures are used, then care shall be taken that the failure mechanism is representative, and that the material temperature limits are not exceeded.

The water shall be renewed monthly.

The hose string shall be filled with the service fluid under investigation and the pressure in the string shall be cycled between zero and the DWP at a rate of 1 cycle per hour. The pressurization and depressurization periods shall each be of 5 min duration ± 10 s, and the dwell time at zero pressure shall be 10 min ± 10 s.

At specified time intervals, samples of hose shall be removed from one of the test assemblies and the remaining hose re-terminated and re-introduced into the test program. Removed samples shall be examined and the hose liner physical properties measured and compared with those of control samples from the same batch.

The hose/fluid combination shall pass this compatibility test if

a) none of the hoses fails during the period of pressure cycling; and

b) the manufacturer's written specification predicts a minimum design life greater than the specified service life.

Alternative test regimes, other than pressure cycling, may be acceptable to meet these requirements.

7.3.7.13 Permeability testing

7.3.7.13.1 General

Permeability tests shall be carried out to determine whether the hose liner is permeable to the specified service fluids. The test temperature and pressure shall be in accordance with the manufacturer's written specification. The results from this test shall be used to characterize a hose design and do not constitute acceptance/rejection criteria.

Tests on other fluids may be required as specified in the manufacturer's written specification.

Tests other than those described in 7.3.7.13.2 and 7.3.7.13.3 may be acceptable.

When carrying out permeability testing, it should be noted that for some materials the permeation rate is a significant function of both temperature and pressure. Permeation tests are only carried out when specified by the purchaser.

7.3.7.13.2 Liquids

The permeability of the liner to liquids shall be measured on a sample at least 1 m (3,28 ft) long using the test apparatus in accordance with ISO 8308. The nitrogen-charge pressure shall be checked daily and adjusted, if necessary, and at all other times the “main” and “venting” valves shall be kept tightly closed. The loss of fluid shall be measured daily over a period of at least 30 d, or until the level of fluid in the burette has fallen below the minimum mark if this occurs sooner. A graph of fluid loss against elapsed time shall be plotted. The average gradient of this graph shall be used to determine the characteristic permeation rate for the particular fluid/material combination.

7.3.7.13.3 Gases

The permeability of the liner to gases shall be measured on a sample 1 m (3,28 ft) long in accordance with ISO 4080.

7.3.8 Component factory acceptance tests

7.3.8.1 Visual and dimensional inspection

During the manufacturing processes, the extrudates and braided reinforcement shall be free from damage, faults or contamination as specified in the manufacturer's written procedures. Raw materials shall also be examined for contamination. Manufacturing parameters shall be periodically monitored and shall comply with the manufacturer's written specification.

As a minimum, the following dimensional checks shall be carried out in accordance with the manufacturer's written specification:

a) for the liner: d, D, concentricity, wall thickness;

b) for the reinforcement: D, pitch (for each layer);

c) for the sheath: D, concentricity;

d) for the completed hose: d, D, concentricity.

Measurements of d shall be performed using a GO/NO-GO gauge to verify that the bore is within the tolerance stated in the manufacturer's written specification.

7.3.8.2 Test fluid

For sample testing, the test fluid shall be in accordance with the manufacturer's written specification.

For integrity tests that are performed on each completed hose length, the test fluid shall be one of the following:

a) specified system control fluid, suitably filtered to allow the final system cleanliness, as defined in the manufacturer's written specification, to be achieved;

b) proprietary storage fluid, filtered and cleaned as in a);

c) town-mains or potable water suitably filtered as in a); the chloride content of town-mains or potable water shall be equal to or less than 20 mg/l (20 ppm) so as not to introduce corrosion for hoses that incorporate stainless steel materials;

d) de-ionized water, suitably filtered and cleaned as in a).

The final choice of pressure-test fluid(s) incorporated in the hoses during shipping, installation and service shall take account of the relevant system and environmental factors and shall be agreed with the purchaser.

The use of two different test fluids during umbilical manufacture is not recommended, as this can require duplicate test equipment during manufacture, load-out and installation.

If freezing temperatures are possible with the use of “water only” test fluids, then a quantity of monoethylene glycol sufficient to prevent freezing should also be proportionately mixed with the water.

If long-term storage of the “water only” test fluids is possible, or if there is a possibility of microbiological growth within the filled hose, then a suitable biocide should also be proportionately mixed with the water.

Storage of the test fluid(s) in both the shipping containers and the hoses shall be such as to prevent freezing.

Completed hose lengths shall be sealed at each end at all times when testing is not in progress.

7.3.8.3 Liner burst test

After extrusion, a 1 m (3,28 ft) length of liner shall be removed from each end of each extruded length and subjected to a burst test. The burst pressure shall be not less than 80 % of the calculated burst pressure, based on the minimum wall thickness, maximum bore diameter and tensile stress at 20 % liner material elongation, using standard thin-wall cylinder theory. The liner shall fail in a ductile manner in order to pass this test.

7.3.8.4 Change in length

On completion of manufacture, an unaged representative sample shall be taken from each end of each manufactured length and subjected to a change-in-length measurement in accordance with the procedure specified in 7.3.7.4.

7.3.8.5 Burst test

On completion of the manufacture, an unaged representative sample shall be taken from each end of each manufactured length and subjected to a burst test in accordance with the procedure specified in 7.3.7.6, with the exception that the inclusion of reinforcement splices or production couplings/end fittings is not a requirement in any of the test samples.

This test may be combined with the change-in-length test in 7.3.8.4.

7.3.8.6 Proof pressure/decay test

On completion of manufacture, a proof test shall be performed. The hose shall be pressurized at a controlled rate up to the proof pressure specified in Table 6. The test pressure shall be measured at both ends of the hose, and shall be maintained within ± 5 % over a minimum period of 30 min. At the end of this period, if the pressure has been maintained, the pressure source shall be isolated and the pressure-decay characteristic monitored over a minimum period of 60 min.

Throughout the proof pressure test period, the ambient temperature shall be continuously monitored. There shall be no evidence of leakage or failure during or at the end of the test period.

NOTE Figure D.1 illustrates the test arrangement and typical pressure response profile.

7.3.8.7 Delivery to umbilical manufacturer

Should completed hoses be transported from the hose manufacturer's facility to the umbilical manufacturer's facility, a proof pressure/decay test as specified in 7.3.8.6, at a test pressure of $1,5 \times p_{DW}$, shall be performed on all hoses following delivery and prior to lay-up.

7.4 Optical-fibre cable

7.4.1 General

Optical-fibre cables shall be capable of continuous operation immersed in a seawater environment.

7.4.2 Fibre type

The fibre type shall be of either single-mode or multimode design. The design shall be as given in the manufacturer's written specification.

7.4.3 Fibre construction

7.4.3.1 Core

The optical-fibre core(s) shall be of cylindrical form, manufactured from silica glass with dopants added to raise the refractive index. The refractive index of the core shall be stated in the manufacturer's written specification.

7.4.3.2 Cladding

Cores shall have a cladding of silica glass to act as the refractive boundary for the core. With purchaser agreement, alternative core and cladding materials may be used but shall consider fusion splicing, hydrogen effects, termination issues and system requirements.

7.4.3.3 Coating

Clad cores shall have protective coatings that require unique colour coding as a means of individual fibre identification. The material used for coating including colour shall not degrade the core.

7.4.4 Cable construction

7.4.4.1 General

The cable construction shall be able to withstand the minimum bending radius specified in accordance with 9.4 without mechanical damage or reduction of performance.

In accordance with 4.1.1 c), the cable-construction materials shall be compatible with fluids with which they may come into contact, for example, terminations.

7.4.4.2 Fibre package

The fibres shall be contained within a carrier package that shall prevent water and minimize hydrogen contact with each fibre. The carrier package and its contents shall be designed to block water ingress in the event that the optical-fibre cable in the umbilical is severed. The package shall include water blocking and a hydrogen scavenger compound to minimize hydrogen contact with the fibres.

The tube package, together with external armouring that may be provided in accordance with 7.4.4.4, shall be designed to provide mechanical protection for the fibres against tensile and crushing loads.

NOTE Tensile protection can be by means of a central strength member and/or external armouring of either metallic form or textile yarn. Mechanical protection can be by means of encapsulation in either a polymeric or metallic tube with or without external armouring.

7.4.4.3 Sheathing

The fibre package can require a continuous extruded polymeric sheath in order to achieve an additional sealing layer and armour bed, where required, in accordance with manufacturer's written specification.

7.4.4.4 Armour/reinforcement

Tensile, axial stiffness and crush protection in addition to that provided by the fibre package can be achieved by means of external armouring, preferably metallic. The material and lay angle(s) of the mechanical protection shall be selected in order to minimize the extension under load while maintaining cable flexibility.

7.4.4.5 Outer sheath

The mechanical protection can require a continuous extruded polymeric sheath in accordance with the manufacturer's written specification.

7.4.4.6 Cable identification

Each individual cable shall have a unique identification and shall be marked along the complete length at regular intervals not exceeding 1 m (3,28 ft), with

a) the manufacturer,

b) the batch number,

c) the fibre type,

d) the number of fibres,

e) the manufacturer's part number,

f) a unique component reference, e.g. “Line 6”.

7.4.5 Termination interface

The design of the optical-fibre cables shall recognize that the cables terminate in some form of water blocking arrangement, which shall function throughout the design life.

The materials of construction or the design shall not impede the long-term stability of the termination interface.

NOTE This part of ISO 13628 is not applicable to the design of optical-fibre terminations for subsea use.

7.4.6 Performance requirements

7.4.6.1 Optical attenuation

The optical attenuation for each fibre at specified wavelengths shall meet the requirements given in Clause 4.

7.4.6.2 Fibre strain

The umbilical and optical fibre cables shall be designed so that potentially damaging residual strain levels are not imposed on the optical fibres. Excessive compression causes increased fibre attenuation and excessive strain causes latent defects and early failure. The optical-fibre package shall be designed and tested so that the residual strain levels fall in a range from − 0,05 % to 0,25 %.

7.4.7 Jointing

7.4.7.1 Cable jointing

If production lengths dictate, optical-fibre cable lengths may be joined together. The joint shall be either a cable splice incorporating fibre splices in accordance with the manufacturer's written specification, or a splice box whereby the individual pigtails can be configured to allow the splicing such that the jointed fibres can be accommodated free of tensile and bending stresses. Whichever method is employed, water and hydrogen shall be prevented from coming into contact with the fibres.

7.4.7.2 Fibre splicing

Jointing of the fibres shall be allowed, with the use of high-strength, qualified fusion-splicing techniques. The acceptance level of splice-loss attenuation shall be as defined in the manufacturer's written specification. Splices shall be individually subjected to tensile proof testing, to the load level defined in the manufacturer's written specification [typically from 700 MPa to 1 750 MPa (100 ksi to 250 ksi)].

The splice region shall be suitably protected and the optical performance, after splicing, shall meet the requirements of Clause 4.

7.4.8 Structural analysis

Structural analysis, taking into account the data generated from the umbilical structural analysis specified in 6.3.9.2, shall be undertaken to confirm the acceptability of the cable design for the loadings it will experience during testing and service.

7.4.9 Manufacturing

7.4.9.1 Fibre manufacture

Fibres shall be produced from high-grade silica glass meeting the manufacturer's written specification, and in accordance with the requirements of IEC 60793-1-1 and IEC 60793-2 or ITU-T G.976.

Fibres shall be identified in accordance with the manufacturer's written specification.

7.4.9.2 Fibre-package construction

The individual fibres are assembled into the fibre package in accordance with the manufacturer's written specification.

7.4.9.3 Sheathing

A sheathing layer(s), where applied, shall be in accordance with the manufacturer's written specification. There shall be no discontinuities observed or detected in the extruded sheath(s). Repairs to the sheath(s) are permissible and shall be performed in accordance with the manufacturer's written specification.

7.4.9.4 Armouring/reinforcement

Where present, this shall be uniformly applied in accordance with the manufacturer's written specification.

7.4.10 Verification/qualification testing

7.4.10.1 General

Verification tests are performed on samples of the particular cable and are intended to qualify the design as being fit for purpose, when considering the characteristics and properties described in 7.4.10.2 to 7.4.10.7.

7.4.10.2 Visual and dimensional

During the manufacturing process, where feasible, in line with current industry standards, each optical-fibre cable shall be visually examined and shall be free from damage, kinks or irregularities. Cable manufacturing processes shall be subject to visual examination. Manufacturing parameters shall be periodically measured, and shall be in accordance with the manufacturer's written specification.

7.4.10.3 Transmission and optical characteristics

Transmission and optical characteristics of the optical fibres shall be verified in accordance with IEC 60793-1-1 and IEC 60793-2.

7.4.10.4 Mechanical characteristics

Mechanical characteristics of the optical fibres shall be verified in accordance with IEC 60794-1-1 and IEC 60794-1-2.

7.4.10.5 Environmental resistance

The environmental resistance of the optical-fibre cable to seawater, hydrogen and service fluids shall be verified in accordance with the manufacturer's written specification.

7.4.10.6 External pressure test

A sample of the optical-fibre cable having a length not less than 10 m (32,8 ft) shall be subject to an external hydrostatic pressure test for a period of 14 days at a minimum pressure equivalent to the maximum installation depth for the umbilical. The specimen's optical fibres shall be joined in series and periodically monitored in accordance with the manufacturer's written specification. Any changes in attenuation measured shall not cause degradation in system performance over the design life of the system.

Following completion of the test, the sample shall be stripped down and examined for any evidence of structural or fibre change that can compromise the design life of the system.

7.4.10.7 Fibre splicing

If a splice is being provided in the cable, then this shall also be subjected to the same qualification testing as the cable.

7.4.11 Acceptance testing

7.4.11.1 General

Acceptance test are performed on 100 % of manufactured cables prior to inclusion within an umbilical.

7.4.11.2 Visual and dimensional

During the manufacturing process, where feasible, in line with current industry standards, each optical-fibre cable shall be 100 % visually examined and shall be free from damage, kinks or irregularities. Cable lay-up, carrier tube fabrication, sheathing and armouring processes shall be subject to visual examination. Manufacturing parameters shall be periodically measured and shall be in accordance with the manufacturer's written specification.

7.4.11.3 Optical time-domain reflectometry/attenuation

Each fibre within the cable shall be subject to an optical time-domain reflectometry (OTDR) test from each end, at wavelengths specified in the manufacturer's written specification.

Graphs shall be produced that detail all the major points, such as start and end of the cable and splices (if present). Attenuation values shall meet the requirements of the manufacturer's written specification.

7.4.12 Delivery testing

If the completed cable is transported from the cable manufacturer's facility to the umbilical manufacturer's facility, an OTDR test as specified in 7.4.11.3 shall be performed on all fibres following delivery, prior to lay-up. Attenuation values shall meet the requirements of Clause 4.

7.5 Metallic tubes

7.5.1 General

Metallic tubes shall be capable of continuous operation immersed in a seawater environment.

7.5.2 Tube size

7.5.2.1 General

All tubes shall be referenced by the nominal ID (if required, minimum ID) and DWP.

Tolerances for the OD, wall thickness, and ovality shall be in accordance with the permissible variations in dimensions as specified in 7.5.8.3. Where alternate OD, wall thickness, and ovality tolerances are proposed, purchaser approval is required. The umbilical manufacturer shall confirm the minimum wall thickness in the tender process.

NOTE Preferred tube sizes are tabulated in Annex C.

In order that the umbilical manufacturer can determine the load cases and combinations of load cases, it is imperative that the purchaser define the spectrum of envisaged operating conditions.

7.5.2.2 Wall thickness

The process of calculating the required wall thickness of a tube for a given design condition is iterative. Initially, the maximum tube ID and the minimum tube OD are selected based on the fluid flow and pressure-test requirements of the tube. The hoop, radial, axial and shear stresses are then used to calculate an equivalent stress, σ_e (due to all load cases), in accordance with the von Mises' criterion. The equivalent stress is then compared to the allowable stress, which depends on the design condition.

If the equivalent stress is less than or equal to allowable stress, the selected tube wall thickness is appropriate. If the equivalent stress is greater than the allowable stress, then the selected tube wall thickness shall be modified and the same process followed until an appropriate wall thickness is determined.

The equations for calculating the tube wall thickness are given in 7.5.2.6 through 7.5.2.8 and a sample tube wall thickness calculation is included in Annex I.

Equations for collapse and buckling are given in Annex J.

The calculations for the wall thickness, t_x, where x is 1, 2, or 3, for use in the stress calculations are given in Table 7.

Table 7 — Wall thickness for stress calculations

Condition	Pressure containment	Combined loading	Fatigue
Operation	$t_1 = t_{nom} - t_{fab} - t_{corr}$	$t_2 = t_{nom} - t_{corr}$	$t_3 = t_{nom} - 0.5 \cdot t_{corr}$
Pressure test and installation	$t_1 = t_{nom} - t_{fab}$	$t_2 = t_{nom}$	$t_3 = t_{nom}$

where

t_{nom} is the nominal wall thickness;

t_{fab} is the maximum fabrication negative tolerance;

t_{corr} is the general corrosion allowance (external and internal corrosion, if applicable).

Corrosion allowance is relevant only for materials susceptible to general corrosion, i.e. unprotected carbon steel.

See 7.5.8.3 for maximum wall-thickness tolerances.

Weldability and handling should be considered when minimum wall thickness is determined.

For fatigue calculations, see 6.2.5.2.

7.5.2.3 Diameter

The nominal diameter may be used in all stress calculations. Equations (1) to (7) use the nominal outer diameter, which equals nominal inner diameter plus twice the nominal wall thickness.

7.5.2.4 Material strength

Specified minimum yield strength (SMYS) shall be used as material strength/yield stress in calculations provided that temperature derating is insignificant and that the tubes are fully annealed to remove any effects from cold working during manufacturing. The effect of temperature on SMYS shall be considered.

7.5.2.5 Load case variables

The functional and environmental loads should be defined as the most probable maximum value in the considered time period.

Design working pressure and maximum or minimum operating temperature (whichever is more onerous) shall be used in all calculations for operational condition, except for fatigue analyses when actual operating pressure and actual operating temperature may be used.

7.5.2.6 Wall thickness calculations

Wall thickness calculations shall be performed per Equations (1) to (6). An example calculation is provided in Annex I.

7.5.2.7 Test pressure

The tubes shall be designed to withstand a minimum test pressure ratio of 1,5 $\times\, p_{DW}$.

A minimum test pressure of $1{,}5 \times p_{DW}$ shall be used for the stress calculations. Any nominal over pressurization utilized in the actual test regime shall not be accounted for in the tube sizing calculations, unless specifically specified by the purchaser in the functional specification. The internal test pressure, p_i, in the tube is calculated as given by Equation (1):

$$p_i = p_{DW} \times 1{,}5 \tag{1}$$

where p_{DW} is the design working pressure (DWP).

7.5.2.8 Stress calculation

Umbilical tubes shall be designed such that the maximum equivalent stress, σ_e, satisfies the criterion of Equation (2):

$$\sigma_e \leqslant \eta_\sigma \times \sigma_{SMYS} \tag{2}$$

where

η_σ is the utilization factor obtained from Table 8;

σ_{SMYS} is the minimum specified yield stress.

$$\sigma_e = \frac{1}{\sqrt{2}} \times \sqrt{(\sigma_h - \sigma_a)^2 + (\sigma_a - \sigma_r)^2 + (\sigma_r - \sigma_h)^2} \tag{3}$$

where

σ_h is the hoop stress; see Equations (4) and (5);

σ_a is the axial stress;

σ_r is the radial stress; see Equation (6) for σ_{ri} and Equation (7) for σ_{re}.

Two load cases shall be considered:

— pressure containment where only internal pressure is acting;

— combined loading, where direct functional and/or environmental are acting in addition to internal pressure.

Table 8 — Utilization factors

Condition	η_σ	
	Pressure containment (internal pressure only)	**Combined loading**
Normal operation	0,67	0,80
Pressure test	0,96	0,96
Installation	—	1,00
Abnormal operation	—	1,00

NOTE The equivalent stress criterion is relevant only for load-controlled conditions. For evaluation and verification of displacement-controlled conditions, the method described in Annex J can apply.

Reference is made to 7.5.8.14 and 7.5.8.15 regarding test pressure.

Hoop and radial stress components may be calculated using Equations (4) to (7):

Hoop stress, σ_{hi}, on the inside wall is given by Equation (4)

$$\sigma_{hi} = \left(p_i - p_e\right) \times \frac{\left[D^2 + \left(D - 2 \times t\right)^2\right]}{\left[D^2 - \left(D - 2 \times t\right)^2\right]} - p_e \qquad (4)$$

where

p_i is the internal pressure;

p_e is the external pressure;

D is the nominal outer diameter;

t is the wall thickness that assumes the value of t_1 or t_2 depending on condition according to Table 7.

Hoop stress, σ_{he}, on the outside wall is given by Equation (5):

$$\sigma_{he} = \left(p_i - p_e\right) \times \frac{2 \times \left(D - 2 \times t\right)^2}{\left[D^2 - \left(D - 2 \times t\right)^2\right]} - p_e \qquad (5)$$

where the symbols are the same as for Equation (4).

Radial stress, σ_{ri}, on the inside wall is given by Equation (6):

$$\sigma_{ri} = -p_i \qquad (6)$$

where the symbol is the same as for Equation (4).

Radial stress, σ_{re}, on the outside wall is given by Equation (7):

$$\sigma_{re} = -p_e \qquad (7)$$

where the symbol is the same as for Equation (4).

Total axial stress, σ_a, shall include axial stress generated due to direct tensile loads, bending stress and end-cap stress when pressurizing the tube.

For combined load cases the following stress components shall be considered:

— hoop stress due to internal pressure and/or external pressure; see Equations (3) and (4);

— radial stresses; see Equations (5) and (6);

— axial stresses due to the end cap load, direct tensile load and bending;

— shear stresses due to torque;

— contact stresses.

A conservative assessment may be made in lieu of accurate calculations.

Equations for collapse and buckling are presented in Annex J.

Special care shall be taken when the tube is subject to a large net external pressure combined with bending, which can lead to buckling.

See 6.2.5.2 for typical load cases for consideration.

7.5.2.9 Fatigue

Fatigue analyses shall be performed on umbilical sections and components subject to fatigue from cyclic loads in order to

a) demonstrate that the fatigue life of the umbilical meets the design-life requirement;

b) qualify the umbilical-host interface accessories as fit for dynamic service;

c) determine the locations and magnitude of wear between components, and demonstrate adequate anti-wear component design;

d) determine the fatigue performance of all critical umbilical components.

Reference is made to fatigue calculations in Clause 6.

7.5.2.10 Ovality

The ovality, f_0, expressed as a percentage, of the in-place umbilical tubes shall be a value agreed-upon between the purchaser and manufacturer, but calculated as given in Equation (8):

$$f_0 = \frac{D_{\text{max}} - D_{\text{min}}}{D} \times 100 \qquad (8)$$

The ovality of a tube incorporated into an umbilical shall be taken into account during a consideration of the required installed conditions for collapse and buckling.

7.5.3 Materials selection

7.5.3.1 General

Materials for metallic tubes shall be selected with due consideration of the fluid being transported, loads, temperature and possible failure modes during installation and operation. The selection of materials shall ensure compatibility of all components of the umbilical. The following material characteristics shall be considered:

— mechanical properties;

— hardness;

— ductility;

— fatigue resistance;

— weldability;

— corrosion resistance.

A matrix for tube materials that are acceptable for use in subsea umbilicals is included in Annex H. The matrix contains typical minimum requirements for each material type.

7.5.3.2 Corrosion

Design-life corrosion resistance shall be demonstrated. The maximum temperature and the conditions that can be experienced by a tube assembly throughout the design life shall also be addressed as part of the corrosion evaluation. The material shall have a critical pitting temperature (under relevant service conditions) and critical crevice temperature (under relevant service conditions), if applicable, that exceed the maximum service temperature. Internal corrosion is not acceptable, as the corrosion products can also damage components connected to the umbilical.

The party responsible for materials selection shall either undertake corrosion testing on the specified service fluids, or provide documentary evidence of previous tests that demonstrate the service fluids with which the materials are compatible.

The following materials-specific considerations shall be made, when applicable:

— certain steels, which can be susceptible to both localized corrosion and environmentally assisted cracking under conditions when water, oxygen and chloride can be present in the fluid, e.g. for water injection, requiring an applications-specific consideration of the corrosion resistance;

— effect of corrosion on fatigue life;

— limited resistance of austenitic stainless steels to corrosion in seawater;

— ensuring electrical continuity for providing corrosion protection to all necessary components;

— possible galvanic corrosion effects between different materials in direct electrical contact in a saline conducting environment;

— sacrificial barrier-coating thickness (zinc cladding) on tubes to achieve the required design life.

7.5.4 Corrosion/erosion protection

7.5.4.1 Design-life corrosion resistance shall be demonstrated, taking into account the maximum continuous temperature.

The tube shall be resistant to pitting/crevice corrosion, in seawater, within the design temperature range and to the specified service fluids being conveyed.

7.5.4.2 Tube constructed from base material that can be liable to external corrosion in a seawater environment shall be suitably protected. This protection may take one or more of the following forms:

a) bonded thermoplastic oversheath;

b) bonded dissimilar metallic oversheath (e.g. zinc cladding) providing cathodic protection;

c) sacrificial metallic fillers incorporated in the interstices of the laid-up tubes;

d) built-in corrosion allowance.

7.5.4.3 Tube constructed from base material that can be liable to internal corrosion and erosion resulting from contact with conveyed fluids shall also be suitably protected. This protection may take the form of one or more of the following:

a) passivation, or other chemical treatment, resulting in an inner corrosion-inhibiting layer;

b) built-in corrosion allowance;

c) built-in erosion allowance.

For both external and internal conditions, other protection methods can be acceptable provided their suitability can be adequately demonstrated. Whichever method is used, it shall be of sufficient adequacy to provide protection for the specified tube design life. Protection systems involving the bonding of a substrate material shall incorporate a bonding system that is resistant to the seawater environment and service temperature.

If joints are introduced to achieve the final production length, or as a result of effecting a repair, the corrosion protection shall be reconstituted in the jointed region. Additionally, if damage occurs to the protection, this shall be repaired in accordance with the manufacturer's written specification.

7.5.5 Hydrogen embrittlement

The party responsible for materials selection shall undertake special considerations of the susceptibility of environmentally assisted cracking (including sulfide stress cracking and hydrogen-induced cracking related to cathodic protection) shall be made. In particular, this applies to material subjected to significant work hardening during fabrication, installation and operation. Parameters for consideration are

- material susceptibility (including effects from manufacture and welding);
- ingress of sea-water (with regards to hydrogen charging from cathodic protection);
- cathodic potential (with regards to hydrogen charging from cathodic protection);
  - stress and strain level,
  - temperature.

7.5.6 Tube manufacture

7.5.6.1 General

Tube for incorporation in an umbilical shall be of seam-welded or seamless construction. The manufacture shall be carefully controlled and monitored. The manufacturing process shall ensure that the raw material and partly finished and finished tubes do not come into contact with contaminants.

All manufacturing steps, from control of received raw materials to shipment of finished tube, shall be defined in the manufacturer's written specification. Essential variables for each manufacturing step shall be established.

7.5.6.2 Tube marking

All tubes supplied by the tubing manufacturer shall be numbered and have identification, as a minimum, in accordance with ASTM A1016/A1016M, ASTM A789/A789M, or equivalent.

If tubes are over-sheathed with a thermoplastic polymer, unique component reference may be achieved by means of colour coding or unique reference.

7.5.6.3 Tube manufacturer's documentation

The quality plan shall contain the information listed in this subclause in addition to that listed in 7.1.2.

Manufacture of the tube shall be performed using the specified precursor materials, following the sequence of activities and remaining within the essential variables specified in the quality plan. Tubes shall be manufactured to specified lengths and joints shall not be allowed unless specified. The wall thickness of the tube shall be in accordance with 7.5.2.5. The manufacture shall be carefully controlled and monitored. The manufacturing process shall ensure that raw material, partly finished and finished tubes do not come into contact with contaminants.

The quality plan shall be verified through the verification testing specified in 5.6.3 and Table 9.

The verification testing of the quality plan should be completed prior to start of production. Verification testing during first day of production is performed at the manufacturer's own risk.

If one or more tests in the verification tests of the quality plan fail(s) to meet the requirements, the quality plan shall be reviewed and modified as necessary, and a complete re-qualification performed.

The following shall be stated in the quality plan and subject to purchaser approval:

— qualification activities in accordance with Clause 5;

— metal-making 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 and PRE;

— material traceability, handling and tube tracking procedure;

— tube forming process;

— method for cold expansion/sizing/finishing, target and maximum sizing ratio;

— final heat-treatment condition and mechanical properties;

— NDE procedures including acceptance criteria;

— list of specified mechanical and corrosion testing;

— dimensional control procedures;

— tube number allocation;

— alignment and joint design for welding and production WPS;

— welding, inspection and non destructive weld testing procedures including acceptance criteria;

— production destructive weld testing, including disposition for failed tests;

— pressure test and cleaning/flushing procedures;

— marking, coating and protection procedures;

— document deliverables (data book content).

7.5.6.4 Changes to essential variables

The following changes in the manufacturing processes shall require new verification tests for the quality plan:

a) tube size (wall thickness or diameter): increase/decrease outside the range approved by purchaser;

b) fabrication facilities;

c) increase/decrease in the agreed alloying elements, outside the tube manufacturer's written specification;

d) modifications to the metal-making process, alloying practice, rolling or working condition and heat treatment;

e) modifications in alignment and joint design for welding and modifications to the welding process.

7.5.6.5 Steel-making

The steel shall be made by any qualified process, using the raw materials specified in the tube manufacturer's written specification, following the sequence of activities and remaining within the essential variables. If a specific type of process is required by the purchaser, that process shall be defined in the tube manufacturer's written specification.

The manufacturing practice, the instrumentation used to ensure proper control of the manufacturing process variables and their tolerances, and the acceptance levels for impurities/inclusions shall be defined in the tube manufacturer's written specification.

Slabs/ingots of finished steel shall be inspected to confirm that it meets the surface finish requirements before plate, strip or tube forming is started.

All elements listed in the material specification, including those added to control material properties, shall be checked for conformance with the specification.

7.5.6.6 Plate and strip manufacture

The manufacturing of plate and strip shall be performed following the sequence of activities and remaining within the essential variables of the qualified manufacturing specification. The manufacturing practice and the instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be specified in the tube manufacturer's written specification.

Repair of plate and strip by welding is not permitted.

7.5.6.7 Degreasing

If the tube-manufacturing process requires the use of lubricants, such lubricants shall be completely removed from the internal and external surfaces prior to the heat treatment.

7.5.6.8 Tube corrosion protection

Corrosion protection, if integral with the tube, is a critical element in the overall reliability of the product. As such, the application process shall be carefully controlled and monitored, and key process parameters shall be continuously measured and recorded.

If a bonding film or layer is used to provide adhesion and/or water-blocking between the tube and the protective oversheath, such film or layer shall be of uniform thickness and consistency, and cover 100 % of the base tube surface.

Integral corrosion protection should be applied as a continuous operation without interruptions. During application, the corrosion protection shall be subject to frequent visual examination for the detection of visible defects such as colour changes, bubbles, inclusions, voids or other surface irregularities. The manufacturer's written specification shall include acceptance/rejection levels for such defects.

Corrosion protection shall be undertaken in accordance with the manufacturer's written specification, which shall address, as a minimum, the following:

a) surface finish and preparation of base tube material to which the corrosion protection mechanism is applied;

b) coating thickness/tolerances and adhesion levels;

c) maximum time period between surface preparation and application of corrosion protection;

d) storage of prepared tube prior to application of corrosion protection;

e) corrosion-protection coating/layer to be free from lumps, coarse areas, loosely adhered particles, blisters, cracks, splits, holes, etc., and to provide full circumferential coverage;

f) application, thickness and consistency of sealer material, if applied, and the effect of these properties on the ability for the CP to remain effective against the corrosion mechanism;

g) electrical continuity between externally clad tube and cladding material;

h) repairs to defective/damaged corrosion-protection mechanisms;

i) reconstitution of corrosion-protection mechanism during tube jointing.

7.5.6.9 Internal cleaning

On completion of manufacture, the tube bore shall be subject to a cleansing program to remove fluid and particulate contaminants. Internal cleaning shall be undertaken in accordance with the manufacturer's written procedure, which shall address, as a minimum, the following:

a) required cleanliness level and methods used to achieve such a level;

b) compatibility of cleansing fluids with the tube material and/or the internally passivated surface, if applicable;

c) flow rates to achieve cleanliness levels without overstressing the tube.

The cleansing program shall be such that the performance of the tube is not degraded. On completion of cleaning, the tube ends shall be sealed to prevent contamination ingression.

7.5.7 Tube welding

7.5.7.1 General

The following requirements are applicable to longitudinal welds and girth welds.

The welds shall meet the minimum requirements of the base material or the weld properties shall be determined, documented and concluded as fit for the design and the application.

All joining shall be undertaken in accordance with qualified welding procedures by qualified personnel. Welds shall be subject to inspection according to a weld-inspection plan approved by the purchaser.

Detailed weld-qualification procedures, together with procedures for non-destructive examination, shall be produced. Such procedures shall include any interpass cleaning and/or any post-weld heat treatment. Procedures shall cover both automated factory-produced welds, manual factory-produced welds and, when relevant, manually produced welds for offshore repair jointing where automated welding might not be practical.

Not all tube dimensions are suited for manual welding. It is the party that shall perform contingency offshore repair jointing that is responsible for repair-weld qualification procedures.

All welding operations shall be carried out in clean, dedicated areas and shall be protected from damaging environmental factors. Welding equipment shall be regularly inspected for cleanliness. The condition of welding electrodes shall be regularly visually examined for correct material grade, profile, position, mechanical and spark-erosion damage. Filler wire or rod shall be checked regularly for correct positioning and operation if an automatic feed system is employed.

Girth welds in tubes should not be placed in high-strain areas in order to mitigate concerns of hydrogen-induced embrittlement due to cathodic protection.

7.5.7.2 Tube and weld preparation

The preparation shall be in accordance with the qualified welding procedure, which shall take into account the following:

a) removal of external corrosion protection to a minimum specified distance from the end of the tube;

b) tube end preparation, including

   1) angular tolerances on the cut end relative to the longitudinal axis of the tube,

   2) ovality of the cut ends,

   3) removal of internal and external burrs,

   4) prevention of swarf ingress into the tube;

c) surface cleaning (mechanical and /or chemical) of the tube adjacent to the end being welded;

d) tube- and weld-head alignment for welding of the tube ends;

e) gas purging, if required;

f) radial and axial alignment of the weld gap within specified tolerances;

g) secure and accurate location of the welding system relative to the tube;

h) control of ambient environment;

i) control of welding equipment parameters.

7.5.7.3 Welding consumables

Welding consumables shall be suitable for their intended application.

All 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 guaranteed maximum value for hydrogen in the weld metal. Recommendations for post-weld heat treatment (maximum temperature, holding time, etc.) should also be provided.

The party responsible for the welding and the welding-consumable manufacturer should agree on the content and the specified limits in the data sheets.

7.5.7.4 Welding procedure qualification

Welding procedures shall be performed and qualified in accordance with national or International Standards or combinations of these as applicable to the particular tube material, and ranges of bore size and wall thickness.

The welding shall not introduce pollution or contamination into the tubes.

All welding operations shall be undertaken by personnel who are qualified to an approved welding procedure. All production welds shall be 100 % visually inspected and NDE-tested by qualified and approved personnel.

NOTE Examples of suitable experience and training are given in ISO 9606. Visual inspection can be performed by approved welders or weld operators.

7.5.7.5 Production weld testing

A weld-inspection plan shall detail production weld test details and frequency. As a minimum, the following shall be stated:

a) destructive or non-destructive examination;

b) location and method of removing sample material for destructive tests;

c) preparation of test sample;

d) identification and traceability of test sample;

e) test procedure description and test method;

f) acceptance criteria;

g) retest criteria (if applicable).

7.5.7.6 Weld repairs

No repairs shall be allowed in the case of defective welds produced using a single-pass welding process. Failed welds and their heat-affected zones shall be removed.

For defective welds arising during a multiple-pass welding process, if the defect occurs during the first pass, the defective weld shall be treated as a single-pass process. If a defect occurs in a subsequent pass, then repair is allowed in accordance with the manufacturer's written qualified repair procedure. After repair, all welds shall be subjected to 100 % visual and NDE inspections.

7.5.7.7 Tube repairs

Repairs to the pressure-retaining component require the complete removal of the defective section of tube followed by butt-welding of the exposed tube ends, or insertion and butt-welding of a spool piece of the same design.

Repairs to the plastic and/or metallic oversheaths that are integral to the tube construction and/or corrosion-protection mechanism shall be undertaken in accordance with the manufacturer's written specification. Any such re-constitution shall maintain the functionality of the sheath and its design purpose.

7.5.8 Steel tube testing

7.5.8.1 General

All tests, except flaring tests and chemical analysis, shall be carried out on samples that contain welds and that are representative of the finished product. Material testing, i.e. qualification, verification and acceptance testing, shall be performed in accordance with Clause 5 and Table 9. The required tests vary with material grade (see Annex H).

A material test plan shall detail production sampling, production test details and frequency. The following shall be stated:

a) destructive or non-destructive examination;

b) location and method of removing sample material for destructive tests;

c) preparation of test sample;

d) test description and test method;

e) acceptance criteria;

f) retest criteria (if applicable).

Table 9 — Tubes testing

Test performed	Qualification tests[a]	Verification (V) tests	Acceptance (A) tests	Weldment	Tube body
Visual and dimensional	—	7.5.8.2	7.5.8.2	—	V and A
Low-cycle fatigue[b]	7.5.8.4	—	—	V	V
Tensile	—	7.5.8.5	7.5.8.5	V and A	V and A
Flattening and/or reverse flattening	—	7.5.8.6	7.5.8.6	V	V and A
Micro-examination	—	Annex H	Annex H	V and A	V and A
Macro-examination	—	Annex H	Annex H	V and A	V and A
Hardness	—	7.5.8.7	7.5.8.7	V and A	V and A
Hardness traverse	—	7.5.8.8	—	V	V
Flaring or flange	—	7.5.8.9	7.5.8.9	—	V and A
Chemical analysis	—	7.5.8.10	7.5.8.10	—	V and A
Corrosion	—	7.5.8.11	7.5.8.11	V and A	V and A
Weld qualification	—	7.5.8.12	—	V	V
NDE examination	—	7.5.8.13	7.5.8.13	V and A	V and A
Burst	—	7.5.8.14	—	V	V
Pressure	—	—	7.5.8.15	A	A

[a] Qualification testing requirements in accordance with Clause 5.

[b] In some cases, it is necessary to evaluate high-cycle fatigue. This is not typically performed by tube supplier and not relevant for all applications. The purpose of the high-cycle fatigue testing is to prove that the fatigue performance assumed in the umbilical design meets the service life requirements.

7.5.8.2 Visual and dimensional checks

Each tube shall be visually inspected. This shall include examination of the tube material(s) for contamination, verification of dimensions and construction. The following parameters shall be measured for all tubes in accordance with the manufacturer's written specification:

a) ID, which may be calculated;

b) OD;

c) diameter of any intermediate layers;

d) ovality;

e) concentricity;

f) tube wall thickness;

g) internal surface flaw/defect;

h) external surface flaw/defect.

The manufacturer's written specification shall include dimensional criteria and inspection methods for all of the above parameters stating acceptance values.

7.5.8.3 Dimensional tolerances

The dimensional tolerances for the tubes shall be in accordance with Table 10. Alternative tolerances may be agreed upon by the manufacturer and the purchaser provided the criteria in 7.5.2 are satisfied.

The tolerance to wall thickness is included in the design equations for pressure containment and collapse (see Annex J), and the values stated in the Table 10 may be substituted if substantiated in the design according to these equations. The tolerance to out-of-roundness is included in the design equation for collapse.

The tolerances in Table 10 also affect the weld geometry and the fatigue properties of girth welds, and shall not be substituted.

NOTE The requirements for dimensional tolerances in Table 10 are in line with the most stringent requirements of ASTM A789, but leave out the discontinuities specified in ASTM A789.

Table 10 — Dimensional tolerances

Characteristic that shall tested	Recommended tolerance	Extent of testing %
Outer diameter[a]	± 0,3 % D^b or ± 0,13 mm, whichever is greater	100
Out-of-roundness[c]	1,0 % D^b	100
Tube wall thickness	±10 % t^d	100
Length of tube	By manufacturer's agreement	100

[a] For sizes equal to or greater than 38,1 mm(1,5 in) refer to ASTM A789 for OD tolerances.

[b] Specified nominal outer diameter.

[c] The out-of-roundness shall be calculated as $D_{max} - D_{min}$, where D_{max} and D_{min} are measured in the same cross-sectional plane.

[d] Specified nominal wall thickness. The wall thickness shall be measured with a mechanical calliper or calibrated non-destructive testing device.

7.5.8.4 Low cycle fatigue tests

The test sample shall include at least one girth weld and longitudinal weld if relevant. One cycle of the test load pattern shall simulate the large strain cycles that the tube will experience throughout manufacture installation and operation. The straining may be performed in uni-axial tension or bending. The cyclic load pattern shall be repeated twice and the sample shall be subjected to adequate NDE for which the acceptance criterion is that no crack development shall take place. If the test piece passes the test, the test load pattern should be cyclically repeated until a through-wall crack develops to document the margin to failure.

The test shall be performed by the tube manufacturer and should be agreed according to Annex A. The pass/fail criteria shall be agreed upon between the purchaser and the manufacturer.

7.5.8.5 Tensile tests

Tensile tests shall be carried out in accordance with ASTM A1016/A1016M, ASTM E8/E8M and ASTM A370. Results shall comply with the material specification. See Annex H for tube material applicability.

Failure in the weld metal during tensile testing is not acceptable for girth welds.

When the tube size is insufficient for preparation of samples according to these standards, full tube samples shall be used. The verification tensile tests shall document sufficient yield- and tensile-strength, and elongation.

7.5.8.6 Flattening tests/reverse flattening test

Flattening tests shall be carried out in accordance with ASTM A1016/A1016M and ASTM A370. Results shall comply with the material specification. See Annex H for tube material applicability.

7.5.8.7 Hardness tests

Hardness tests shall be carried out in accordance with ASTM A370, ASTM A789/A789M, ASTM A1016/A1016M and ASTM E92. Results shall comply with the material specification. See Annex H for tube material applicability.

7.5.8.8 Hardness traverse

Hardness traverse tests shall be carried out in accordance with ASTM E384. Results shall comply with the material specification. See Annex H for tube material applicability.

7.5.8.9 Flaring or flange tests

Flaring and/or flange tests shall be carried out in accordance with ASTM A1016/A1016M, ASTM A789/A789M, and ASTM A370. Results shall be in accordance with ASTM A789/A789M, or equivalent. See Annex H for tube material applicability.

7.5.8.10 Chemical analysis

Complete chemical analysis shall be undertaken. In the case of high alloy materials, this shall include a ferrite content verification in accordance with ASTM A1016/A1016M, ASTM E562 or ASTM E1245. The tube component elements and ferrite content shall be within the limits specified in the manufacturer's written specification. See Annex H for tube material applicability.

7.5.8.11 Corrosion test

The tubes, including welds if applicable, shall be corrosion-tested in accordance with ASTM G48-03, method A. The specimen geometry, specimen preparation, test temperature, temperature monitoring, pH envelope and test acceptance criteria shall be in accordance with the manufacturer's written specification. See Annex H for tube material applicability.

7.5.8.12 Weld qualification

7.5.8.12.1 All welding operations shall be qualified, including testing in accordance with an internationally recognized standard. Such standards include, but are not limited to

a) ISO 15607,

b) ISO 14732,

c) ANSI/ASME B31.3,

d) ASME BPVC, Section IX.

7.5.8.12.2 Requalification shall be necessary if there is a change in an essential variable in the welding process. Significant variables include, but are not limited to

a) heat input parameters outside allowable range,

b) gas composition,

c) weld consumables.

In accordance with ANSI/ASME B31.3 and ASME BPVC, Section IX, a single qualification report may cover a range of applicable bore sizes and wall thicknesses.

7.5.8.13 Non-destructive examination

All tubes shall be subject to non-destructive examination (NDE) in accordance with ASTM A1016/A1016M, or equivalent, subject to the maximum allowable size of defect that can be tolerated by the service condition. Appropriate NDE methods and techniques shall be used to monitor tubes along each complete length for defects in the tube wall in seamless tubes and longitudinal weld integrity in seamed tube. All tubing shall be 100 % examined by ultrasonic and eddy-current examination for flaw detection in accordance with the requirements given in ASTM A1016/A1016M. Ultrasonic examination shall be performed according to ASTM E213 on the whole tube body. For seam-welded tubes, additional examination of the seam weld in accordance with ASTM E273 is required. Eddy-current examination of the entire length of all tubes that have a propensity for the formation of an intermetallic phase imbalance shall be performed in accordance with ASTM E309 using ferromagnetic detection equipment. All tubes shall be tested by PMI before shipment from the tube manufacture plant. All strip and orbital welds shall be subjected to 100 % radiography testing in a minimum of two planes. All NDE procedures and operators shall be qualified in accordance with an internationally recognized standard. Such standards include, but are not limited to

a) ISO 9712,

b) ANSI/ASME B31.3,

c) ASME BPVC, Section V.

All welds shall be subject to NDE using the method and acceptance criteria detailed in the qualified welding procedure. Welds not in accordance with the procedure acceptance criteria shall be deemed unacceptable.

Pores are the only acceptable weld-defects. Acceptable size and pore concentration shall be subject to agreement between the manufacturer and purchaser and considerations shall be made taking into account

— tube dimensions,

— pore geometry,

— pore location within the weld,

— number of pores.

Consideration shall be given to the sensitivity, calibration and limitations of any NDE method employed such that non-acceptable defects shall be located and defective tubes identified and segregated for further examination and possible corrective action.

See Annex H for tube material applicability.

7.5.8.14 Burst test

A minimum of two samples of each tube design and featuring all weld types shall be subjected to a burst test for verification purposes.

If the delivered tube contains strip-splice welds (bias welds) or orbital welds, then these shall be included in the burst test samples. Orbital welds performed by the umbilical manufacturer as part of tube-string welding or included as part of tube lay-up (tie-in weld) shall be included. The weld to the intended end-fitting design(s) and material(s) for the topside and subsea tube termination interface shall also be included. This weld may be performed on a different sample by a party other than the tube supplier.

Multiple welds may be included in the same sample, provided the spacing between welds does not affect the results. Samples for burst testing shall include a minimum tube length of 400 mm with a minimum of 150 mm between welds.

The minimum burst pressure shall be $2 \times p_{DW}$.

7.5.8.15 Pressure test

Tubes or coils of tubes, when welded into strings on bobbins/reels, shall be subjected to a pressure test to a minimum of $1{,}5 \times p_{DW}$ for a minimum of 4 h in accordance with the manufacturer's written specification.

For sample testing, the test fluid shall be in accordance with the manufacturer's written specification.

For integrity tests that are performed on each completed tube length, the test fluid shall be one of the following:

a) specified system control fluid, suitably filtered to allow the achievement of the final system cleanliness, as defined in the manufacturer's written specification;

b) proprietary storage fluid, filtered and cleaned as in a);

c) town-mains or potable water suitably filtered as in a); the chloride content of town-mains or potable water shall be equal to or less than 20 mg/l (20 ppm) so as not to introduce corrosion for tubes that are fabricated of stainless steel materials;

d) de-ionized water suitably filtered and cleaned as in a).

The final choice of pressure-test fluid(s) that shall be incorporated in the tubes during shipping, installation and service shall take account of the relevant system and environmental factors and shall be agreed with the purchaser.

The use of two different test fluids during umbilical manufacture is not recommended, as this can require duplicate test equipment during manufacture, load-out and installation.

If freezing temperatures are possible with the use of “water only” test fluids, then a quantity of monoethylene glycol sufficient to prevent freezing should also be proportionately mixed with the water.

If long-term storage of the “water only” test fluids is possible or there is a possibility of microbiological growth within the filled tube, then a suitable biocide should also be proportionately mixed with the water.

If tubes undergo intermediate welding operations during the laying-up operation, the fluid shall be part or fully removed prior to welding.

Storage of the test fluid(s) in both the shipping containers and the tubes shall be such as to prevent freezing.

Completed tube lengths shall be sealed at each end at all times when testing is not in progress.

8 Terminations and ancillary equipment design

8.1 Design principles

The design shall be carried out in accordance with the philosophy in Clause 5 and the relevant parts of Clauses 6 and 7.

Terminations and ancillary equipment should be designed for the actual loads experienced by the component. The safe working load for terminations and ancillary equipment may be different from the limit states of the umbilical.

The design shall also take into consideration temperature effects during transport and installation, installation method and possible repair and intervention situation after long-time immersion.

Sufficient length for re-termination of pig-tails, re-welding of tubes and re-splicing of hoses shall be included.

The design documentation shall state whether the terminations, ancillary equipment and umbilical are designed for intentional free-flooding.

For subsea terminations, the compatibility of non-metallic materials with permeated fluids shall be documented. The topside termination shall be designed to handle fluids and gases coming out through the interstices of the umbilical.

Continuity or isolation shall be incorporated between the umbilical, the ancillary equipment and the interfacing hardware as required for the overall corrosion protection system design.

Corrosion protection through coating shall be designed for the service life to a standard as agreed by the purchaser.

8.2 Design process

The design principle is that the end termination shall meet the same functional requirements as the umbilical.

Free-span corrections between the J-tube bellmouth or subsea termination interface and seabed shall be designed in accordance with the project specific design basis and Clause 6.

If the design incorporates isolation valves and/or electrical/optical shorting/test points requiring access, the design shall be such that these can be readily accessed and operated. The method of access and operation shall be as specified in the manufacturer's written specification.

If the umbilical is intended for temporary lay-down, pressure relief during retrieval shall be considered. If temporary cable end sealing is used, a double watertight barrier should be included.

8.3 Armour terminations

Armoured umbilicals shall be terminated with end terminations with a minimum loading capability equal to or exceeding the maximum tensile load of the umbilical, unless a lower value is agreed upon with the purchaser.

Unarmoured umbilicals shall be terminated with mechanical end terminations with a minimum loading capability equal to or exceeding the maximum tensile load of the umbilical, unless a lower value is agreed upon with the purchaser.

8.4 Tube and hose terminations

Permanent hydraulic-line end fittings shall accommodate the maximum tube/hose test pressure to which they are fitted.

Whenever a permanent line-end fitting is used for test purposes, a temporary adapter and a directional pressure bleed-off valve should be assembled between the end fitting and the test hose interface. The temporary adapter and valve should be rated for the maximum test pressure, and the valve should also allow for shut-in of pressure.

Tube materials should be checked at interfaces between umbilical tube and the termination-unit tube for compatibility in terms of strength and corrosion resistance. Girth welds, if used in areas of high strain, should be qualified for those conditions in order to mitigate concerns of hydrogen-induced embrittlement due to cathodic protection.

Connectors (tube and hose) shall be installed by qualified personnel in accordance with a qualified procedure. The terminations shall be tested in accordance with the manufacturer's written specification.

Umbilical tube connection welds to subsea and topside terminations shall be performed in accordance with an agreed method and a qualified procedure. Weld type and criteria shall be agreed with the purchaser.

8.5 Cable terminations

For electric/optical fibre cable terminations that are permanently installed subsea (e.g. penetrators, connectors, etc.), the design shall take into account the requirement for effective water-blocking at the cable entry, pin-to-pin conductive connectors and pigtails, if applicable. The electrical cables shall be terminated such that the electrical conductors are protected against sea water by a minimum of two barriers. The termination chamber shall be pressure balanced.

All elastomeric materials within connectors and splice chambers shall be compatible with the design environment; this also applies if one sealing barrier fails. The failure of a water-ingress barrier shall not create a consecutive failure, e.g., insulated conductors should not be in direct contact with metal or other conductive materials.

The electrical connectors shall be qualified hardware, installed by qualified personnel using a qualified procedure.

If an electrical connector can be exposed to extended immersion in a seawater environment without connecting to the mating half, suitable blanking arrangements shall be incorporated. Such blanking arrangements shall both provide mechanical protection and prevent electrolytic action between adjacent pins in the event electrical power is applied to the connected electrical cores.

A positive visible identification subsea of a fully mated connector or protection plug should be part of the connector design.

The terminations shall be tested in accordance with the manufacturer's written specification.

The splice between the umbilical conductor core and the electrical connector pigtail conductor core shall include a water and gas block to stop penetration along the conductor core. The capability to withstand internal pressure shall be better than or equal to that of the conductor insulation.

The umbilical subsea termination shall be constructed to limit the consequences of faults in the water barriers.

Vulnerable parts, like boot seals, should not be located at the lowest point; redundant systems should be located in separate units.

8.6 Pull-in head

A pull-in head shall be used to pull the umbilical along the seabed or through the I- or J-tube. The pull-in head shall be designed to withstand installation loads without damage to the umbilical or its functional components.

The pull-in head shall be designed, if possible, to allow uninterrupted travel over rollers/sheaves and through I- or J-tube risers without damage or snagging. The manufacturer shall assess the size relationship between the I- or J-tube internal and pull-in head diameters.

The pull-in head shall be designed to house the umbilical functional components and any temporary caps/plugs, and internal volume shall be sufficient to accommodate umbilical component tails without compromising their MBRs.

All bolts, fasteners, pad-eyes and linkages should be capable of withstanding the installation loads and shall be recessed or flush with the housing.

Any pad-eye or D-ring permanently attached to the pull head shall not exceed the diameter of the pull head.

The design should allow for access to internal components for monitoring and/or testing purposes.

The pull-in head may incorporate anode(s) for corrosion protection, in the event that the unit is left subsea for an extended period of time.

Electric and optical fibre cables shall be sealed to prevent seawater ingress. Particular care shall be taken when considering cable sealing for umbilicals that can be laid down at full seabed pressure for extended periods of time.

The pull-in head is in general regarded as lifting equipment, for installation.

If required by the purchaser, the pull-in head shall incorporate a swivel when overhead clearance is limited. Limited overhead clearance may also necessitate a stackable pull head assembly.

The pull-in head design should be based on the same stress criterion as for metallic tubes stated in 7.5.2.8. The safety factor shall be 0,59 (equal to 1/1,7).

A proof test shall be carried out at a load approved by the purchaser. Proof test may be performed before connecting the pull-in head to the umbilical and its components providing the same connection design and connection hardware has previously been proven at the proof test load in accordance with 5.6.2.

Reference is made to DNV – *Rules for Planning and Execution of Marine Operations*[28] or an approved code proposed by the contractor.

8.7 Topside hang-off

A topside hang-off shall be used to secure the umbilical to the top of the I- or J-tube riser or other securing locations. The hang-off equipment shall be designed to withstand static or dynamic loads associated with vessel motions and installation forces, and to transfer the maximum tensile load without damaging the umbilical or umbilical components.

The hang-off design shall take into account that, once installed, inspection access at the top of the I- or J-tube might not be practical. The potential for long-term corrosion or creep at the load-bearing components shall be addressed.

During hook-up at a topside facility, it shall be possible to bleed off any internal pressure inside the lines in a controlled manner with containment.

8.8 Subsea termination interface

A subsea termination interface shall be used to provide the transition between the umbilical and its subsea termination.

Within this termination, the tensile-strength members of the umbilical, such as armour wires, rods or metallic tubes themselves, are physically coupled to the unit using an approved method.

At such an interface, there is a transition in stiffness, which normally requires the use of a bend restrictor or stiffener in order to protect the umbilical from excessive localized bending during handling or deployment.

The design of the interface shall be such that the components are not subjected to detrimental stresses when they are connected to the subsea umbilical termination.

8.9 Subsea umbilical termination

A subsea umbilical termination shall be used to connect the umbilical mechanically and functionally to the subsea system.

Suitable handling facilities may be included, if required, for use during load-out and installation. This is mechanically attached to the subsea termination interface and the various functional components of the umbilical connected to their appropriate lines/connections, housed within the unit.

The pressure-containing parts of the termination shall be subjected to hydrostatic pressure testing prior to connection to the umbilical. The test pressure should be 1,5 times the design pressure for a minimum of 2 h. No permanent deformation or damage shall be observed after the testing. The test shall confirm no leakage.

8.10 Bend restrictors

Bend restrictors (sometimes referred to as bend limiters) are intended to limit the bending of the umbilical in the region where they are located. This is typically at a location where the umbilical is connected to a rigid termination.

These devices provide a mechanical positive locking to assist in handling and maintain the umbilical position when in service.

The most common types are comprised of a series of profiled segments, sometimes split and then bolted together during assembly (sometimes referred to as “vertebrae” bend restrictors).

Units are typically installed for a length of 90° of coverage based on the appropriate bending radius of the umbilical, but may be longer or shorter depending on application.

Bend restrictors should be designed to accommodate the anticipated load and angle combinations.

Overall size, mass and centre of gravity are required for handling purposes.

Materials of construction can be metallic or thermoplastic, depending on functional requirements.

The design of the bend restrictor shall take account of the size, mass and centre of gravity of the subsea termination and their effect, including low-cycle fatigue, on the umbilical during load-out, deployment and subsea pull-in. The bend-restrictor design and length determination shall also take into account the requirements for free-span corrections. Possible effects of rock dumping and added moment from the bend restrictor itself shall be considered in the design.

The bend restrictor shall be mechanically protected during handling.

NOTE For umbilicals with a large centre tube, the termination interface can result in large free spans.

Bend restrictors should be used on all terminations where the selected locking radius determines the length at minimum 90° cover angle.

8.11 Bend stiffeners

8.11.1 General

Bend stiffeners provide a transition in bending stiffness from the umbilical to a rigid attachment.

These are usually in the form of a conical mass of polyurethane resin surrounding the umbilical, the properties and envelope of which are designed for the particular application.

8.11.2 Dynamic bend stiffeners

Dynamic bend stiffeners are used to limit the bending stresses that are caused by environmental loads and imposed on an umbilical when in service.

These are typically employed at the fixed departure position on a floating structure, such as I-tube base or vessel hang off. They can also be employed where there is a transition between a rigid structure and a continuously moving umbilical.

Dynamic bend stiffeners shall be designed to consider various load cases that combine associated tensions and angles found from a dynamic analysis. The riser-tube departure angle should also be considered along with operational temperature.

Documentation of overall size, mass and centre of gravity are required for handling purposes.

In all cases, the designer of the dynamic bend stiffeners shall provide a design report that includes a tension and curvature plot along the unit at a defined temperature.

The attachment mechanism for these devices can be flange mounted, which attaches directly to the riser tube base, or alternatively, a latchable system that is either automatically mated during pull-in or ROV assisted. The mechanism shall also feature provisions for detachment in the event of reverse cross haul or at final decommissioning.

8.11.3 Static bend stiffeners

Static bend stiffeners are used to provide an increase in bending stiffness at the point of attachment to a termination.

In the case of armoured umbilical structures containing components that can tolerate higher curvature, molded-design bend stiffeners may be used in place of bend restrictors but, in each case, the installation conditions and handling should be first evaluated.

In static applications such as a repair joint, the profile allows a smooth, streamlined transition between umbilical and joint diameter. This reduces risk of snagging during handling, deployment or recovery.

8.12 Ancillary equipment

8.12.1 Joint box

A joint box may be used to join umbilical sub-lengths to achieve overall length requirements or to repair a damaged umbilical. Each umbilical end being joined shall have a termination, if applicable. These shall be joined using a connecting sleeve or barrel that allows for the transmittal of the load from one sub-length to the other.

The joint box shall be of a streamlined design, with a bend restrictor at each end, and shall be of compact size to facilitate reeling, storage and installation requirements.

The joining of the electric cables, optical fibres, hoses and tubes within the joint box shall be in accordance with the manufacturer's written specification.

Joint boxes should not be incorporated in any section of an umbilical that operates in a dynamic mode.

8.12.2 Weak link

A weak link is an optional component designed to protect the umbilical and equipment connected to the umbilical from excessive line loads. The required load at which the weak link shall be activated shall be defined in the manufacturer's written specification. The weak link shall be designed to have a design life equal to or greater than the umbilical.

For weak-link designs that are integral to the umbilical, in order to facilitate installation and retrieval of the umbilical, the weak link shall have an override mechanism, which shall be easily removable and replaceable when the weak link is installed on the seabed. With the override mechanism in place, the weak link shall be capable of withstanding the maximum umbilical tensile working load without either being activated or suffering mechanical failure.

If the weak link is activated, the functional lines shall be cleanly severed. Damage to the services shall be minimized by ensuring that the internal umbilical components are not excessively loaded during activation. The design shall facilitate repair of the umbilical after activation.

An alternative weak-link design may be employed in the form of a shearing guillotine, which acts on jumper hoses or cables installed between the subsea umbilical termination/distribution unit and a subsea system. The jumpers severed shall be replaceable subsea.

Other approaches to the design of weak links (such as multi-coupler arrangements) may be acceptable and shall be defined in the manufacturer's written specification. If a weak link is required, the manufacturer's written specification shall state the type of weak-link design being used.

8.12.3 Buoyancy attachments

Depending on the installed configuration, a dynamic umbilical can necessitate buoyancy attachments in the form of modules, collars, tanks, etc., to achieve the necessary configuration and dynamic motions. Depending on the installed configuration, an umbilical, especially the dynamic segment, if applicable, can require “clamped” or a similar type of connections for certain appurtenances, such as buoyancy modules, collars, tanks, tension hold back clamps, etc., to achieve the necessary installed configuration for dynamic motions. The attachment devices (e.g. clamps) shall be designed for the smallest minimum OD of the umbilical and not based solely on the manufacturer's minimum OD. Therefore, the design shall also include provisions for the further reduction in umbilical OD due to installation and environmental factors, such as the external water pressure (assuming the interstices are not fully flooded); high tension, which tends to reduce umbilical OD due to a tightening of the helix; or long-term creep of the umbilical cross-section due to materials such as sheathing or fillers. Testing of such devices shall also be conducted over a sufficiently long period and under the proper conditions to mimic installation or installed conditions. The method of attachment shall not induce stress cracking of the umbilical sheath; nor should the method of attachment induce excessive strain on the umbilical and its functional components.

Design considerations shall include amount of buoyancy provided, effects of water depth, allowable clamping pressure onto umbilical, potential change in umbilical diameter with tension or effects of long term creep.

8.12.4 Centralizers

Centralizers provide a localized increase in umbilical diameter, which limits the lateral movement inside a guide or riser tube. Such units are used particularly in segmented riser tubes where the umbilical can be subjected to excursions from current motions.

These devices usually are split in two halves, which allow for ease of fitting during installation.

Designs may include an inner segmented or split clamp that is firmly attached to the umbilical and have a secondary thermoplastic molded split section that locates around the inner clamp.

Design consideration shall include the length of the centralizer, clearance between outer clamp and tube ID, and also the clamping pressure to attach inner clamp around the umbilical.

8.12.5 Vortex-induced vibration strakes

Vortex-induced vibration (VIV) strakes are molded units attached along a length of free hanging umbilical to suppress the effects of VIV. For ease of installation, these consist of interlocking half shells, molded to suit the particular size of umbilical.

The units are usually a helical strake with a triangular profile and cover a specific length of umbilical that is at risk of being subjected to VIV in the water column.

Design considerations shall include anti-fouling properties, clamping arrangement, and installation method.

8.12.6 Riser-tube seals

Riser-tube seals are intended to block the free movement of seawater within the tube, which may contain corrosion inhibitor to protect the inner surface of the tube.

They are usually provided as split compliant halves that seal onto the outer diameter of the umbilical and the inner surface of the tube. They are typically installed at the base of the riser tube. Attachment may be to the base of the tube itself or, alternatively, they may be of a self-locating design.

Design considerations shall include installation method and sealing differential pressure.

8.12.7 Tie-back clamps

Tie-back clamps are intended to provide a means of attaching an anchor chain or wire to the umbilical to facilitate a particular in-service umbilical arrangement.

Depending on anticipated loads, it can be necessary to attach these to the tensile components within the umbilical itself. Alternatively, split clamps that are clamped around the umbilical may be used.

Design considerations shall include tensile loading, clamping pressure, length of clamp, creep, installation method and the effects of any localized bending that can be encountered on the umbilical.

8.12.8 Temporary hold-back clamps

Temporary hold-back clamps are used as an installation aid, when the umbilical cannot be supported by the vessel tensioner during installation. This typically can be during handling of a termination through the tensioner, or attaching an appurtance to the umbilical itself.

It is necessary to design these to grip the umbilical over a sufficient length to restrain the umbilical while it is subjected to the anticipated installation loads.

Design considerations shall include the anticipated loads, allowable clamping pressure, umbilical diameter while under tension, creep, length of clamp and clamp connections for hold back wire or chain.

8.12.9 Bellmouth

A bellmouth is not an umbilical attachment. The use of a bellmouth, however, can eliminate the need for a bend stiffener at the base of the riser tube.

The use of such a structure on a floating host should be checked for compatibility with the umbilical being installed, especially with respect to umbilical fatigue caused by repeated bending and tension fluctuations.

Design considerations shall include anticipated tensions, bellmouth profile (curve definition), thickness of bellmouth material, attachment to riser tube, departure angle and overall envelope to avoid interference with other adjacent tubes/bellmouths.

A bellmouth is technically not as suited to provide fatigue protection as a bend stiffener. This should be kept in mind particularly for umbilical designs where fatigue is believed to govern the design.

8.12.10 Riser clamps

Riser clamps are used to attach an umbilical to a rigid or flexible structure in a piggy-back configuration.

Design considerations shall include riser and umbilical diameters, clamping pressure, installation method, length difference between umbilical and riser and allowable free span between clamps.

9 Umbilical design

9.1 Temperature range

The umbilical and its constituent components and materials shall be capable of operating continuously within the specified temperature range for the specified design life. The maximum and minimum temperatures shall be specified in the manufacturer's written specification, based on the functional requirements of Clause 4.

NOTE Continuous or frequent exposure to elevated temperatures can affect the design life of the umbilical.

9.2 Maximum tensile load

The maximum tensile load for the umbilical in the straight condition shall not be more than the value stated in the manufacturer's written specification. The allowable tensile load for the umbilical at a particular bend radius shall be based on the manufacturer's capacity curves.

9.3 Ultimate tensile load

The ultimate tensile load, with the umbilical straight, shall be in accordance with the manufacturer's written specification.

In all cases, the specified load level shall be such that, under all possible installation and service conditions, an adequate margin of safety is demonstrated to exist by analysis.

9.4 Minimum bend radius

The minimum radius to which the umbilical can be bent for storage, installation and service without affecting its performance shall be as stated in the manufacturer's written specification. The minimum bend radius of the electrical cables, hoses, tubes and optical fibre cables shall also be as stated in the manufacturer's written specification.

9.5 Cross-sectional arrangement

The umbilical shall be designed to meet the functional requirements of Clause 4, the design requirements of Clause 6 and the mechanical properties of the manufacturer's written specification. Consideration shall be given to the following.

a) The cross-section should be as compact and symmetrical as possible. This may be achieved by the use of additional components or fillers.

b) If steel tubes form part of an umbilical that also includes thermoplastic hoses and/or cables, consideration shall be given to the crushing forces exerted by steel tubes during manufacture, reeling, installation and service.

c) If fillers are used in the interstices of the umbilical, the filler material should be selected with consideration of the crushing forces on the bundle due to umbilical manufacture, installation and service.

d) The cross-sectional arrangement shall take into account the requirement for the umbilical to free-flood at a rate commensurate with the installation speed, such that the external forces imposed during installation do not damage the components.

9.6 Lay-up

Individual functional components (electric cables, optical fibre cables, hoses, tubes, fillers, etc.) shall be laid up using a qualified method to form the umbilical bundle or sub-bundle.

If required, the bundle lay-up procedure shall be carried out with the hoses pressurized. The pressure level used shall be in accordance with the manufacturer's written specification, which shall be sufficient to prevent distortion of the hoses. If required, all subsequent manufacturing operations shall be carried out with the hoses pressurized in accordance with the manufacturer's written specification.

9.7 Sub-bundles

Sub-bundles, which may be comprised of electric cables, optical fibre cables, hoses, tubes or combinations of components, shall be designed and dimensionally sized to provide a circular configuration. The sub-bundle should be designed as symmetrical as possible about its central axis.

To maintain stability after laying up the sub-components, a binder tape shall be applied at a constant helical angle.

For geometrical and/or mechanical requirements (e.g. interfacing with an electrical penetrator), the bundled and taped subcomponents may be over-sheathed in a thermoplastic material as specified in the manufacturer's written specification.

Any sheathing of the sub-bundle shall be such that it is capable of being applied and subsequently capable of being readily removed without causing damage to the functional component contained within.

9.8 Inner sheath

When an umbilical is armoured, an inner sheath shall be applied over the taped bundle to provide mechanical protection, increase bundle stability and provide a bedding for the armour wires. The sheath construction shall be:

a) for static applications: either a continuously extruded thermoplastic material or a layer of helically applied synthetic fibre roving; the material shall provide sufficient resistance to abrasion and stress cracking during load-out and installation;

b) for dynamic applications: a continuously extruded thermoplastic material.

The sheath shall be of sufficient thickness to ensure proper distribution of radial compression between the armour wire and the bundle. The material purity, thickness of the sheath, and the tolerance for thickness and concentricity, shall be in accordance with the manufacturer's written specification.

The sheath extrusion process shall be in accordance with the manufacturer's written specification. It shall be selected by the manufacturer to suit the subsequent armouring process (if applicable) and to ensure that the bundle components can move freely and independently of each other during bending and flexing.

9.9 Armouring

Umbilicals that contain electrical conductors and/or optical fibres, but do not include load-bearing tubes, shall be armoured or shall include a suitable strain member. For umbilicals that are torque-balanced and/or are subjected to high-tensile loading, the armouring shall consist of two or more contra-helically applied layers of steel armour wires. (If required, other suitable materials that provide the specified performance may be used.) The armour wires shall be applied under uniform tension and designed to limit rotation as umbilical tension varies from zero to the maximum working axial load. For dynamic umbilicals, the armouring may also serve to provide ballast to achieve the necessary stability during dynamic operation. For multi-layer armour and/or ballast packages, additional layers shall be applied in the direction opposite to the adjacent layer(s). The size and lay lengths of the armour wires shall be specified by the manufacturer to provide the necessary tensile strength, axial elongation, bending stiffness and weight for the design life of the umbilical. Filler rods may be used in the armouring packaging.

NOTE EN 10257-2 and ASTM A411 provide specifications for suitable steel wires.

For an umbilical containing steel tubes, the laid-up tubes can have sufficient inherent tensile capacity to provide strain relief in the event electrical conductors are incorporated within the umbilical. In this particular instance, the tube wall thickness shall be suitably sized to accommodate the stresses resulting from pressurization and tensile loading during service and/or installation.

In the event of onerous installation and/or service conditions, the inclusion of an armour layer for mechanical protection of the components, or ballasting of the umbilical, shall be considered as part of the design performance analysis.

If required, thermoplastic filler rods may be used in place of armour wires to minimize the tensile strength and/or mass of the umbilical. The fillers shall be distributed uniformly with the steel wires.

9.10 Outer sheath

An outer sheath shall be applied as

a) a continuously extruded thermoplastic sheath, or

b) a covering of helically applied rovings.

For dynamic applications, a continuously extruded thermoplastic sheath shall be employed in accordance with 9.8.

To provide a visual indication of twist during installation, a high-visibility line of contrasting colour shall be applied along the umbilical length.

9.11 Length marking

The umbilical shall be sequentially marked in lengths of 100 m (328 ft) or 500 ft (152,4 m) increments, with the exception of the first and last 100 m (328 ft) or 500 ft (152,4 m) which shall be sequentially marked in 10 m (32,8 ft) or 50 ft (15,2 m) increments. The marks shall be durable throughout storage, load-out and installation of the umbilical and legible to divers or underwater video cameras providing all-round (360°) visibility and with a minimum character height of 25,4 mm (1,0 in).

10 Umbilical manufacture and test

10.1 Umbilical manufacture

10.1.1 General

Manufacturing operations shall be done according to manufacturer's written specifications and procedures and in accordance with the requirements of this section. New or unproven processes shall be qualified and related documentation maintained.

Manufacturing shall be defined under a manufacturer's inspection and test plan, which shall define procedures for stranding, extrusion, lay-up, armouring, handling and storage for all materials and processes included in the manufacturing of the umbilicals. The scope of such plan(s) shall address the processes above-mentioned as well as packaging, storage, spooling, shipment, cleanliness of area and equipment and any other aspect that can lead to potential failure or degradation, from the receipt of raw material and sub-components throughout the manufacturing and delivery of the completed umbilical.

10.1.2 Lay-up

The lay-up operations shall be carried out in a clean, dedicated controlled area that shall be subject to a regular cleaning schedule.

If relatively stiff components are being laid up, consideration shall be given to the following:

a) minimizing contact forces between the components and the laying-up machine, and appropriate routing design, to prevent damage to the components;

b) maintaining the bend radius at all times equal to or greater than the radius required to produce the maximum allowable bending strain, as specified in the manufacturer's written specification;

c) where required, pre-forming the components to facilitate manufacture of the umbilical bundle or sub-bundle;

d) minimizing built-in torsion in individual components during the bundling process.

For both planetary and oscillatory cabling, the components, sub-bundles and fillers shall not be subject to excessive compressive and tensile loadings. If the weight of a component or sub-bundle can induce damaging loads, the pay-off reels shall be powered.

In order to minimize damage to the external surface of the components, contact forces between the components and the bundling machine shall not exceed the values defined in the manufacturer's written specification. To further minimize surface damage, consideration shall be given to rollers placed wherever such contact forces are relatively high.

Continuous inspection procedures shall be undertaken to ensure that the components are not gouged, scratched or otherwise damaged during bundle assembly.

Consideration shall be given to the identification of one or more components in the cross-section of each bundle or intermediate bundle if the bundle is symmetrical.

If a component weld, splice or joint is performed during the lay-up, the component details and length location shall be recorded on a lay map.

While stored on processing reels or passing through the bundling machine, the component bending radius shall be maintained at all times equal to or greater than the radius required to produce the maximum allowable bending strain. Such a minimum bending radius shall be defined in the manufacturer's written specification.

The bundled components or intermediate bundled components shall be stored on a suitably sized reel and/or carousel in a dedicated and controlled area. This area should preferably be dry. In case this is not feasible, the manufacturer shall propose measures to ensure that the bundle is sufficiently dry prior to extrusion for purchaser approval. The spooling tension and/or number of stacked layers shall be such as not to induce damaging deformation to the bundle structure or individual components.

10.1.3 Inner sheath

The bundle or sub-bundle shall be kept dry prior to and during passage through the extruder.

During extrusion, the following process parameters shall be measured and recorded in accordance with the manufacturer's written specification:

a) extruder barrel/head temperatures;

b) melt pressure/temperature;

c) screw speed/power requirement;

d) haul-off speed;

e) OD measured in two planes.

If the inner sheath is comprised of rovings, these shall be applied under uniform tension. The tension applied to the roving yarns shall be checked for each bobbin at the commencement of each production run and thereafter in accordance with the manufacturer's written specification. Splices within the roving shall be produced and validated in accordance with the manufacturer's written specification. Bitumen, or equivalent roving adhesive, shall be applied in a controlled manner at a controlled rate according to the manufacturer's specification.

During sheath application, the product shall be subject to frequent visual inspection to ensure that the coverage is uninterrupted and uniform and that no extraneous material is included under the sheath. Sheath thickness shall be monitored/measured. Care shall be taken to ensure that the bundle (or sub-bundle) is not stretched and the binder tape is not disturbed during this process.

Repairs to a sheath are allowable and shall be performed in accordance with the manufacturer's written specification. Sheath repairs (description and location) shall be recorded on the lay map.

10.1.4 Armouring

The operation shall be carried out in a clean, dedicated, controlled area that shall be subject to a regular cleaning routine.

Breaking strength, yield strength and load-extension measurements shall be performed on samples from each batch of armour wire to confirm that the material properties are within the specified limits.

Armour wires shall be wound uniformly onto armour bobbins and subsequently processed in a manner that does not damage or reduce the effectiveness of the galvanizing layer (if present) or contaminate it with extraneous matter.

During armour application, the bundle and its components shall not be subject to excessive compressive loadings, which can result in deformation or damage. Separator tapes applied between armour layers, if used, shall be applied at uniform tension. The tension applied to the armour wires shall be checked for each bobbin at the commencement of each production run and thereafter in accordance with the manufacturer's written specification.

During armour application, the product shall be subject to frequent visual inspection to ensure that the coverage is uninterrupted and uniform and that no extraneous material is included under the armour. Care shall be taken to ensure that the sheathed bundle is not stretched and that the sheath is not disturbed during this process.

If armour-wire welds are included in an armouring layer, they shall be staggered and shall be made in accordance with the manufacturer's written specification. Armour-wire weld locations shall be recorded on the lay map.

10.1.5 Outer sheath

Application of the outer sheath shall follow the same process and repair requirements as for the inner sheath.

The longitudinal stripe shall be visually inspected in accordance with the manufacturer's written specification for continuity and evidence of twist in the umbilical.

10.2 Qualification and verification tests

10.2.1 General

Qualification and verification tests, as required by the customer and specified in the contract, shall be undertaken on full-scale umbilical samples to support the design of the umbilical. Tests shall be defined as qualification or verification by the purchaser according to the provisions in Clause 5, and performed using a separate length manufactured prior to main production or sample(s) from the production length. The umbilical manufacturer may request a waiver for any of the following tests by providing justification that the test conditions fall within a previously qualified design envelope:

a) lay-up trial;

b) combined torque balance and tension test;

c) bend stiffness test;

d) end-strength terminations (pull-head and subsea termination);

e) combined tension and bending test;

f) bundle squeeze/crush test;

g) internal/external friction-factor assessment;

h) bundle impact test;

i) dynamic fatigue test, umbilical and bend-stiffener-system design qualification;

j) free-flooding rate;

k) hydrostatic diameter reduction and collapse resistance of cross-section;

l) topside termination interface tests (also subsea, if applicable);

m) repair splice qualification (bundle).

The objectives of all full-scale tests are described in Annex G with a selection of example procedures. Test procedures incorporating test purpose, test method, test acceptance criteria and test reporting shall be developed by the manufacturer to address the general objectives and any project specific objectives.

Umbilical prototype or production material used as samples for the full-scale umbilical qualification or verification tests shall first be subjected to integrity tests of all components as specified in manufacturer's specification.

Details of qualification and verification tests shall be included in the quality plan.

10.2.2 Monitoring during full scale umbilical tests

Consideration shall be given to monitoring the umbilical components during many of the full-scale tests as an integral part of the mechanical test. Monitoring levels and “integrity” criteria shall be specified in the test procedure.

Tubes and hoses may be pressurized.

Electrical cores shall be subject to continuous monitoring of the conductor path at relevant sampling frequencies, where sensible and practical, with each conductor in the umbilical connected in series.

Electrical cores shall be measured for insulation resistance before, during, and after completion of the mechanical testing, where sensible and practical.

Optical fibres may be subject to light-signal monitoring (optical continuity) where sensible and practical, or to measurement made before or after the test.

If tests require tensile-loading of the umbilical, the mechanical means of anchoring shall employ the same design principles as for the service umbilical system.

11 Factory acceptance tests

11.1 General

The tests detailed in 11.2 to 11.10 are the minimum requirements for each manufactured umbilical length. If the acceptance criteria for a test are not met, the cause of the failure shall be investigated and a report compiled.

Factory acceptance tests (FATs) shall be undertaken either prior to or after fitment of end terminations.

NOTE Some types of termination can preclude the possibility of carrying out some test types after they are fitted or, alternatively, modified/reduced test parameters can be necessary. For instance, some types of electrical connectors might not be capable of withstanding a high voltage test.

Additional FATs may be required to confirm the integrity and performance compliance of components or umbilical, resulting from additional design or design verification requirements, or assembly of sub-bundles. If required, these tests, including acceptance/rejection criteria if applicable, shall be specified in the manufacturer's written specification.

Umbilical FATs that shall be performed are specified in 11.2 to 11.10.

11.2 Visual and dimensional inspection

During the manufacturing processes, the components, partially completed and completed umbilical shall be free from damage, faults or contamination. Raw materials should also be inspected for contamination. Manufacturing parameters shall be periodically monitored in accordance with, and shall comply with, the manufacturer's written specification.

11.3 Electrical continuity at the termination

Resistance measurements shall be performed to verify electrical continuity between the termination components for which protection by the cathodic protection system is intended.

11.4 Trial termination fit-up

Trial assembly of all temporary and permanent termination hardware shall be undertaken.

11.5 Electric cable

On completion of umbilical manufacture, the electrical cores shall be subject to the following FATs:

a) DC-conductor resistance, as specified in 7.2.10.4;

b) insulation resistance, as specified in 7.2.10.5;

c) high-voltage DC, as specified in 7.2.10.6;

d) transmission-line characteristics, as specified in 7.2.10.7, 7.2.10.8, 7.2.10.9 and 7.2.10.10;

e) cross-talk, as specified in 7.2.10.11;

f) time-domain reflectometry, as specified in 7.2.10.12.

Inductance, capacitance and impedance characteristics shall be measured only if the overall length is sufficiently short so as not to introduce spurious results.

11.6 Optical fibre cables

On completion of umbilical manufacture, the optical fibre cables shall be subject to an optical time-domain reflectometry test as specified in 7.4.11.3.

11.7 Hoses

On completion of the umbilical manufacture, the hoses shall be subject to the following FATs.

a) Proof pressure/decay test: This is specified in 7.3.8.6 at a test pressure of $1{,}5 \times p_{DW}$ over a minimum period of 4 h; however, a longer period may be required as agreed between purchaser and manufacturer;

b) Flow test: The manufacturer's written specification shall state the nominal flow rate that each hose shall be required to pass.

   The manufacturer shall calculate expected pressure drops for the specified fluid at the nominal flow rate, and where equipment limitations allow, the test shall require that the nominal flow rate is passed through the hose. A constant high-pressure supply shall be connected to one end of each manufactured hose length and the other end shall be vented to atmosphere. The test fluid shall be passed through the hose until the pressure reading at the hose inlet is constant within 5 %, and the flow rate is constant within 5 %. The flow rate, pressure drop across the hose and fluid temperature at inlet and outlet shall be recorded. The actual pressure drop and the calculated pressure drop shall be compared and the difference between the two shall not exceed the tolerance value stated in the manufacturer's written specification.

   NOTE Reasonable correlation can be expected in turbulent flow, but not under laminar flow conditions, where a poor correlation is expected. For short umbilicals [typical length less than 200 m (656 ft)], a poor correlation is expected.

c) Dynamic response: This is an optional test performed in accordance with the procedure described in Annex D. The results from this test shall be used to characterize a hose within an umbilical and do not constitute acceptance/rejection criteria.

d) Fluid cleanliness: On satisfactory completion of all other acceptance tests, each hose length specified in the manufacturer's written specification shall be flushed with the specified test fluid.

   The highest possible flow rate shall be used which does not result in the hose being subject to a pressure greater than the DWP at the hose inlet. The fluid temperature shall be monitored at inlet and outlet continuously to ensure that the hose temperature rating is not exceeded. Each hose length shall be flushed for a complete volume change and thereafter until the cleanliness level is reached. At the end of this period, three consecutive fluid samples per hose shall be taken at intervals of at least 10 min, using the procedure specified in ISO 4406. The cleanliness levels shall meet or exceed the value(s) specified in the manufacturer's written specification.

   For convenience, short hose lengths may be connected together to facilitate the flushing requirements. For hose pressures in excess of 69,0 MPa (10 000 psi), an inlet pressure lower than the hose DWP may result due to limitations in flushing equipment capacity.

   The flow test and the fluid cleanliness tests may be combined.

11.8 Tubes

On completion of umbilical manufacture, the tubes shall be subject to the following FATs:

a) proof pressure test in accordance with the manufacturer's written specification at a minimum test pressure of $1,25 \times p_{DW}$ for a minimum of 4 h;

b) flow test in accordance with the procedure of 11.7.1 b);

c) fluid cleanliness in accordance with the procedure of 11.7 d).

11.9 Terminations

Resistance measurements shall be performed to verify electrical continuity between components being connected to the cathodic protection system.

11.10 Continuity check

After fitment of the final end terminations (i.e. subsea umbilical termination), an electric, optical, and hydraulic continuity check shall be performed to ensure correct line identification and tags applied.

12 Storage

12.1 General

Upon satisfactory completion of all umbilical FATs, the umbilical shall be stored on a carousel, a reel or a turntable, or coiled into a storage tank until load-out is undertaken. If stored outside, considerations shall be taken to avoid damage due to environmental factors, e.g. temperature variations, direct sunlight.

If an umbilical is being stored for an extended duration, typically in excess of six months, and/or periods of temperature extremes, consideration should be given to the effect on the fluid within the hoses and tubes. If necessary, the fluid shall be replaced by a more appropriate fluid. The requirement to change fluid and fluid type shall be defined in the manufacturer's written specification, which shall also detail frequency of inspection and testing to confirm product integrity.

If an umbilical is stored on a reel, the reel-flange diameter shall be greater than the diameter of the outermost layer by at least one umbilical diameter. The diameter of the reel shall take into account end-termination dimensions and bend stiffener/bend limiter limitations. Spooling of an umbilical onto its storage reel (which may also be the shipping and/or installation reel) shall be undertaken with sufficient back-tension to minimize the risk of loose turns developing when the product is removed from the reel.

In recognition that the umbilical may be subjected to tests during, or at the end of, the storage period, both ends shall be readily accessible.

Whether stored on a reel or carousel, the number of layers shall be such as not to impart damaging forces to the underlying layers. Reels and carousels shall be located on flat, stable ground in a safe area away from machinery and/or processes that produce corrosive and/or damaging products, and away from constantly used work areas. If appropriate, suitable barriers shall be erected to minimize the risk of damage as a result of collision with passing vehicles.

12.2 Protection of unterminated umbilical components

12.2.1 Electrical cables

Electrical cores shall be capped and sealed to prevent water ingress.

12.2.2 Optical-fibre cables

Optical fibre cables shall be capped and sealed to prevent water ingress.

12.2.3 Hydraulic hoses or tubes

In the case of umbilicals containing hoses or tubes, each hose/tube shall be filled with fluid, and the ends assembled with suitable pressure-retaining fittings.

12.3 Spare length

A spare length may be manufactured as a separate item or it may be part of the main umbilical as an overlength. The precautions described in 12.2 shall be applied to the spare length. The spare length shall be clearly and indelibly marked with identification references in accordance with the manufacturer's written specification.

12.4 Repair kits

Repair kits for jointing umbilical lengths shall be stored under cover in suitable containers to prevent damage and deterioration of quality and to provide protection for offshore shipping. The containers shall be clearly labeled. The labeling shall include the expiration date of any parts of the kit (e.g. resins, solvents) that have limited shelf lives.

12.5 Handling for integration tests

It can be necessary to carry out integration testing of umbilicals. In the case of short, relatively light umbilicals this may be undertaken away from the manufacturer's premises. Care shall be taken to ensure that any umbilical transportation or handling is undertaken without infringing any of the handling or storage parameters or causing damage to the umbilical.

The manufacturer shall prepare a procedure for the transportation and handling that shall state who is responsible for the handling of the umbilical at each stage. All transportation and handling shall be carried out in accordance with this procedure.

13 Pre-installation activity

13.1 Umbilical information

The manufacturer shall provide, as a minimum, the following umbilical installation interface information:

a) outer jacket finish details, including external and internal friction coefficients, both dry and wet;

b) maximum tensile strength;

c) ultimate tensile strength;

d) axial stiffness;

e) bending stiffness;

f) mass (weight) in air (when hoses/tubes filled with the installation fluid);

g) weight in water (when hoses/tubes filled with the installation and service fluids);

h) length (and tolerance on/accuracy of length);

i) length-marking details applied, and their direction;

j) quantity and location on length of buoyancy modules as required;

k) nominal diameter and tolerance;

l) minimum bend radius under installation conditions (plus capacity curve for installation conditions);

m) load-torque characteristics (torque-balance);

n) maximum crushing load per unit length;

o) allowable combination of axial steady state and fatigue loads, and number of cycles, to which the umbilical may be subjected during deployment;

p) repair joint dimensions and fitting procedure;

q) pressure being applied to the hoses and tubes during load-out and installation;

r) hose/tube sizes, termination details for connections and DWPs;

s) power/signal/optical characteristics;

t) details of storage prior to load-out;

u) confirmation of longitudinal line for twist monitoring;

v) umbilical termination test connection details;

w) any test results specified by the purchaser to determine installation parameters shall be made available.

13.2 Route information

Purchaser shall provide the following seabed and environmental information along the entire route, including areas identified for placement of any excess umbilical length:

a) seabed topography along the proposed route corridor of required/agreed width;

b) seabed water-depth profile along the route corridor;

c) seabed conditions, e.g. rock outcrops, boulders, sediments, debris, obstructions;

d) seabed geotechnical parameters relevant to umbilical stability on the seabed and any planned burial;

e) adjacent pipelines, cables and other seabed structures (existing and planned), or those being traversed;

f) current and tidal information relevant to umbilical deployment, as well as seabed stability;

g) loop currents information relevant to umbilical installation.

13.3 Terminations and ancillary equipment information

The installer shall be provided with at least the following information on the proposed system of termination of the umbilical:

a) dimensions;

b) mass (weight) in air;

c) weight in water;

d) safe working load values for terminations;

e) details of functional interfaces with subsea structure;

f) lifting arrangements designed into the termination, weak-links, junction boxes, production/repair joints and ancillary items, if applicable;

g) temporary and permanent pull-in or hang-off arrangements on the platform;

h) I- or J-tube messenger wire/rope to include checking clearance with the I- or J-tube, if fitted.

All offshore assemblies shall be fit-up tested prior to installation. Permanent ROV-visible markings should be applied on terminations. The marking shall be in accordance with ISO 13628-8.

13.4 Host facility information

The purchaser shall provide the relevant details of the platform(s). These include, as a minimum

a) the plan/elevation/envelope of host substructure and topsides;

b) I- or J-tube dimensions, condition of sealing surfaces (if applicable), geometry and locations on the platform for pad-eyes, shackles and winches;

c) I- or J-tube bellmouth sealing details and bend- limiter/stiffener interface details, if applicable;

d) the pipeline and riser positions;

e) other activities scheduled for the work site during the installation operations;

f) detail drawings relating to the top of I- or J-tube and surrounding area, including any obstructions over I- or J-tube, risers already installed; and

g) zone and/or area classification rating.

The purchaser shall inform the installer of the permit-to-work system and the nature and location of any known obstructions.

Suitable sites on the platform shall be provided, as necessary, for the installer to mount appropriate vessel-positioning system stations, installation aids and pull-in winches. Details of services available on the host facility (if any) shall also be provided.

All offshore assemblies shall be fit-up tested prior to installation.

13.5 Subsea structure information

The purchaser shall provide details of the subsea structure and equipment, so that the subsea pull-in of the umbilical termination can be planned, if relevant.

13.6 Host facility visit

The installer should visit the fixed and/or floating offshore facilities to examine the I- or J-tube(s) and hang-off positions in order to decide where to position the pull-in winch, temporary rigging, testing and monitoring equipment. The requirements on equipment regarding safety zoning and other applicable requirements shall also be established. Feasibility of proposed ROV operations shall be assessed.

14 Load-out

14.1 General

Responsibility for handling the umbilical at every stage shall be clearly defined, and the exact point in the operation at which responsibility is transferred from one party to another shall be agreed before operations commence.

NOTE 1 The information in 14.2 to 14.11 assumes that all operations at the load-out site are coordinated and controlled by the installer.

NOTE 2 Occasionally, for example if the umbilical has been used for integration tests, the load-out might not be from the umbilical manufacturer's facility.

14.2 Technical audit of load-out facilities

The installer should visit the load-out site and inspect the onshore facilities intended for use, and assess the acceptability of the equipment and location for the operation.

The matters considered in the course of the visit shall include the following, as a minimum:

a) installation vessel:

   1) constraints on the draught of the vessel and other dimensions,

   2) mooring and maneuverability requirements,

   3) craneage operations between the quayside and the vessel;

b) umbilical storage facilities:

   1) storage system,

   2) access to facility,

   3) arrangement of terminations and ancillary equipment,

   4) limitations on handling from storage due to umbilical parameters (mass, minimum bend radius, crush load limitations) and terminations/ancillary equipment,

   5) protection during storage;

c) onshore umbilical handling systems:

   1) type of system,

   2) method of control and communications,

   3) manning requirements (including necessity for 24 h working),

   4) pay-out speed range,

   5) interface with storage facility,

   6) interface with vessel umbilical handling system,

   7) requirement to provide additional equipment (e.g. portable-cable engine, roller path, etc.),

8) limitations on handling due to umbilical parameters (mass, minimum bend radius, crush load limitations) and terminations /ancillary equipment,

9) craneage and lifting facilities for handling terminations and ancillary equipment.

The availability of on-site manpower and support functions, together with safety requirements, shall be reviewed.

The lifting-equipment certification shall be examined.

14.3 Load-out procedure

An onshore load-out procedure shall be developed by the umbilical manufacturer. A load-out procedure from the quayside shall be developed by the installer, describing the proposed operation and identifying all the onshore equipment used. The manufacturer shall provide supporting information for the onshore load-out for inclusion within the installer's procedure. The end of the umbilical system that it is necessary to load first shall be stated, as shall the order of umbilical loading in the case of more than one umbilical being loaded. The procedure shall include details of the method and equipment being used in handling terminations, joints, weak links, ancillary equipment, etc.

14.4 Pre-load-out meetings

Meetings shall be held between the installer and the manufacturer to establish the basis for the load-out operation and to confirm the point of hand-over of responsibility for the umbilical. Critical aspects shall be reviewed and emphasized, including, but not limited to, the following:

a) chain of command for the operation and point of hand-over of responsibility;

b) responsibilities and staffing for the load-out;

c) interfaces between the installer and the manufacturer;

d) communications procedures;

e) review of the load-out procedure and contingency;

f) timetable for load-out, including timetable for necessary access permits;

g) handling of terminations/ancillary equipment and any intermediate joints;

h) equipment provided for repairs;

i) inventory list of loose items from the quayside and method of packing;

j) assistance from the manufacturer for pre- and post-load-out tests;

k) provision of all necessary information to the vessel master for the calculation of vessel stability;

l) safety procedures and the generation of a safety plan.

14.5 Pre-load-out tests

14.5.1 General

Pre-load-out tests shall be carried out if the umbilical system has been transported from the manufacturer's works to another site or has been stored for more than three months.

The tests shall be carried out prior to the load-out operation, but with a sufficient time interval such that rectification can be carried out, if necessary.

NOTE Annex B summarizes the tests specified in the main body of this part of ISO 13628.

14.5.2 Electric cables

14.5.2.1 DC-conductor resistance test

The temperature-corrected DC-conductor resistance shall be measured as specified in 7.2.9.3 and shall be within ± 2 % of the values obtained during the umbilical FATs.

14.5.2.2 Insulation resistance test

The insulation resistance between individual conductors and between conductors and screen and/or earth shall be measured as specified in 7.2.9.4 and compared with those obtained during the FAT. Any changes shall be evaluated.

14.5.3 Optical fibre cables

An OTDR trace shall be obtained for each fibre and, if possible, from both ends as specified in 7.4.11.3.

The OTDR traces obtained shall be compared with those obtained during the FAT and any changes shall be evaluated.

14.5.4 Hoses/tubes

14.5.4.1 Hydraulic control hoses/tubes

The test fluid shall be as specified in 7.3.8.2.

14.5.4.2 Hose pressure/decay test

A pressure/decay test as specified in 11.7 a), but to $1{,}1 \times p_{DW}$, shall be carried out on each hose line in the umbilical.

The test pressure and fluid temperature shall be measured at both ends of the hose, if possible.

14.5.4.3 Tube pressure test

A pressure test as specified in 11.8 a), but to $1{,}1 \times p_{DW}$ for a minimum of 4 h, shall be carried out on each tube that is in the umbilical.

14.6 Load-out operation

Following berthing of the installation vessel, the load-out supervisor shall arrange for the following:

a) a briefing for all personnel involved in the operation to explain the procedures being adopted, including communications procedures and the timetable for the load-out; particular emphasis shall be placed on the safety plan for the operation;

b) examination of calibration and functional testing records of the onshore and vessel-based equipment being used and confirmation that these are all current.

Upon satisfactory completion of the preliminary activities, the load-out shall be allowed to commence.

14.7 Stopping and starting the load-out

All operations shall be coordinated by the load-out supervisor and shall aim to prevent the possibility of injury to personnel or damage to assets and/or the umbilical. If, in the view of an operator involved in the operation, there is a problem, or a potential problem, that person shall have the authority to halt the load-out in a controlled manner. Once the operation has been stopped, authorization for recommencement of load-out shall be given only by the load-out supervisor, and shall be given only after the problem has been resolved or the potential problem averted. A nominated individual shall record all stops and starts with event description.

14.8 Handling of the umbilical

14.8.1 General

The handling of the umbilical during the load-out shall be carried out and monitored in a manner such that the umbilical, terminations and ancillary equipment are not subjected to any damage.

14.8.2 Twist

The umbilical shall be visually monitored at all times throughout the operation to watch for the presence of twist. The presence of significant twist shall be investigated. Allowable limits of twist shall be defined within the umbilical manufacturer's written specification. The manufacturer shall specify handling guidelines for any change in direction or plane that can induce twist/torsion in the umbilical.

14.8.3 Bending

The bend radius of the umbilical during the load-out shall, at all times, be greater than allowable bend radius based on the manufacturer's capacity curve for the umbilical.

14.8.4 Lifting the umbilical

If it is necessary to lift the umbilical, properly qualified bend shoes or webbing strops shall be used. At no time shall wire ropes directly attached to the umbilical be used for this purpose. If strops are used, care shall be taken to avoid infringing the minimum bend radius requirement or inducing buckling, by using multiple strops.

The use of chinese fingers is permitted, if appropriate and qualified for product and loads considering the umbilical design and the internal coefficient of friction.

14.8.5 Transfer across spans

If the umbilical is transferred without support, the tension shall be such that the resulting catenary does not infringe the minimum bend radius. At each end of the span, the umbilical shall be supported by bend shoes, sheaves, chutes or bellmouths of a suitable radius.

The catenaries shall be carefully monitored, and the load-out speeds altered accordingly, to ensure that the catenary tensions and profiles remain within the limits specified in the load-out procedure.

If the storage facility is not directly alongside the point at which the vessel is berthed, a gantry may be used for transporting the umbilical to the vessel. Alternatively, roller paths or caterpillars may be used.

14.8.6 Terminations

Terminations shall be handled using certified lifting devices. The conduct of the operation shall be planned so as to ensure that the load-out handling of the termination does not introduce unacceptable levels of tension, twist or bending into the umbilical at the termination.

The subsea termination shall be fastened on-board the vessel in a position that allows access for testing of the umbilical and in the orientation required (with respect to the vertical) to ensure subsequent satisfactory pull-in and connection to the subsea structure.

14.8.7 Weak link

Prior to commencement of the load-out, the weak link(s), if fitted, shall be checked to verify that their override system (if applicable) is in place and that there is no possibility of inadvertent actuation during load-out or subsequent deployment.

14.9 Load-out monitoring

14.9.1 General

For load-out involving transfer spooling of the umbilical from the land-based storage facility onto the installation/shipping vessel storage facility, the umbilical system shall be subject to monitoring. The procedures in 14.9.2 to 14.9.6 shall be undertaken. If specified by the purchaser, a full series of post-load-out tests shall be carried out.

14.9.2 Electric cables

The conductor continuity shall be monitored at a specified sampling frequency during the load-out operation. The system used shall be capable of recording brief breaks in continuity. Should there be any loss of continuity, the operation shall be halted and a DC-conductor resistance test on individual cables shall be carried out in accordance with the requirements specified in 7.2.9.3.

14.9.3 Optical fibre cables

The attenuation of the fibres shall be monitored at regular intervals, as agreed with purchaser, during the load-out operation using an OTDR. Should there be any change in attenuation or any apparent discontinuity in the fibre, the operation shall be halted and an investigation shall be carried out.

14.9.4 Hoses/tubes

Each hose/tube shall be pressurized to a gauge pressure of 7,0 MPa (1 015 psi) unless otherwise specified in the manufacturer's written specification. On reaching the specified pressure to within $\pm$ 5 % and of the same value at each end of each fluid line, the pressure source shall be isolated and the pressure versus time characteristics monitored during the load-out operation.

Throughout the load-out period, the ambient temperature shall be continuously monitored. There shall be no evidence of leakage or failure prior to, during, or on completion of the load-out operation.

14.9.5 Visual examination

The umbilical shall be examined during the load-out operation for signs of distortion, kinking, surface damage, raised diameters, bird-caging of armour wires or other defects. The examination shall be carried out over 100 % of the umbilical length. A nominated individual shall record all visual imperfections with description.

14.9.6 Umbilical length

The installer shall ensure that the length loaded out onto the vessel is as specified, and that length markings as required for the subsequent lay operations are marked on the umbilical.

14.10 Load-out on a reel or carousel

In cases where the umbilical is not transpooled to the installation vessel, there is no requirement for load-out monitoring. However, a full series of post-load-out tests shall be carried out.

14.11 Post-load-out tests

The following tests shall be carried out immediately after the load-out operation:

a) electric cables (see 14.5.2):

   1) DC-conductor resistance,

   2) insulation resistance,

   3) high-voltage DC test (see 7.2.10.6), which should be considered for medium- and high-voltage cables subject to termination constraints;

b) optical fibres (see 14.5.3): OTDR;

c) hydraulic (see 14.5.4):

   1) hose pressure/decay test,

   2) tube pressure test.

15 Installation operations

15.1 General

The information provided in Clause 15 is of a general nature, since the installation operation, in terms of route, type of lay and protection used, can be conducted in many different ways.

15.2 Requirements for installation vessel and equipment

The installation vessel and its installation equipment shall be in good condition and working order, and be verified according to relevant regulations and safety plans prior to the vessel mobilization.

Items of lifting equipment shall have suitable certification.

Vessel equipment requirements shall include, but not be limited to, suitable

a) communication facilities;

b) navigation and positioning systems (surface and subsea), including applicable recording, processing, displaying, plotting and storage;

c) lay chutes, of a size or shape that avoid infringement of the allowable bend radius and that avoid causing damage through crushing/pinching of the umbilical;

d) conveyor systems to move the umbilical without the presence of uncontrolled spans or the possibility of the umbilical coming into contact with surfaces other than those of the handling and storage systems;

e) cable engines;

f) powered/unpowered sheaves;

g) trenching/burial equipment;

h) ROV spread;

i) diving spread;

j) tension-measuring equipment to continuously monitor and record the tension to which the umbilical is subjected (alarms shall be included within the system);

k) length-measuring system;

l) departure angle measuring equipment to continuously monitor the angle at which the umbilical leaves the vessel (alarms shall be included within the system);

m) umbilical functional testing equipment;

n) installation aids;

o) pull-in winch swivel and vessel termination deployment wire swivel;

p) device to cut the umbilical, and holding clamps, in case of emergency;

q) storage system;

r) tensioners and main winch system lay-out.

It shall be ensured that the umbilical, with its associated terminations, can be handled, moved across the deck of the vessel and over-boarded in a safe manner without the possibility of damage and hold-ups due to sharp edges, rough surfaces and obstructions.

The installer shall carry back-up equipment on-board the vessel whenever this is practicable, and shall ensure that at all times suitable spares are available for the rapid repair of all essential items.

15.3 Pre-installation survey

15.3.1 General

Before commencing the umbilical installation, the installer shall carry out a pre-installation survey along the proposed route and width of corridor, unless the purchaser has arranged for others to undertake it.

The pre-installation survey shall be carried out using positioning and navigation equipment equivalent to that being used during the installation operations.

The survey shall identify any seabed obstructions and debris that can be hazardous to the umbilical or can impede installation. The installer shall propose suitable methods of seabed preparation for those areas where such preparation is considered necessary, and shall carry out that preparation.

15.3.2 Requirements of survey

Consideration shall be given during the pre-installation survey to the following activities:

a) surveillance of the planned route using a side-scan sonar or an ROV in order to confirm the data from earlier activities and to survey the right-of-way for the umbilical installation vessel;

b) confirmation of the position of any adjacent pipelines, cables, moorings, umbilicals or other structures;

c) establishing the position and identity of any pieces of debris that lie along the proposed route and in a defined corridor on either side of it; removal of debris, if necessary and feasible, should be undertaken subsequently;

d) survey of possible route deviations that can be necessary to avoid debris, environmentally sensitive areas, or to comply with contingency plans or to use up excess umbilical length prior to termination lay-down;

e) survey of the host facility areas, including the I- or J-tubes and the area of termination lay-down;

f) confirmation of connector arrangement;

g) confirmation that any pre-installed messenger wires and fittings are in good condition and usable;

h) confirmation that all subsea preparations for any pipeline crossings are satisfactory;

i) deployment of temporary installation aids, if necessary (e.g. at turn points on the route), and mud mattresses at subsea termination positions;

j) deployment of transponders or beacons at critical positions (e.g. pipeline crossings) on the route and at the target area for lay-down of the umbilical subsea termination;

k) bathymetric sub-bottom profiler and side-scan sonar surveys of the route;

l) longitudinal profile, seabed conditions and water depth along the route length and subsequent correction to lowest astronomical tide by making allowance for the predicted tide during the survey;

m) carrying out of a magnetometer survey along the route; if there are any anomalies between this survey and the results of the sonar survey, they should be further investigated.

15.3.3 Reporting

The output from the survey shall include the following:

a) report on the proposed route, including full details of any hazards identified, environmentally sensitive features identified, seabed preparations required and debris to be cleared; this shall highlight any discrepancies between information supplied to the installer and the survey findings;

b) set of survey video tapes, which include the camera position on the display;

c) route map, indicating water depth, possible route deviations and the positions of any hazards or debris.

15.4 I-tube or J-tube pull-in operations

15.4.1 General

In the course of installing umbilicals, it is usually necessary to carry out I- or J-tube pull-in operations.

15.4.2 Preparatory work

Prior to initiating the pull-in, a number of activities as follows shall be carried out in order to ensure that the operation can be completed successfully:

a) review of installation calculations, to establish limit loads during the pull-in operation;

b) review of the pull-in rigging dimensions with regards to the internal diameter of the entire length of the I- or J-tube, gauging (pigging) of the I- or J-tube to check that it is clear of obstructions and fouling;

c) installing the messenger wire into the I- or J-tube (if one is not already in place);

d) establishment of pull-in equipment and personnel on the host facility; this includes installing the winch, and its associated rigging, including the load-monitoring and umbilical-functional testing equipment, and preparing the hang-off arrangement;

e) check of communications facilities.

If a messenger wire has been in an I- or J-tube for longer than six months, the predicted strength of the wire should checked against the expected loads it will handle.

The messenger wire should not be considered as the pull-in cable.

15.4.3 Weather window for pull-in

The availability of a suitable weather window shall be established prior to initiating operations. The required window shall take account of the predicted duration of the pull-in and lay operations, vessel and equipment capabilities and the results of installation analyses regarding sea state versus umbilical loading.

Site-specific weather and wave forecasts, updated on a daily basis, shall be available on the lay vessel.

Due regard shall be given to the length of time during which the umbilical can remain at the over-boarding chute in one location without causing damage to the deployed umbilical due to localized flexing at the point of over-boarding. Provision shall be made to avoid extended duration of point loading/flexing of the umbilical.

15.4.4 Initiation of pull-in operations

Following successful completion of the host-facility preparatory activities described in 15.4.2, the pull-in operation may proceed and the vessel may approach the host facility.

On entering the zone around the host facility, vessel operations shall become subject to all the regulatory requirements that pertain to operations on the host facility, including obtaining the necessary permits.

15.4.5 Visual survey

Following the arrival of the lay vessel in the vicinity of the host facility, a visual check of the seabed and I- or J-tube entrance shall be carried out by either ROV or diver. The purpose of this is to check both the physical condition of the I-tube or J-tube, and the seabed conditions and profile on the route into the I- or J-tube to confirm the findings of the pre-installation survey.

If the I- or J-tube is fitted with a blind flange at the bottom, it is also necessary to remove this flange. A transponder may be attached to the I- or J-tube bellmouth at this time if one is required for subsequent operations.

The identity, position and condition of the messenger wire shall be established at this stage. If the messenger wire is attached to a clump weight, the exact position of the clump weight shall be determined. This operation is particularly important if there is more than one I- or J-tube in close proximity, and hence more than one clump-weighted messenger wire. It is also essential to ensure that there is no possibility of two or more messenger wires becoming entangled in subsequent operations.

15.4.6 Recovery of the messenger wire

On the host facility, the winch pull-in wire shall be fastened to the messenger wire at the top of the I-tube or J-tube. The bottom end of the messenger wire shall then be attached to the wire of the winch positioned on the deck of the lay vessel. The deck winch shall then be used to recover the messenger wire onto the deck of the vessel as the host-facility winch pays out.

NOTE 1 It can be necessary to use significant tension when the messenger wire is attached to a diaphragm in the I- or J-tube bellmouth.

NOTE 2 Once the end of the messenger wire is on the vessel deck, the clump weight (if present) is removed and the recovery procedure continued until the end of the pull-in wire is on the deck. The end of the umbilical can then be attached to the wire.

Unless otherwise agreed, a swivel link shall be used to attach the pull-in wire to the pull-in head to reduce the torsion introduced during installation.

15.4.7 First end pull-in

The pull-in head shall be over-boarded from the vessel and the umbilical paid out from the vessel. The vessel position shall be adjusted to produce the required catenary so that the umbilical enters the I- or J-tube at the correct angle and that the umbilical is not dragged excessively along the seabed or subjected to over-bending.

Monitoring of the pull-in operation shall be undertaken using

a) the tension-monitoring equipment on the host facility,

b) the tension-monitoring equipment on the vessel,

c) the ROV visually monitoring the umbilical in the vicinity of the I- or J-tube entry, to establish the catenary shape, extent of seabed contact (if any), umbilical bend radius and umbilical twist,

d) the amount of umbilical paid out.

Pull-in tension shall be carefully monitored and compared with the previously calculated values. Any increase in tension above that previously agreed shall result in suspension of the operation and investigation of the cause of the increase.

At the point at which the pull-in head is about to enter the J-tube bellmouth, particular emphasis shall be placed on the information provided by the ROV video camera, in order to remove any possibility of the pull-in head snagging at this time. Similar care shall also be taken as the I- or J-tube seal and bend stiffener (if they are pre-installed on the umbilical) approach the I- or J-tube entrance and their required position in the I- or J-tube. Small vessel movements can be required at this point to ensure that entry is unimpeded.

15.4.8 Securing the umbilical on the host facility

On arrival at the relevant deck level, the umbilical shall be securely fastened.

NOTE The permanent hang-off arrangement, either a mechanical termination of the armour wires or resin encapsulation of the wires, can be fitted as soon as the pull-in is completed, if the termination has not been attached to the umbilical prior to the pull-in. Alternatively, if the permanent method takes a long period of time, the fastening can be made temporarily (using split clamps, chinese fingers, etc.) so that the testing and lay can proceed without delay. The permanent hang-off can be constructed later.

15.4.9 I- or J-tube sealing and chemical protection

All chemicals used, and their ultimate combination within the tube, shall be confirmed at as early a stage as is compatible with the umbilical materials with which they come into contact.

If the umbilical hang-off does not seal the top of the I- or J-tube, it can be necessary to fit a suitable top seal. The top seal and hang-off arrangements shall have a provision for the introduction of chemical treatments, if required.

The bottom of the I- or J-tube may be sealed, although this is installation-specific. The seal may already be in place at the end of the pull-in operation if pre-installed onto the umbilical prior to the pull-in. In some cases, the seal is operational at the end of the pull-in without any further intervention. On other occasions, it can be necessary for some form of intervention by diver or ROV to make the seal operative. In situations where there is no pre-installed seal, it is necessary to fit it after the pull-in and hang-off have been completed.

Chemical inhibitors, biocides and oxygen scavengers may be introduced into the I- or J-tube to provide protection to the I- or J-tube material.

15.4.10 Second end pull-in

This operation is required in the case of host facility-host facility umbilicals, and also in the case where the lay of a host-facility-subsea umbilical commences at the subsea end. The I- or J-tube pull-in at the second end, although similar in many ways, can be more complicated than a pull-in operation at the start of the lay due to the presence of the umbilical, which has already been laid, and the catenary to the vessel.

The procedures used shall include close tension control and visual monitoring of the catenary, the seabed umbilical subject to displacement and the entrance to the I- or J-tube.

15.4.11 Movement of vessel away from the host facility

In the case of a first end pull-in, the lay vessel shall proceed to lay the umbilical along the planned route in order to clear the immediate vicinity of the host facility as soon as the pull-in is complete. Simultaneous lay and bury operations necessitate the launching of the burial vehicle prior to the lay-away, unless this has been done prior to the pull-in. Simultaneously, the host-facility connection of umbilical test and monitoring equipment shall be carried out, if the monitoring is being undertaken from the host facility. Commencement of the main lay of the umbilical along the route beyond the immediate vicinity of the host facility shall not proceed without confirmation that the umbilical testing has been satisfactorily completed, the monitoring equipment is connected and operational and pressurization (if applicable) has been achieved, unless otherwise specified in the procedures.

For a second-end pull-in, the vessel shall move away at the completion of the pull-in.

15.5 Lay-down of subsea termination (first end)

If the initial part of the operation is the installation of a subsea termination, this is carried out in place of the I- or J-tube pull-in operations described in 15.4.7 to 15.4.11.

Any necessary work required to prepare the seabed shall have been carried out. The termination shall be overboarded and lowered to its designated position on the seabed. The termination shall be equipped with position-monitoring equipment, e.g. transponder and light stick, to aid position monitoring. Prior to overboarding, any pressure balance arrangement shall be confirmed as suitable for installation and service. Depending on the design of the system, the designated position may be the final position, or a subsequent pull-in to a manifold can be required. As the termination is lowered, the umbilical position and tension shall be carefully monitored and controlled to avoid the generation of slack within the umbilical length. Once the termination is on the seabed and suitably secured, the umbilical routing away from the termination shall be as designed.

Considerable care shall be taken if the termination is of a design that can give rise to the presence of significant hydrodynamic forces, due to currents, vessel heave or the wake from thrusters. These forces can induce large rates of twist into the umbilical by virtue of termination rotation.

15.6 Lay route

The umbilical lay route shall be shown on umbilical route alignment charts. These charts shall show the way-points, the coordinates of changes in direction of the route and the corridor within which the umbilical shall be laid. The charts shall also detail the extent and location of any additional protection required (e.g. tubular protectors or mattressing), the presence of other umbilicals and risers, pipelines and pipeline crossings and dimensioned target areas for lay-down of the umbilical subsea terminations.

15.7 Handling requirements for the main lay

The major mechanical requirements during the main lay shall be to avoid the following:

a) introduction of excessive slack in the vicinity of the touch-down position, by virtue of low tension/large departure angle, to preclude the possibility of loop formation;

b) infringing the minimum bend radius at the touch-down point;

c) introduction of large rates of twist into the umbilical, to reduce the probability of loop formation and bird-caging; unless otherwise agreed, a swivel link shall be used to reduce the torsion introduced during installation;

d) application of excess tension, which can overstress the umbilical;

e) flexing the umbilical close to the over-boarding point, where catenary loads are at their maximum, and at the touch-down point for extended periods to exclude the likelihood of fatigue failures of the umbilical structure.

15.8 Vessel positioning to achieve required touch-down

The umbilical touch-down point shall be continually visually monitored by the ROV to verify that the umbilical is being laid within the required corridor as defined on the route alignment charts. This shall be achieved by means of reference to the ROV's on-board acoustic transponder. The ROV high-resolution sonar (if fitted) can also be used to confirm, by reference to other seabed features, that the umbilical remains within the defined corridor. If the ROV suffers technical problems of a nature that means that it cannot carry out the monitoring function, then the lay shall be stopped and precautions should be taken to avoid damage of the umbilical.

It is particularly important to control length when the vessel is altering course. In the situation where the route is curved, the vessel is moved from one alter-course point to the next by entering the coordinates of each location using the umbilical lay reference, allowing for umbilical touch-down layback. The ROV shall monitor the touch-down position to ensure the umbilical continues to be laid in the correct corridor.

If a crab lay is undertaken, the offset between the vessel and the touch-down point, as indicated by the ROV transponder, should be used to make an estimate of the effects of currents and tides so that the route can be altered to take account of this.

NOTE 1 Subsea beacons laid during the pre-installation survey can assist with positioning at critical points along the route.

NOTE 2 If the vessel is headed in the direction of lay with the umbilical being laid over a stern chute, any deviation of the umbilical lead from directly astern of the vessel route due to the presence of cross-currents or tides can easily be estimated. If it is considered necessary, a small vessel offset can be applied at any subsequent turn point to take account of any tidal current.

NOTE 3 In very deep or ultra-deep water, it can be necessary to monitor the touch-down point with side-scan sonar or an ROV deployed from a separate survey vessel.

15.9 Control and monitoring of length laid

Umbilical length paid out shall be monitored against distance travelled along the planned route in order to

— detect whether excessive umbilical length is being laid, and

— allow the lay of a fixed umbilical length over the planned route while ensuring correct positioning of the subsea terminations in the pre-determined lay-down target area.

A computation of the umbilical length paid out shall be made continuously.

As each umbilical marking passes a specified datum mark on the vessel, a navigation fix shall be taken and the following information recorded and/or calculated:

a) time and date;

b) reference number of the navigation fix;

c) coordinates of overboarding point;

d) coordinates of touch-down point;

e) distance along route as laid (kilometre point);

f) marked umbilical length at datum;

g) equipment reading of umbilical length measurement;

h) overlength since last calculation;

i) cumulative overlength;

j) distance to end of lay;

k) umbilical remaining inboard of datum mark;

l) catenary tension at overboarding point;

m) mean umbilical pay-out rate.

NOTE 1 Some of this information can be pre-calculated to facilitate simple rapid checks that the lay is proceeding as planned.

NOTE 2 Details regarding length control at completion of lay are given in 15.12.

15.10 Integrity monitoring during lay

15.10.1 General

Integrity monitoring may be undertaken from the host facility if the first operation is an I- or J-tube pull-in. In situations where the first operation is the lay of a subsea termination, integrity monitoring shall be carried out from the installation vessel.

15.10.2 Electric cables

The conductor continuity shall be monitored at a specified sampling frequency during the lay operation. If there is any loss of continuity, the operation shall be halted and a DC-conductor resistance test on the individual cables shall be carried out in accordance with 7.2.10.4.

NOTE Certain termination arrangements can preclude this test from being carried out (e.g. inductive couplers).

15.10.3 Optical fibre cables

Each optical fibre shall be monitored at a specified sampling frequency using an OTDR or other optical means. If there is a significant change in attenuation or a loss in continuity, the operation shall be halted and the cause of the fibre problem investigated.

15.10.4 Hoses/tubes

Each hose/tube shall be pressurized to a gauge pressure of a minimum of 7,0 MPa (1 015 psi) unless otherwise specified in the manufacturer's written specification, and this pressure shall be locked in for the duration of the umbilical lay. The pressure in each hose/tube shall be continually recorded. If there is any unexplainable loss of pressure or if the behaviour of one hose/tube string relative to the rest is markedly different, the operation shall be halted and the cause of the pressure loss investigated.

15.10.5 Visual inspection

The umbilical shall be examined visually during deployment for signs of distortion, kinking, surface damage, bird-caging of armour wires or other defects defined in the installer's written specification. The examination shall be over 100 % of the umbilical length.

If the umbilical is designed to be free-flooding, a visual inspection should be performed during installation to confirm that the free-flooding is taking place.

NOTE Lack of flooding might not be apparent until sufficient water depth is achieved.

15.10.6 In-line termination

In the case of a mid-point termination, a full pressure test to system design pressure shall be performed to verify the integrity of the made-up termination assembly before proceeding with the installation. Electrical and optical testing shall also be required, if included in the umbilical.

If two or more umbilicals are joined with a mid-point termination, consideration should be given to depressurizing the laid umbilical and re-pressurizing it again following umbilical mating.

In some circumstances, it might not be possible to provide the pressurization; this should be agreed between purchaser and manufacturer.

NOTE For deepwater service, it can be necessary to increase this pressure to minimize the number of times it is necessary for the vessel to stop to re-pressurize the fluid lines due to temperature-related pressure drop. The pressure is agreed upon by the installation contractor and the purchaser.

Tests for consideration are the following:

a) hydraulic:

   1) flow check,

   2) pressure test;

b) electrical:

   — DC resistance,

   — insulation resistance,

   — TDR;

c) optical: ODTR.

15.11 Burial operations

15.11.1 General

Ploughing or trenching, if required, shall be performed as a single-pass operation. If the required burial depth is not achieved, then the required protection shall be provided by other means. Application of the additional protection shall be carried out so as not to put the umbilical at any risk.

Deployment/recovery of ploughs and trenchers shall not take place within a radius of 50 m (152 ft) of any subsea facility.

15.11.2 Monitoring during the burial operation

The burial operation shall be continuously monitored both by the on-vehicle instrumentation and from the surface, using both ROV and surface survey, navigational, and sonar systems.

As a minimum, the following parameters shall be monitored:

a) tow force (for a plough);

b) loads induced on the umbilical;

c) configuration of the umbilical in front of, and through, the vehicle;

d) burial depths;

e) vehicle and vessel positions;

f) area ahead of the vehicle, for obstructions.

If at any time the instrumentation or visual inspections indicate that damage to the umbilical can have occurred, the installer shall interrupt the trenching or ploughing operation and perform a diver and/or ROV video survey of the damaged area.

15.11.3 Interaction with umbilical

The minimum bend radius of the umbilical during the burial operation shall not be less than that specified in the manufacturer's written specification.

15.12 Approach to subsea termination position (second end)

As the subsea termination lay-down position is approached, arrival at the correct point shall be ensured by carefully monitoring the lay distance remaining and gaining or losing umbilical length over route length as required. A transponder shall be deployed on the termination during lay-down to give accurate positioning at seabed touch-down.

Any contingency plans for route deviations shall be agreed prior to mobilization, as part of the initial development of procedures.

Having continually compared the umbilical length deployed with the position on the route, the length of umbilical remaining for deployment in comparison with the planned route distance still to go shall be assessed approximately 1,0 km to 2,0 km (0,62 miles to 1,24 miles) from the lay-down target area. If necessary, a revised route to accommodate the umbilical length remaining shall then be produced. This procedure shall be repeated and the route revised at appropriate distances [typically 100 m to 200 m (328 ft to 656 ft) initially, decreasing to 25 m (82 ft) when within 200 m (656 ft) of the lay-down position]. By adoption of this technique, any residual umbilical length can be used up gradually, thereby avoiding the necessity to deal with large amounts of excess umbilical length in the area where the termination is put down. If the umbilical is being buried, it is desirable to bury as much as possible so as to minimize the length requiring alternative protection.

Alternatively, in the case of congested areas, the approach adopted can be to limit putting excessive length on the seabed. In this case, the umbilical is laid towards the final way-point at a short, measured distance from the final target. It can then be determined what the actual overlength of the umbilical is. Subsequently, in the field, the overlength can be reduced, the umbilical terminated and testing carried out.

15.13 Lay-down of subsea termination

The dimensions and location of the target area for the termination lay-down shall be marked on the route alignment chart and physically on the seabed with a transponder. In soft soil conditions, a mattress should be laid as part of the pre-installation work.

The final lay-down of the umbilical shall be carried out so that the umbilical lies on the seabed with the extra length arranged in an “S”, a “C” or other configuration so that the pull-in does not cause the umbilical to infringe its minimum bend radius.

NOTE A pre-deployment test of the umbilical and subsea termination can be carried out, although if the previous testing and monitoring activities are satisfactory, the slightly increased risk to the umbilical can make this activity unnecessary.

Preparations shall then be made to overboard the termination. Light sticks and a transponder shall be attached to the end of the winch wire or crane hook and/or the termination to facilitate a properly controlled deployment of the end termination onto its target area.

The termination shall be lowered into the water, with the vessel manoeuvring as required to maintain the desired umbilical lay-down route. As the termination approaches the seabed, the installer shall confirm that the correct lay-down location and orientation can be achieved without compromising the integrity of the umbilical. If necessary, the termination shall be raised from the seabed and repositioned.

15.14 Pull-in of subsea termination

In the case of a multi-coupler arrangement, the act of pulling the termination into its final position shall cause the functional connections to be made. Alternatively, the functional connections shall be made by jumper hoses and/or cables; this is effected after pull-in.

The angular orientation of the termination with respect to the subsea structure is particularly critical in the case of a multi-coupler arrangement.

A detailed procedure shall be prepared for the final stages of pull-in depending on the particular design. Factors to be considered include

a) details of mechanical fastening;

b) installation of cathodic protection straps.

Once the termination is in the specified final position, the necessary mechanical fastenings shall be installed. In the case of a multi-coupler arrangement, this completes the connections and hence the pull-in. If jumpers are used, these shall be installed paying due attention to any temporary jumper connections that can be required as part of the flushing or test procedures.

15.15 Pipeline crossings

The design of any pipeline crossing shall include positive separation between pipe and umbilical.

As the lay vessel approaches the crossing area, the location of the crossing shall be checked. Visual observation of the area by ROV (and use of sonar) shall also be undertaken, and the touch-down point carefully monitored over the crossing. A transponder shall be installed at the crossing to ensure that an accurate location fix can be made, thereby achieving the correct placing of the umbilical at the crossing point.

For burial operations, it shall be necessary to transfer the plowshare/cutter back to the surface of the seabed short of the crossing point and to return the vehicle back to the vessel deck and secure it there for the crossing. No attempt shall be made to fly the plough/trencher over the pipeline; it shall be fastened on deck during the crossing. Ploughing/trenching shall then be restarted on the other side of the crossing.

Further protection shall be added to ensure that the umbilical is not exposed to damage at the crossing.

15.16 Buoyancy attachments

The contractor's installation procedures shall address

— adequate access area on the installation vessel to install buoyancy attachments prior to overboarding umbilical;

— umbilical marking for buoyancy attachments;

— visual confirmation during installation that the proper configuration of the umbilical is achieved (i.e. lazy wave) and no elements have slipped during installation;

— final configuration verification as part of the post lay/installation survey.

15.17 Arming of the weak link

The arming of the weak links, if fitted, shall be carried out on completion of

a) burial of the umbilical by plough or trencher (if required);

b) second end pull-in and hook-up of termination;

c) attachment of any weak-link restraints to the structure.

However, the above shall be done before the installation test, which in this context may be a post-pull-in test or a final system functional test.

15.18 Post-lay survey

In the case of a simultaneous lay-and-bury operation, the post-lay and post-burial surveys shall be combined.

The post-lay survey shall be carried out (usually by the installer) in order to confirm the as-laid position of the umbilical and to confirm the absence of damage to the umbilical.

The survey shall be carried out either as a separate operation using visual observation from an ROV, if a lay and post-burial operation is undertaken, or from the plough/trencher if a simultaneous lay-and-bury operation is performed.

The video recording shall include a display overlay showing the camera-position coordinates and heading.

15.19 Post-burial survey

A survey of the entire route of the umbilical immediately following burial shall be undertaken.

NOTE This is normally carried out by the installer.

The survey shall show that the burial operation has been carried out in accordance with the specified requirements.

The survey shall be carried out by ROV and should include the following:

— video survey of the entire length of the umbilical route;

— identification of the positions of any unburied or unsupported lengths of the umbilical.

If shown that it is necessary, the installer shall carry out suitable remedial work. In these circumstances, the relevant areas shall be surveyed again by video.

The documentation shall include the following items:

a) written report of the survey findings;

b) full set of video tapes of the survey;

c) charts showing the as-buried position and depth of burial of the umbilical.

15.20 Post-pull-in test

These tests shall be performed once the subsea termination has been pulled in and secured to its final position.

In the case of a multi-coupler arrangement, the act of pulling the termination into its final position shall cause the functional connections to be made. In this event, the post-pull-in test becomes the post-hook-up test.

These tests include

a) electrical (see 14.5.2):

    1) DC-conductor resistance,

    2) insulation resistance;

b) optical fibres (see 14.5.3): OTDR;

c) hydraulic (see 14.5.4):

    1) hose proof-pressure/decay test,

    2) tube pressure test,

    3) flow test, which shall be performed and compared against a similar system test arrangement.

For testing of subsea-to-subsea installations, a suitable temporary termination shall be manufactured to allow looping of all electrical and hydraulic services for testing purposes. If such a unit is supplied, it should be diver- or ROV-operable.

15.21 Post-hook-up test

These tests shall be performed, if practicable, once the subsea functional connections have been made. Care shall be taken that these tests cause no damage to the control system.

These tests include

a) electrical (see 14.5.2):

    1) DC-conductor resistance,

    2) insulation resistance;

b) optical fibres (see 14.5.3): OTDR;

c) hydraulic, for which the test pressure for the post-hook-up hydraulic tests shall be $1{,}0 \times p_{DW}$ for control lines, and $1{,}1 \times p_{DW}$ for chemical lines (see 14.5.4):

    1) hose proof pressure/decay test,

    2) tube pressure test.

15.22 Retrieval of installation aids

The installer shall be responsible for retrieving all temporary subsea and host-facility installation aids after successful completion of installation of the umbilical.

15.23 Contingencies

The installer shall carry out a risk assessment study to cover foreseeable occurrences, including common mode failures, and produce suitable procedures.

The decision to implement all actions in connection with contingency procedures shall be the responsibility of the authority designated within the procedures.

15.24 Repairs

Each repair shall be installation-specific. Repair procedures shall be prepared and qualified, prior to the commencement of the installation, for the repair of the umbilical.

At the time at which damage is suspected, the installation operation shall be suspended to permit investigation and assessment of the problem. If required, testing shall be undertaken to assess the nature and extent of the problem, and the exact location of any fault.

Parameters, such as vessel and touch-down positions, date, time and environmental conditions when the lay operation is suspended, shall be noted for reference in any subsequent investigation.

15.25 Post-installation survey

The installer shall carry out a survey along the entire subsea route of the umbilical, including the I- or J-tube bellmouth(s) and subsea termination. The survey shall be carried out using a side-scan sonar and/or a video camera mounted on an ROV, and equipped with a remote monitor so that the survey can be viewed as it takes place.

The survey shall verify that the umbilical and associated accessories (e.g. seals, weak link, bend restrictor, protection) have been installed in accordance with the specification requirements, and that all temporary installation aids have been removed.

The post-installation survey shall also include all umbilical terminations and anchor points, which shall be inspected for leakage and damage.

The recording shall include a display/overlay showing the equipment position coordinates and heading, so that the as-laid position of all items is recorded.

If the survey shows that the installation requirements specification has not been met, the installer shall undertake appropriate remedial work.

NOTE The various surveys (post-lay/post-burial) can be combined into a single post-installation survey, provided that the integrity of the system is not compromised.

Annex A
(informative)

Information that should be provided in a purchaser's functional specification

A.1 General

This annex provides guidelines for information being provided in a purchaser's functional specification for an umbilical system, which references this part of ISO 13628 as the detailed standard for the design, manufacture, test and installation of the umbilical incorporated in the umbilical system. These guidelines, set out below, are not intended as mandatory, but are intended as a convenient reference such that the umbilical manufacturer is provided with sufficient information to ensure that the umbilical is correctly designed for its intended function.

Functional requirements not specifically required by the purchaser which can affect the design, materials, manufacturing, testing, installation deployment and operation of the umbilical/umbilical system should be specified by the manufacturer in the manufacturer's written specification.

The purchaser should specify project-specific design requirements and considerations within a purchaser's functional specification, which may be based on A.2 and A.3.

The purchaser shall provide contact information about the different suppliers of the different parts of the subsea system in order to facilitate communication among these suppliers on technical issues.

A.2 Information that should be provided

A.2.1 Scope of development

The manufacturer should be aware of the scope of the development for which the umbilical system is intended and where it is incorporated as part of the development. This should be provided by means of narrative description and schematic arrangement drawings.

Additionally, the manufacturer should also be aware of the proposed direction of umbilical lay, installation sequence and method by which the umbilical system will be installed.

A.2.2 Scope of supply

The scope of supply with respect to the umbilical system should be clearly defined, including but not limited to the following:

a) number and lengths, including spare lengths, of each umbilical design;

b) type of terminations and ancillary equipment required;

c) prototype and production test scope and acceptance criteria;

d) documentation requirements.

A.2.3 Applicable codes, standards and regulations

Applicable codes, standards and regulations that apply to the design, manufacture and test of the umbilical/umbilical system, or that can have an influence, should be clearly defined and the order of precedence given. This should cover national, international and purchaser specifications. Any purchaser requirement amendments to this part of ISO 13628 should be clearly stated.

A.2.4 Operating environment

The relevant operating environment applicable to the design, installation and operation of the umbilical and the umbilical system should be clearly defined. This should include, but is not limited to, the following:

a) fishing: intensity and methods used at location;

b) location: geographical data for the installation location;

c) water depth: design water depth, variations over umbilical location and tidal variations;

d) seawater data: minimum and maximum temperatures;

e) temperature: minimum and maximum air temperature during storage, installation and operation; storage/operation including localized areas where extreme temperatures can be experienced, e.g. floating production-system turret with the umbilical adjacent to high-temperature flowlines; environmental temperature (impact of adjacent flowlines carrying flowing fluids);

f) survival conditions;

g) seabed conditions: description, density, shear strengths, friction coefficients, seabed scour, sand waves and variations along umbilical route;

h) marine growth: maximum values and variations along length;

i) ice: maximum ice accumulation, or drifting icebergs and ice flows;

j) current data: as a function of water depth, direction and return period, and including the known effects of local current phenomena;

k) wind data: direction, speeds, frequencies;

l) wave data: significant and maximum waves, associated periods, wave spectra as a function of direction and return period;

m) host information and RAOs;

n) rock dumping: it shall be stated whether rock dumping is planned; this is particularly relevant for subsea termination interface design.

NOTE Additional environmental data are required to carry out installation and service analysis.

A.2.5 Specific purchaser requirements

A.2.5.1 General

The following requirements specific to the umbilical system should be clearly defined:

a) service life (and, for dynamic service analysis, the required safety factor);

b) design life;

c) target reliability data;

d) umbilical length (including manufacturing tolerance);

e) functional requirements (the number, type, and duty rating of each component);

f) umbilical characteristics:

   1) for static umbilicals, this is normally limited to maximum working load, maximum mass, and minimum bend radius if these are likely to impact on the shipment and/or installation equipment;

   2) for dynamic umbilicals, this should address, in addition, the following:

      i) submerged weight/diameter ratio per metre of length ($N \cdot mm^{-1} \cdot m^{-1}$) taking into account the filling of the interstices with seawater;

      ii) buoyancy attachment (number off, location, upthrust);

      iii) loads and minimum bend radii at key interfaces of the installed configuration;

g) component characteristics;

h) test fluids for tube/hose and umbilical;

i) service fluids.

The purchaser should specify

— the control fluid,

— injected fluids for continual and occasional chemical treatments (dosages, exposure times, concentrations and frequency), and

— possible produced fluids or gases (composition of individual phases).

A.2.5.2 Component characteristics and design criteria

This part of ISO 13628 defines acceptance criteria for hoses and metallic tubes, and gives guidance on the design of terminations.

Table A.1 shows an overview of the different umbilical components and their design criteria. Table A.1 includes references to the subclause that defines these criteria. For components where no reference is available, the design criteria are subject to agreement.

Table A.1 — Design criteria for umbilical components

Component	Strength contribution	Design criteria	Reference
Power cables	Can make a significant contribution to tensile strength Compressive (radial) strength contribution is significant.	Deformation Fatigue Temperature	None
Control cables	Low contribution to umbilical strength, but shall be able to withstand the imposed deformation Included in global stiffness calculations Not a strength member, but taken into account	Deformation Fatigue Temperature	None
Optical signal cable	Low contribution to umbilical strength, but shall be able to withstand the imposed deformation Included in global stiffness calculations Not a strength member, but taken into account	Deformation Fatigue Temperature Elongation Over-length Axial stiffness	None
Hoses	High in static Low in dynamic	Burst Collapse	7.3 and Annex C
Metallic tubes	High	Yielding Buckling Collapse Ovality Fatigue	7.5
		Wear	None
Fillers	Low	Wear Degradation Ageing Case-by-case basis	None
Coating/ Sheathing	Low	Thickness Out of roundness Max strain level Wear Depend on reason for applying sheathing	None
Tapes	Low	Axial strength Ageing	None
Terminations	Low	—	—
Armouring	High	Yielding Buckling Fatigue	None
Steel wire	High	Yielding Fatigue	None

A.2.6 One-off functional requirements

Functional requirements that it is necessary to meet only once, but that are necessary for the installation or operation of the umbilical/umbilical system, should be stated.

A.2.7 Interfaces

Interface areas between the umbilical and mating arrangements should be clearly defined. The connector requirements for both end terminations in the umbilical should be specified. This should include connector type, welding specification, seal type and sizes.

Interface details including, but not limited to, the following should be specified:

a) purchaser-supplied pull-in and connection tools, terminations and mating test connectors, etc.;

b) geometric, dimensional and imposed loading data;

c) purchaser-supplied installation aids and equipment;

d) structures to which the umbilical will be connected, including fixed and floating host facilities, subsea christmas trees and manifolds.

A.2.8 Installation requirements

The purchaser should specify performance requirements for installation services being provided, considering the following as a minimum:

a) all information requested by the party that designs the umbilical: dynamic amplification factor, sea state, equipment details, e.g. method of installation, belt geometry, number of belts, caterpillar material, friction force, etc.;

b) for installation by the purchaser, the purchaser should specify any anticipated installation loads and associated curvatures, any load restrictions, any requirements on load restrictions, clamping/tensioner loads, over-boarding chute requirements, installation tolerances and any other facility limitations;

c) for installation by the manufacturer, the purchaser should specify any requirements for season, environment, vessel limitations, installation tolerances, restrictions due to conflicting activities, and installation scope (including trenching, burial, testing, inspection, surveying and documentation).

The purchaser should specify any requirements for recoverability and reusability of the umbilical within its service life.

A.2.9 Responsibilities

The purchaser is responsible for procuring the umbilical or services intended for the design, construction or modification of the umbilical.

The manufacturer is the party contracted as responsible for design (including materials selection), construction, planning, execution and documentation of manufacturing.

The responsibilities should be allocated as given in Table A.2.

Table A.2 — Activities and responsibilities

Activities	Responsible party	
	Purchaser	Manufacturer
Provide design basis and system information	X	—
Provide list of chemicals/fluids which will be transported	X	—
Provide information on materials and service fluid compatibility	—	X
Define the required reliability level for the umbilical system including terminations and auxiliary equipment; shall be based on reliability assessment of the entire subsea system	X	—
Perform design, analysis and construction according to this part of ISO 13628	—	X
Perform systematic review for pre-delivery phases	X	—
Perform systematic review for post-delivery phases	X	—
Planning, execution and documentation of manufacturing	—	X
Planning, execution and documentation of installation; provide information to the party carrying out the design	X	—
Perform installation analysis	(X)[a]	—
Define functional requirements	X	—
Identify the need for qualification testing	(X)[b]	X
Decide whether qualification tests are carried out and define acceptance criteria	X	—
Carry out systematic review or analysis for all phases, e.g. manufacturing, load out, instillation, and operation	X	—

[a] Unless otherwise specified.

[b] The evaluation of the manufacturer's historical project statistics and its relevance for a given project, and hence the project's need for qualification testing, shall be approved by the purchaser.

A.3 Design basis document

A.3.1 The design basis should, as a minimum, include

— system information (e.g. system description, functional of umbilical within field development);

— functional requirements for all functional components (i.e. internal pressure specification, corrosion allowance specification and temperature envelope for all fluid conduits);

— temperature range within which the umbilical shall be capable of operating continuously at the specified service temperature for the specified design life;

— specification of transported fluids, including pressure limits top sides and subsea, flow requirements, flow limits (i.e. volume flow);

— field environmental data, including umbilical ambient environment;

— field layout (i.e. field topography and water depth);

— seabed routing;

- tolerances on umbilical length;
- design load cases, as referenced in Clause 6 (e.g. accidental, ballasted, traverse).

A.3.2 For dynamic applications, the design basis should, as a minimum, include

- geotechnical data (e.g. friction factors, seabed stiffness);
- environmental loading data, e.g. wave and current data, definition of vessel coordinate system, direction of axes, vertical placement of coordinate system origin with respect to sea surface, vessel draughts;
- vessel motion transfer functions;
- water depth at vessel and maximum water depth (bathymetry);
- vessel schematic including
  - umbilical hang-off location (coordinates),
  - vertical top departure angle,
  - horizontal departure angle (Azimuth),
  - size of I- or J-tube, ID, MBR;
- vessel RAOs;
- definition of rotational response (e.g. deg/m, rad/m, rad/rad, deg/ft, etc.);
- definition of phase angles (e.g. degree or radians or other; phase lead or phase lag);
- definition of vessel heading relative to waves and current (e.g. does a 180° heading represent head seas or following seas);
- hang-off location(s) in vessel coordinate system (see above).

NOTE Static umbilicals are treated as dynamic during the temporary state of installation.

Annex B
(informative)

Umbilical testing

B.1 Schedule of tests performed as part of the manufacturer's quality assurance programme

Tables B.1 to B.8 reference the subclause containing the relevant information.

Table B.1 — Electric cables/electric cable elements

Test	Verification	Component FAT	Delivery acceptance[a]	Umbilical FAT
Visual and dimensional characteristics	7.2.9.2	7.2.10.2	—	—
Conductor resistance	7.2.9.3	7.2.10.4	7.2.10.13 a)	11.5 a)
Resistivity of screening layers	7.2.9.9	—	—	—
Insulation resistance	7.2.9.4	7.2.10.5	7.2.10.13 b)	11.5 b)
High-voltage DC	7.2.9.5	7.2.10.6	—	11.5 c)
High-voltage AC	7.2.9.6	—	—	—
Complete voltage breakdown	7.2.9.7	—	—	—
Partial discharge	7.2.9.8	—	—	—
Inductance characteristics	7.2.9.11	7.2.10.7	—	11.5 d)
Capacitance characteristics	7.2.9.12	7.2.10.8	—	11.5 d)
Attenuation characteristics	7.2.9.13	7.2.10.9	—	11.5 d)
Characteristic impedance	7.2.9.14	7.2.10.10	—	11.5 d)
Cross-talk	—	7.2.10.11	—	11.5 e)
Spark test	—	7.2.10.3	—	—
Time-domain reflectometry	—	7.2.10.12	—	11.5 f)

[a] These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

Table B.2 — Optical fibre cables

Test	Verification	Component FAT	Delivery acceptance[a]	Umbilical FAT
Visual and dimensional characteristics	7.4.10.2	7.4.11.2	—	—
Transmission characteristics	7.4.10.3	—	—	—
Mechanical characteristics	7.4.10.4	—	—	—
Environmental resistance	7.4.10.5	—	—	—
External pressure	7.4.10.6	—	—	—
Optical time-domain reflectometry	—	7.4.11.3	7.4.12	11.6

[a] These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

Table B.3 — Hoses

Test	Verification	Component FAT	Delivery acceptance[a]	Umbilical FAT
Visual and dimensional characteristics	7.3.7.3	7.3.8.1	—	—
Change in length	7.3.7.4	7.3.8.4	—	—
Leakage	7.3.7.5	—	—	—
Burst test – liner	7.3.7.6	7.3.8.3	—	—
Burst test – hose	7.3.7.6	7.3.8.5	—	—
Proof pressure/decay	—	7.3.8.6	7.3.8.7	11.7 a)
Impulse	7.3.7.7	—	—	—
Cold bend	7.3.7.8	—	—	—
Collapse	7.3.7.9	—	—	—
Volumetric expansion	7.3.7.10	—	—	—
End fitting anti-rotation	7.3.7.11	—	—	—
Fluid compatibility	7.3.7.12	—	—	—
Permeability	7.3.7.13	—	—	—
Flow test	—	—	—	11.7 b)
Dynamic response[b]	—	—	—	11.7 c)
Fluid cleanliness	—	—	—	11.7 d)

[a] These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

[b] Optional tests, undertaken if specifically requested by the purchaser.

Table B.4 — Tubes

Test	Verification	Component FAT	Delivery acceptance[a]	Umbilical FAT
Visual and dimensional	7.5.8.2	7.5.8.2	—	—
Tensile	7.5.8.5	7.5.8.5	—	—
Flattening and/or reverse flattening	7.5.8.6	7.5.8.6	—	—
Metallographic examination	Annex H	Annex H	—	—
Hardness	7.5.8.7	7.5.8.7	—	—
Hardness traverse	7.5.8.8	—	—	—
Flaring or flange	7.5.8.9	7.5.8.9	—	—
Chemical analysis	7.5.8.10	7.5.8.10	—	—
Corrosion	7.5.8.11	7.5.8.11	—	—
Weld qualification	7.5.8.12	—	—	—
NDE examination	7.5.8.13	7.5.8.13	—	—
Burst	7.5.8.14	—	—	—
Pressure	—	7.5.8.15	7.5.8.15	7.5.8.15
Flow test	—	—	—	11.8 b)
Fluid cleanliness	—	—	—	11.8 c)

[a] These tests are to be undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

Table B.5 — Umbilicals

Test	Verification/qualification	Component FAT	Umbilical FAT
Visual and dimensional characteristics	—	11.2	11.2
Electrical continuity at the termination	—	—	11.3
Trial termination fit-up	—	—	11.4
Lay-up trial	10.2.1 a)	—	—
Combined torque balance test	10.2.1 b)	—	—
Bend stiffness	10.2.1 c)	—	—
End termination strength and fatigue	10.2.1 d)	—	—
Combined tension and bending test	10.2.1 e)	—	—
Crush	10.2.1 f)	—	—
Internal/external friction factor assessment	10.2.1 g)	—	—
Bundle impact test	10.2.1 h)	—	—
Fatigue	10.2.1 i)	—	—
Free flooding rate	10.2.1 j)	—	—
Hydrostatic test	10.2.1 k)	—	—
Topside termination interface test	10.2.1 l)	—	—
Repair splice qualification	10.2.1 m)	—	—

B.2 Schedule of tests performed as part of the installer's load-out and installation program

Tables B.6 to B.9 list the tests performed as part of the installer's load-out and installation program, together with the subclause reference in this part of ISO 13628 containing the relevant information.

Table B.6 — Electric cables

Test	Pre-load-out[a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Conductor resistance	14.5.2.1	14.11 a) 1)	—	15.20 a) 1)	15.21 a) 1)
Insulation resistance	14.5.2.2	14.11 a) 2)	—	15.20 a) 2)	15.21 a) 2)
High-voltage DC	—	14.11 a) 3)[b]	—	—	—
Continuity	—	—	15.10.2	—	—

[a] These tests are required only for umbilicals stored for periods in excess of three months.

[b] Required for cables with ratings in excess of 1 kV.

Table B.7 — Optical fibres

Test	Pre-load-out[a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Optical TDR	14.5.3	14.11 b)	15.10.3	15.20 b)	15.21 b)

[a] These tests are required only for umbilicals stored for periods in excess of three months.

Table B.8 — Hoses

Test	Pre-load-out[a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Proof pressure/decay	14.5.4.2	14.11 c) 1)	—	15.20 c) 1)	15.21 c) 1)
Pressure integrity	—	—	15.10.4	—	—

[a] These tests are required only for umbilicals stored for periods in excess of three months.

Table B.9 — Tubes

Test	Pre-load-out[a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Proof pressure	14.5.4.3	14.11 c) 2)	—	15.20 c) 2)	15.21 c) 2)
Pressure integrity	—	—	15.10.4	—	—

[a] These tests are required only for umbilicals stored for periods in excess of three months.

Annex C
(informative)

Hose and tube preferred sizes

Tables C.1 and C.2 give the preferred hose and tube sizes.

Table C.1 — Preferred hose size/pressure ratings

Nominal bore		DWP	
mm	(in)	MPa	(psi)
6,3	(1/4)	20,7	(3 000)
9,5	(3/8)	20,7	(3 000)
12,7	(1/2)	20,7	(3 000)
15,9	(5/8)	20,7	(3 000)
19,0	(3/4)	20,7	(3 000)
25,4	(1)	20,7	(3 000)
31,8	(1 1/4)	20,7	(3 000)
38,1	(1 1/2)	20,7	(3 000)
6,3	(1/4)	34,5	(5 000)
9,5	(3/8)	34,5	(5 000)
12,7	(1/2)	34,5	(5 000)
15,9	(5/8)	34,5	(5 000)
19,0	(3/4)	34,5	(5 000)
25,4	(1)	34,5	(5 000)
6,3	(1/4)	51,7	(7 500)
9,5	(3/8)	51,7	(7 500)
12,7	(1/2)	51,7	(7 500)
6,3	(1/4)	69,0	(10 000)
9,5	(3/8)	69,0	(10 000)
12,7	(1/2)	69,0	(10 000)

Table C.2 — Preferred tube size

Nominal bore	
mm	(in)
6,3	(1/4)
9,5	(3/8)
12,7	(1/2)
15,9	(5/8)
19,0	(3/4)
25,4	(1)
31,8	(1 1/4)
38,1	(1 1/2)
50,8	(2)

Annex D
(normative)

Characterization tests for hoses and umbilicals

D.1 Hose

D.1.1 Volumetric expansion test

D.1.1.1 This test shall be performed in accordance with ISO 6801, or an equivalent method.

D.1.1.2 This method requires measurements to be made on new and unaged hose.

D.1.1.3 Test samples shall not be less than 3 m (9,8 ft) in length between end fittings and shall not be tested within 24 h of completion of manufacture of the hose.

D.1.1.4 Prior to undertaking volumetric expansion measurements, precondition the hose by pressurizing the hose sample with water or other compatible incompressible fluid to the DWP. Maintain the DWP for a period of 5 d, during which the pressure shall be lowered to atmospheric pressure and returned to the DWP once per day. After completing the 5 d pressure cycle, test the sample for volumetric expansion three times within 48 h using the procedure in D.1.1.5, and select the pressure ranges starting at the highest pressure.

D.1.1.5 Define the pressure range for the volumetric expansion measurement, from the DWP down to nominally 10 % of the DWP. The pressure steps shall be in decrements of 7,0 MPa (1 015 psi) down to the nominally 10 % DWP level. Connect the test assembly between the test manifolds, taking care not to introduce twist into the hose. Fill the system and test sample with water or other incompressible and compatible fluid and purge to eliminate any entrapped air.

One hour ± 5 min before measuring the volumetric expansion, pressurize the test sample to the DWP ± 5 % at a uniform rate of pressure rise, and ensure that the fluid level is set correctly in the burette.

On reaching the DWP, open control valve (see Figure D.1) and allow the hose to depressurize into the burette in a controlled manner, until the first pressure level is reached. Close the control valve and record the displaced volume in the burette.

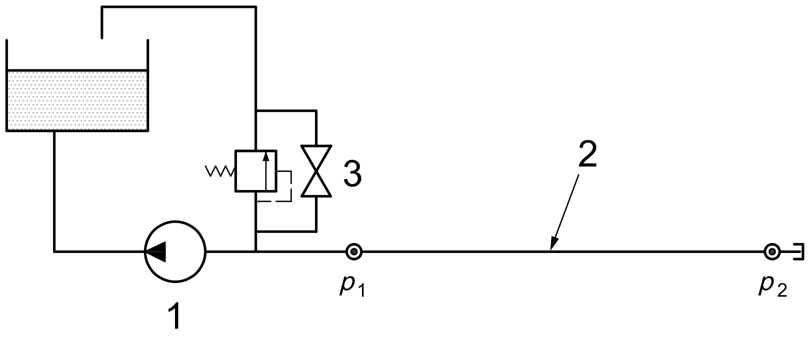
Repeat the procedure for the remaining predetermined pressure levels, allowing a period of 45 s ± 5 s to elapse between each stage of depressurization. If necessary, withdraw fluid to maintain the pressure at the selected level. The volumetric-expansion measurements shall be recorded within 5 s of reaching the defined incremental measurement level.

D.1.1.6 The measured results taken from the burette readings may be expressed as either TVE or AVE, either in terms of cubic centimetres per metre (cubic inches per foot) or as a percentage volume change.

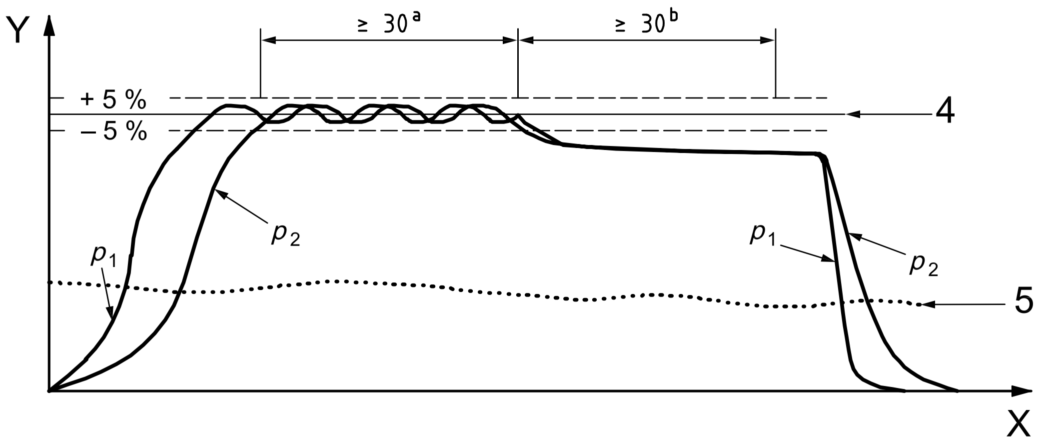
AVE is the volume of fluid collected in the burette, without correction, i.e. by not subtracting from the measured result the calculated change in test fluid volume for the same pressure changes. TVE is the volume of fluid collected in the burette to which corrections have been made so that the measured volume change applies to the hose structure only.

NOTE 1 Specification of a time period to measure the fluid displacement from the hose sample is required to systematically account for the viscoelastic behaviour of the hoses. The bulk of the fluid escapes from the hose in a few seconds. However, the remainder then comes out over a reasonable time.

NOTE 2 There is a difference in volumetric expansion measurements measured over short and long time intervals. A set of volumetric-expansion measurements made with significantly differing drainage times from data point to data point has a poor repeatability. A slight difference in the slope of the volumetric expansion vs. pressure curves is likely, depending on the drainage time used. Therefore, in order to make comparable measurements, and to achieve the best volumetric expansion measurement accuracy, a fixed drainage time is used.



a) Test arrangement



b) Pressure vs. time during test

Key

X time, expressed in minutes
Y pressure, expressed in pascals (bar)
1 pump
2 hose under test
3 control valve
4 test pressure
5 temperature
p_1 pressure at the hose outlet
p_2 pressure at the remote end of the hose

[a] Period during which the pressure is maintained at ± 5 %; see 7.3.8.6.

[b] Period during which the pressure is allowed to decay; see 7.3.8.6.

Figure D.1 — Proof pressure/decay test arrangement

D.1.2 Dynamic hose response test

D.1.2.1 General

This test method specifies the procedure for determining the dynamic response characteristics of a thermoplastic hose. The test is designed to simulate emergency shutdown of subsea equipment and provides information for the simulation of hydraulic performance. The test shall be performed on the specified hose(s) in the completed umbilical when stored on a reel or carousel. A typical test set-up is shown in Figure D.2.

D.1.2.2 Test procedure

Each nominated hose within the umbilical shall be connected in turn to the hydraulic supply and filled with the specified control fluid. The size of the vent valve and jumper hose connecting the vent valve to the vent fluid reservoir tank shall be chosen to offer minimal resistance to the discharge flow.

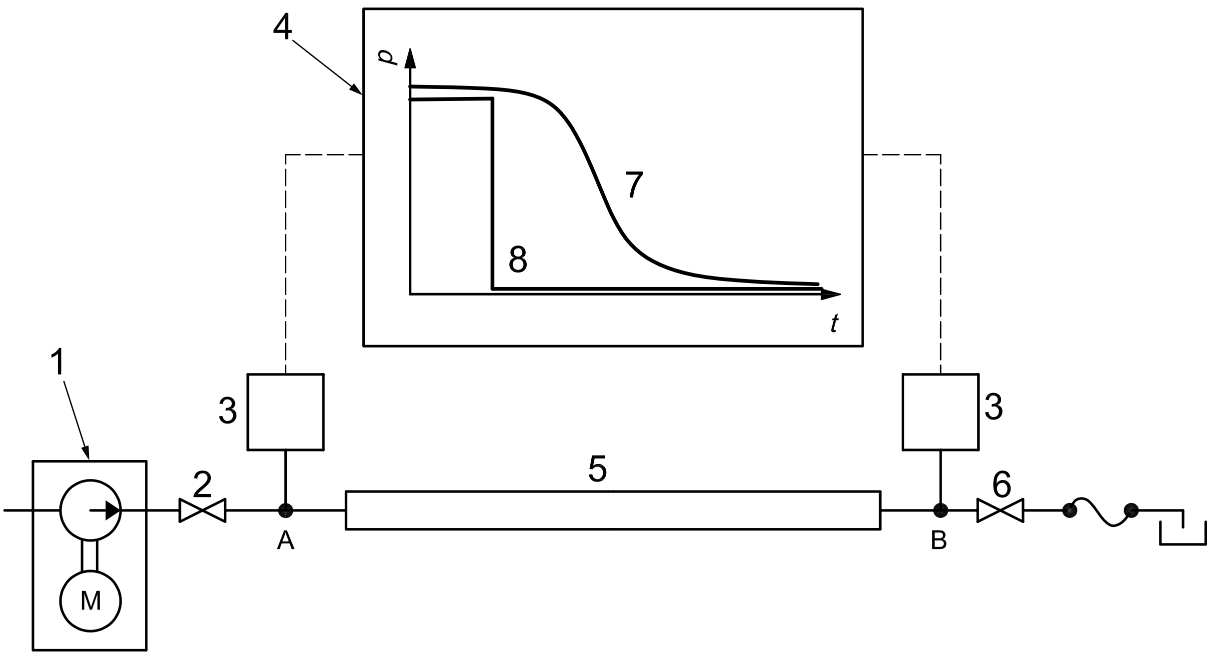
This procedure shall be repeated a further two times for each hydraulic control hose in the umbilical being subjected to this test.

Alter bleeding air from the hose, close the full-flow vent valve at the remote end of the umbilical. Pressurize the hose to the DWP, with the rate of pressure rise and decay no greater than 1,0 MPa/min (150 psi/min), and allow the pressure to stabilize for 5 min ± 10 s. Re-pressurize the hose to the DWP and again allow the pressure to stabilize. Repeat this procedure until the pressures at ends A and B of the hose remain within 2 % of each other, and within 3 % of the maximum working pressure, for a period of 5 min ± 10 s.

At the end of the final stabilization period and with the charge valve closed at the supply end of the umbilical and the recorder running, rapidly open the vent valve.

The recorder should remain running until the pressure at end A is within 1 % of the pressure at end B or the pressure at end A no longer continues to fall.

The air temperature and test fluid temperature shall be recorded.



Key

1 hydraulic power supply
2 charge valve
3 pressure transducer
4 strip chart recorder with typical pressure/time trace
5 umbilical
6 vent valve
7 curve for end A
8 curve for end B

Figure D.2 — Schematic arrangement of test set-up for dynamic response of hoses

D.2 Umbilical bend stiffness test

D.2.1 A sample of the completed umbilical may be subjected to a series of bending regimes to allow its inherent stiffness to be determined. For umbilicals containing hoses, the stiffness shall be obtained for the following conditions:

a) hoses pressurized to the recommended installation value;

b) all hoses pressurized to a common value as stated in the manufacturer's written specification.

For static umbilicals, condition a) should apply and for dynamic umbilicals, condition b) should apply.

D.2.2 The bend stiffness shall be measured on a specimen length with a minimum sample length of not less than one lay length.

The following is an example of test set-up; other test set-ups may be used (e.g. three point bending).

a) One end of the umbilical shall be anchored with all the components locked to produce a built-in end condition.

b) Transverse load increments shall be applied to the other end and the deflection shall be measured 30 s ± 5 s after load application.

c) No more than a further 30 s ± 5 s shall elapse before applying the next load increment.

The load shall be decreased in a similar manner.

D.2.3 Bend stiffness shall be calculated and the section modulus obtained for the sample length. The following shall also be done.

a) Repeat the bending cycle until of hysteretic behaviour converges.

b) Plot the load-displacement loops.

c) Use the results to calibrate software tools.

Annex E
(informative)

Fatigue testing

The test regimes shall be in accordance with the manufacturer's written specification, taking into account installation and service parameters. The testing shall be designed so that in conjunction with analysis the required service life is demonstrable, with, if required, a suitable margin of safety to cover any uncertainties in the design analysis and information.

An umbilical intended for static service after installation shall be verified by demonstrating that the design can withstand the loads and flexures experienced primarily during the installation process. Normally, the most critical area is where the umbilical is overboarded during installation and can be exposed to high tensile loads and repeated flexure during the deployment. It is, however, important that a thorough analysis is carried out to confirm that the most critical area is identified.

The test regime selected shall demonstrate that the umbilical satisfies these requirements for an agreed duration and/or minimum number of load cycles as stated in the manufacturer's written specification in order to demonstrate the required service life.

If it is shown that flexing is the critical regime, testing to determine the fatigue resistance during installation deployment is based upon a representative sample of umbilical being repetitively flexed to a predetermined radius and straightened while subject to tension by means of an applied load. The applied load and flexing frequency shall be representative of the predicted installation conditions. The sample shall withstand the specified number of flexures without impairing the umbilical functionality, or component failure. If components have been bundled using the oscillatory method, the region of umbilical that is subject to flexing shall include changes of direction in the components.

An umbilical intended for dynamic service after installation shall be verified by demonstrating that the design can sustain the loads and flexures that will be imposed on the umbilical throughout its operational life. Depending on the installed configuration and host vessel motions, the umbilical can be subject to a whole spectral range of flexure conditions that can cover one or more of the following:

a) high axial load with low angles of flexing;

b) low axial load with high angles of flexing;

c) high axial load with high angles of flexing;

d) low axial load with low angles of flexing.

For shallow-water installations, low axial loads with high angles of flexing at the vessel hang-off are expected. For deepwater installations, high axial loads with low angles of flexing at the vessel hang-off are expected. The other conditions can occur as a result of the installed configuration, e.g. mid-water buoy. As a result of these factors, a dynamic umbilical can be exposed to a wide range of environmental variables, and test regimes shall take account of such variables. The effect of such variables on the axial load within the umbilical and the degree of flexure are normally determined by analysis of the installed system. From this analysis, it is possible to develop a test matrix with respect to defined fatigue motions, see example provided in Table E.1.

The results of the analysis can show that a significant number of flex cycles occurs at very low levels of angular deflection. At such levels of deflection, the cyclic stress levels in the electrical conductors and armour wires can be so low that they cannot be observed on their S-N curves. In these situations, the necessity to perform fatigue testing at such low angles should be considered. The selected test regime should, however, as a minimum, impart the same level of fatigue damage to the umbilical as it is expected to withstand during its operational life.

To verify the fatigue performance of the umbilical at the vessel exit region, the umbilical should be subject to a bending under tension at a built-in end fitting test. If the in-service built-in end fitting incorporates a bend stiffener or other means of strain relief, a stiffener or strain-relief device of the same design should be incorporated in the test sample.

The length of the umbilical sample shall be determined from assuring that the sample includes a sufficient number of lay lengths or pitch lengths of the helix of each umbilical component to accurately simulate the effect of friction and wear among different umbilical components.

The testing set-up should, if possible, be capable of simulating, monitoring and recording the functional loads at the critical fatigue location determined from the global analysis at the umbilical operating parameters (pressure, temperature, etc.), namely the following:

- dynamic tension plus dynamic bending variations of the structural umbilical components as determined by the global analysis;
- steel tube pressurization at operating pressure;
- electrical continuity of each electrical cable;
- continuity of optic-fibre cable;
- other operational parameters, e.g. temperature.

Provisions should be made to stop the test rig cycling if any of the monitored functionalities moves outside the predetermined minimum and maximum threshold values.

A report should document the design and calibration of the testing set up, strain measurement layout (if applicable) and measurements, testing procedure, results from the tests performed at each milestone, results from post-test examination, fatigue-damage calculations and the critical fatigue location based on the actual test load values.

Table E.1 — Typical test matrix for flex-fatigue testing of a dynamic umbilical

Test block	**Load** kN (klbf)	**Number of cycles**	**Deflection angle** degrees	**Period** s	**Duration** d (unless otherwise noted)
A	250 (56,2)	$1,45 \times 10^6$	± 2	4	66,7
B	260 (58,5)	$5,1 \times 10^5$	± 3	4	23,5
C	280 (62,9)	4×10^5	± 4	5	23,0
D	300 (67,4)	$2,5 \times 10^5$	± 5	6	17,3
E	320 (71,9)	$1,7 \times 10^5$	± 6	8	15,6
F	350 (78,7)	$2,15 \times 10^5$	± 8	10	24,7
G	400 (89,9)	2 500	0 to +10	10	0,3
H	400 (89,9)	2 500	0 to −20	10	0,3
Total	—	3×10^6	—	—	5,7 months
NOTE Loads, angles, number of cycles and periods are illustrative only. In practice, it is desirable that they be derived from analysis.					

Annex F
(informative)

Load-effect analysis

F.1 Structural analysis

F.1.1 General

Umbilicals are compliant structures where relative deformations occur between components during bending. This gives some complexity with respect to describing the structural behaviour for combined loading due to the coupling between internal reaction forces from tension and torsion and the associated friction between the interfaces.

For small tension and torsion loads, the internal reaction forces and the associated friction resistance against relative motions are normally small and the structural response due to bending is dominated by the elastic deformation of each component. However, for deepwater and ultra-deep-water dynamic applications with high associated top tensions, the contact pressure and friction resistance can become large and can, hence, induce significant additional axial stresses as well as wear and fretting effects that it is necessary to take into account in fatigue evaluations.

It is recognized that fretting can occur in cases with metal-to-metal contact and significant contact pressure in combination with alternating stresses while the contact surfaces basically are in the stick-slip regime. It has the effect of inducing cracks at the contact surface and, hence, reducing the fatigue capacity of the components. Fretting can be taken into account by S-N testing under defined load and environmental conditions. In cases where the entire contact surface slides relative to each other, this behaviour is replaced by wear, having the effect of reducing the structural area and increasing the stresses of the components.

Friction effects also influence the global cross-sectional performance in terms of the moment-curvature behaviour and the associated stiffness and damping parameters that are input into global analyses. Typically, friction, wear and fretting effects become more important when the water depth (applied tension) increases.

F.1.2 Overview of structural analysis methods

F.1.2.1 Methods for the structural analysis of umbilicals cover the range from simple analytical methods to advanced FE analysis. With regard to structural behaviour, the applied assumptions inherent in these models depend on the applied loading.

F.1.2.2 For tension and torsion loads, it is normally assumed that no axial relative displacements take place between components, i.e. all components are forced to move in the same cross-sectional plane. The cross-section stiffness, including the load sharing between each component, can then be calculated by formulating the imposed strain from tension and torsion in combination with geometry, pitch length, cross-sectional area and material properties. Models formulating tension and torsion behaviour may be classified into

— analytical equations, basically assuming that there are no gaps between structural components;

— computerized methods that handle the umbilical as a set of concentric layers and where gap and radial effects are handled by iterative procedures considering geometry, kinematics and material properties; contact pressures on each layer are assumed to have a uniform distribution, which means it is necessary to evaluate the local crush load effects from contact pressures separately;

- 2D or 3D FEM methods, where each cross-sectional component is handled individually and where internal reaction forces are handled on component level; either the local radial contact force effects, as a result of internal reactions between components, are treated automatically or it is necessary to evaluate them separately.

F.1.2.3 With respect to the response to external loads, such as installation crush loads, the available models may be classified into

- analytical models based on a conservative assumption of load sharing between components;

- FEM methods, including full contact formulation taking the inherent geometric and material properties into account.

F.1.2.4 The response in bending is more complicated since relative displacements can occur. The physical behaviour in bending can be divided into the following two regimes:

- stick regime, where plane surfaces remain plane as in traditional beam theory; this behaviour governs until the shear stress between components at the neutral axis of the umbilical exceeds the frictional resistance governed by the friction coefficient and the internal reaction forces from tension and torsion or external loads;

- slip regime, where the friction resistance is exceeded and relative displacements occur; for the constantly curved case, this means that helical components move by relative displacement from the compressive side towards the tensile side of the umbilical.

F.1.2.5 The above behaviour gives rise to friction stresses that results in addition to the purely elastic bending stress imposed on all components during bending. For low tensions and torsions as applicable for shallow-water applications, the internal reaction forces are normally small and so also is the imposed friction stress. In such cases, the behaviour is governed by elastic bending and the associated stresses can be calculated by analytical methods based on differential geometry. For high tensions, it is necessary to consider the friction contribution during fatigue calculations, as well as possible fretting and wear effects. Models for calculating relative displacements and friction stresses may be classified into

- analytical models, assuming that the curvature is constant, where elastic bending and relative displacements are calculated based on differential geometry; the friction stress is estimated based on considering the friction force along a quarter pitch of each helical component, i.e. the friction stress is treated as a harmonic function with maximum tensile and compressive stresses at the tensile and compressive sides of the umbilical;

- computerized methods, where the tension- and torsion-induced contact pressures are handled iteratively and where the contact pressure is used as a boundary condition when calculating the friction forces; elastic bending effects are handled by differential geometry and the same quarter-pitch assumption as described above is used when calculating the frictional stress;

- 3D FEM methods, formulating all relevant physical effects including arbitrary curvature profiles and where the full equilibrium equation is solved for each component.

F.1.2.6 Any of the above methods may be calibrated by full-scale testing. However, care should be taken with respect to model calibration of dynamic applications where the tension or curvature exceeds the range of previous applications. In such cases, there are two physical effects to which it is necessary to give special consideration: the frictional effect noted above and possible end effects that occur due to curvature gradients along the pitch of helical components or due to limited length from the curved section to the end fitting. This can give rise to significant magnification of the dynamic stresses relevant for fatigue calculations that it is necessary to document either by structural testing or by applying models where such effects are included.

Table F.1 gives a summary of the different approaches that may be used.

Table F.1 — Structural analysis approaches

Tension and torsion loads	External loads	Bending
Analytical methods assuming all gaps closed	Analytical methods based on a conservative assumption of load sharing	Analytical methods based on assuming constant curvature when calculating elastic bending and friction effects[a]
Computerized methods, assuming the umbilical to consist of concentric layers and where radial and gap effects are solved iteratively	FEM methods, taking the inherent geometry into account and where internal reaction and deformation effects handled on individual component level	3D FEM methods solving the full equilibrium equation taking arbitrary curvature and end effects into account
FEM methods, where radial and gap effects are handled on component level	—	—

[a] The main limitation of analytical methods for bending stress calculation is related to the end effects that can occur due to the combination of bending gradients and/or small lay angles of helical components.

F.1.3 Calibration of structural analysis methods

It is necessary to calibrate the structural analytical methods by testing. Such tests may be classified as given in Table F.2.

Table F.2 — Qualification of structural analysis methods

Objective of test	Type of test
To verify the model for load sharing due to tension and torsion loads	a) Axial and torsion stiffness test measuring: – The axial strain as a function of applied axial load: To validate the coupling between tension and torsion, two options apply: either one end is rotationally free and the associated torsion is measured, or both ends are rotationally fixed and the associated torsion moment is measured. – The torsion as a function of applied torsion moment: To further validate the coupling between tension and torsion, two options apply: either one end is axially free so that the associated axial strain can be measured, or both ends are axially fixed so that the associated tension load can be measured. b) Strain-gauge testing where strain gauges are placed on individual components and the strains are measured for the above load conditions.
To verify the model for crush load evaluations	Crush testing, where the umbilical is exposed to the maximum load encountered during installation and operation including the relevant geometry of loading.
To verify the bending stress model	a) Bending stiffness testing where the moment curvature relationship is measured: By designing the test set-up in such a way that simultaneous tension and torsion loads can be applied, friction and end effects may be evaluated from the resulting moment curvature diagram. b) Strain gauge testing where components of the umbilical are equipped with strain gauges and the umbilical is exposed to combined loading in terms of tension, torsion and curvature: End effects may be built into the test by applying end fittings at both ends, such that the umbilical components are axially fixed.
To verify the stress and fatigue model	Fatigue testing, where the umbilical is exposed to combined loading in terms of tension, torsion and curvature.

F.2 Comparison of umbilical designs

Structural analysis is an efficient tool for an evaluation of the degree of new technology in umbilical designs. With respect to fatigue performance, the following parameters should be considered, as a minimum, when evaluating the need for and the extent of qualification testing:

— maximum tension and curvature;

— maximum component stress level from tension and curvature;

— contact pressure between components;

— cross-section lay-out and lay angle;

— material properties in terms of mechanical and corrosion performance.

Any qualified analytical method qualified in accordance with F.3 may be used to assess stresses from tension and curvature as well as the contact pressure.

F.3 Fatigue analysis strategies

F.3.1 Alternative strategies for fatigue analysis may be applied as illustrated in Figure F.1.

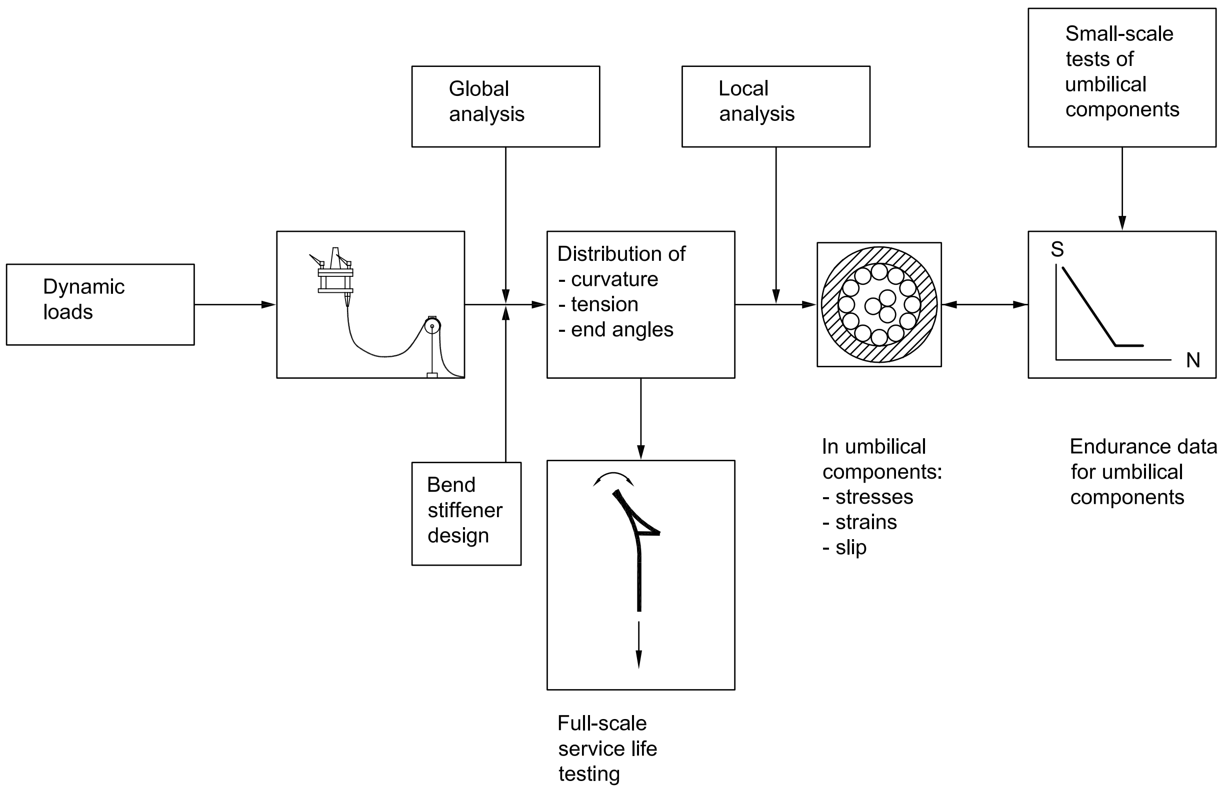


Figure F.1 — Schematic presentation of fatigue analysis strategies

From the global analysis, classes of tension and curvature or classes of tension and end-angle variations are defined. In order to verify the fatigue performance for a given application, the different strategies are to

- use the results from global analysis as a basis for a full-scale prototype test in order simulate the service life of the umbilical;
- use local analysis to transfer the global load effects into stress and strain and combine this with component S-N data to calculate the fatigue damage.

Different strategies may be used in order to calculate local stresses and fatigue damage from the time series of global responses, either by the use of tension and curvature or by tension and end angle. The tension-and-curvature option is relevant in cases where end effects are deemed small or if this effect is handled by a scaling factor. It is also necessary to note that this scaling factor can vary as a function of curvature and, therefore, it is necessary to cover the relevant curvature ranges. In cases where end effects are handled by a 3D formulation, relevant load histories of tension and end angles from global analyses are required.

F.3.2 Different procedures may be applied to calculate the fatigue damage using the methods described in F.3.1. Among these are the following:

- global analysis based on the regular wave approach, where the classes of curvatures and tension responses are applied as input to local stress analyses;
- global analysis based on the irregular wave approach, where the time series of tension and curvature are found; with regard to further processing of these time series to calculate the stress and fatigue, different alternatives apply:
  - conversion of the time series of global responses in terms of tension and curvature into time series of stresses by a validated analytical formula and directly calculate the fatigue damage by time series processing,
  - application of the joint distribution of tension and curvature and identification of classes of curvature and corresponding tension by time-series processing, e.g. rainflow counting; the response classes can then be applied as input to analytical or numerical stress analysis.

    The response classes may be obtained by alternative strategies:

    - if the tension variation is small (i.e. the stress variation due to tension is insignificant with respect to fatigue), the mean tension can be applied for all classes of curvature variations,
    - if the tension variation is moderate (i.e. the curvature variation is still the governing effect), a relationship between tension and curvature can be established based on regression analysis,
    - if the tension variation effect has the same order of magnitude as the curvature effect, then it is necessary to base the time series processing on selecting either tension or curvature as a master quantity to obtain classes of simultaneous tension and curvature variations;
  - joint distribution procedures, which also apply if the tension and end-angle approach is used.

F.3.3 In general, it is necessary to investigate different positions in the umbilical cross-section and along the umbilical to ensure that the worst-case location is identified. With regard to handling the effect of environmental load direction, different assumptions may be applied.

- On the basis of the wave and direction scatter diagrams, identify the worst-case direction and conservatively assume that all classes be applied in this direction. In that case, the cross-sectional positions being checked are limited to one plane.

— Take full account for the directionality in order to distribute the fatigue damage over the cross-section. This requires definition of the sea-states for a number of directions based on the wave and direction scatter diagram. For each direction, a regular or irregular approach is used. However, this requires a 3D description of the umbilical stress and fatigue model in order to distribute the fatigue over the cross-section. It is necessary to describe the curvature about two axes, whereas it is necessary to describe the angle variation in 3D.

F.4 Global load effect analysis methodology

F.4.1 General

F.4.1.1 The purpose of global load effect analyses is to describe the overall static and dynamic structural response of the umbilical system. A global cross-sectional description in terms of resulting force/displacement relations (axial force versus axial elongation, bending moment versus curvature and torsion moment versus twist angle) is applied in such analyses.

Global response quantities can be grouped into the following main categories:

— resulting cross-sectional forces (effective tension, bending moments, torsional moment);

— global umbilical deflections (curvature, elongation, angular orientation);

— global umbilical position (co-ordinates, distance to other structures, position of seafloor touch-down point on seafloor, location of umbilical point of no motion on the seabed, etc.);

— support forces at termination to rigid structures (e.g. resulting force and moments at root end of bend stiffener).

F.4.1.2 These response quantities are given directly as output from global riser analyses. In addition, the following combined (i.e. simultaneous) responses are of special importance for umbilical design.

— Combined effective tension/curvature response: This is the basis for an evaluation of the structural strength of the umbilical as well as the calculation of fatigue stress in the individual components of the cross-section.

— Combined effective tension/relative angle response close to supports: This is the basis for the design of bend-limiting devices (e.g. bend stiffener, bellmouth) at fixation to rigid structures.

Static analyses should be carried out using a full nonlinear approach. Several alternatives are available in subsequent dynamic analysis restarted from the static equilibrium configuration. Treatment of nonlinearities is the distinguishing feature among available dynamic analysis techniques. Knowledge of governing nonlinearities for the actual system, as well as treatment of nonlinearities in established analysis techniques, is crucial for the accuracy and, hence, the choice of an adequate analysis strategy. An overview of commonly used dynamic FE analysis methods is given in Table F.3.

Table F.3 — Dynamic FE analysis techniques

<table>
<tr><th rowspan="2">Method</th><th colspan="2">Nonlinearity</th></tr>
<tr><th>Environmental load</th><th>Structure</th></tr>
<tr><td>Nonlinear time domain (NTD)</td><td rowspan="2">Morrison loading
Integration to actual surface elevation</td><td>Geometric stiffness
Non-linear cross-section
Seafloor contact
Contact surface (e.g. bellmouth)
Large 3D rotations</td></tr>
<tr><td>Linearized time domain (LTD)</td><td rowspan="2">Linearized at static equilibrium position</td></tr>
<tr><td>Frequency domain (FD)</td><td>Linearized at static equilibrium position (stochastic linearization in case of irregular excitation)</td></tr>
</table>

Umbilicals in dynamic service operated from floating hosts are normally arranged in compliant configurations. This means that host motions are absorbed by a change in geometry of the configuration. Such systems are normally associated with a pronounced nonlinear response characteristic. Nonlinear time-domain analysis shall, hence, be considered as the primary method of analysis for umbilicals. The nonlinear time domain approach should allow unlimited translations and rotations in 3D space.

Linearized time-domain and frequency domain analyses may be applied provided that the adequacy of such analyses is documented by verification against nonlinear time domain analysis.

F.4.1.3 The main dynamic loading on umbilicals in dynamic service is governed by waves and associated host motions. A regular or irregular wave representation may be applied in the analyses. “Regular wave” refer to a deterministic, harmonic wave with a given period and amplitude. “Irregular wave” refer to a stochastic wave generated from a given wave spectrum. One or combinations of the following methods should be applied:

— irregular-wave analysis in the time domain;

— regular-wave analysis in time domain;

— irregular-wave analysis in the frequency domain.

F.4.1.4 Wave-period variation should be considered for regular- and irregular-wave analyses to identify the most unfavourable loading condition. This is of special importance for regular-wave analyses, which can be subjected to severe bias for dynamically sensitive systems. The period variation should be performed with due consideration of the following:

— statistical variation of wave period;

— eigenvalues of the umbilical system;

— peaks in host motion transfer function;

— period dependencies in load intensity, e.g. splash-zone loads in case of disturbed kinematics.

It should be documented that the duration of irregular time-domain analyses is sufficient to obtain extreme load effect estimates with sufficient statistical confidence. This is of particular concern in case of combined WF and LF loading. The methodology as outlined in DNV OS-F201 may be applied.

It is required that the use of any simplified modelling and/or analysis technique be verified by more advanced modelling and/or analyses. In particular, the validation, as specified in Table F.4, should be considered for representative (critical) load cases. For further details, see DNV OS-F201:2001, Appendix D.

Table F.4 — Validation analysis methods overview

Applied method	Method for validation
Linearized time domain analysis	Nonlinear time-domain analysis
Frequency-domain analysis	Time-domain analysis
Regular-wave analysis	Irregular-wave analysis

F.4.2 Cross-sectional modelling in global analyses

As outlined in F.1 to F.3, the umbilical can have rather complex global cross-sectional characteristics of bending due to the stick/lip behaviour caused by the contact forces and friction between the components of the umbilical. Globally, this results in a hysteretic moment-curvature characteristics of the cross-section, which depend on the mean tension in the umbilical. In general, the global cross-sectional characteristics of a typical umbilical can be summarized as follows.

— Different structural damping properties are related to axial, torsional and bending deformation of the umbilical.

— The axial- and torsional stiffnesses may be regarded as constant for a given tension in the umbilical.

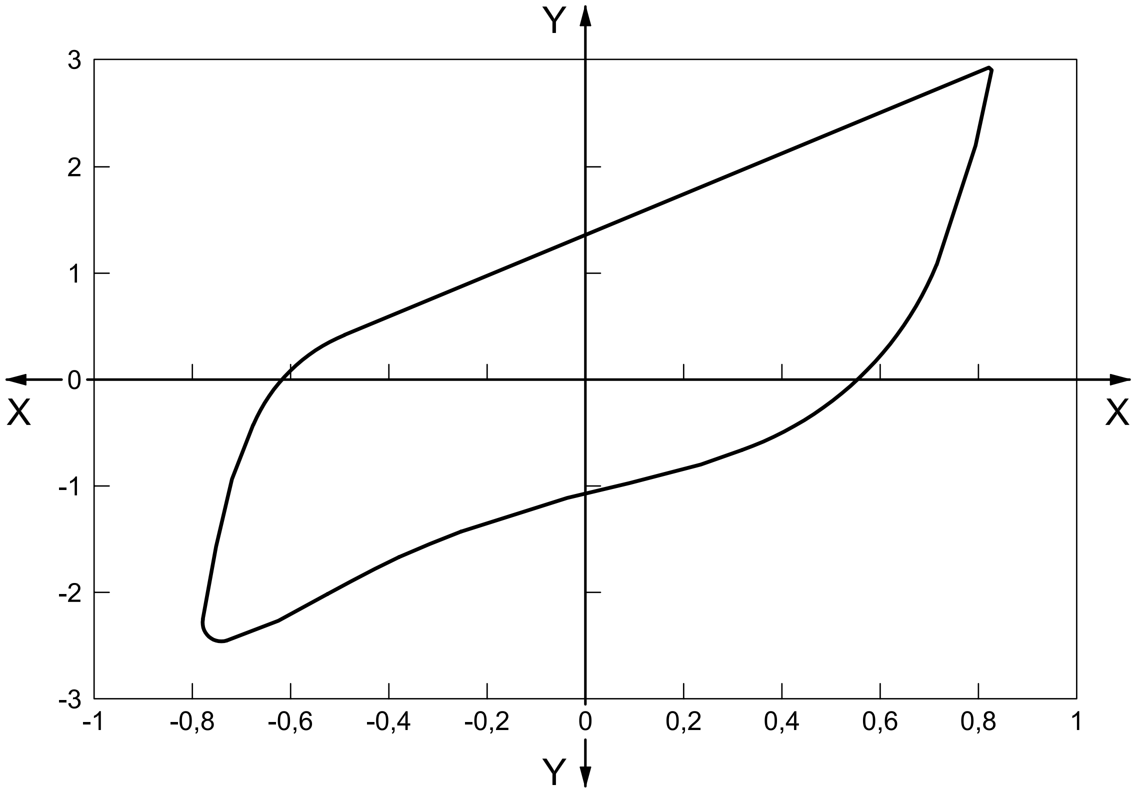
— The structural damping related to axial and torsional deformations may be approximated by a viscous damping model (i.e. constant linear damping model). An equivalent damping level of 1 % to 5 % should be expected.

— A pronounced moment-curvature hysteresis is observed for large-amplitude bending due to slippage between the components, see Figure F.2. The characteristics of the bending hysteresis are governed by the material properties of the layers and the friction between the layers. An equivalent damping level of up to 20 % to 30 % can be observed for a full-slip condition.

— The umbilical behaves as a solid cross-section for small-amplitude bending. This is because the frictional forces between the components prevent sliding. An equivalent damping level of 1 % to 5 % may be expected.

It should be noted that the damping figures given above should be regarded as only representative; they are used to give a qualitative illustration of the damping mechanisms of umbilicals. Assessment of structural damping should be performed on a case-by-case basis, based on testing of the actual or a similar cross-sectional design.

Thus, it can be concluded that the damping and stiffness properties in bending is a strongly non-linear phenomenon. This results in the amplitude-dependent stiffness and damping properties of umbilicals exposed to dynamic loading. Furthermore, the structural damping and stiffness can vary significantly along the umbilical. Large structural damping is experienced in areas with large dynamic bending (e.g. at supports where bending response is controlled by bend-limiting devices). Smaller damping is experienced in areas with small dynamic bending.



Key

X curvature, (1/m) × 10

Y bending moment, expressed in kilonewton-metres

Figure F.2 — Representative example of measured bending hysteresis

The global dynamic load effect analyses of umbilicals are typically carried out by time-domain dynamic FE simulations while VIV and free-spanning analyses normally are performed in FD. A global description of the cross-sectional properties of the umbilical is required for such load effect analyses. The following modelling alternatives may be applied.

a) An equivalent viscous damping model is recommended for small-amplitude vibrations, e.g. VIV and free-spanning analyses. The structural damping slightly on the lower side should be applied as a conservative approximation. Constant cross-sectional stiffness values representative for small-amplitude vibrations should be applied. This formulation is applicable to TD as well as FD formulations.

b) A consistent cross-sectional model can be obtained by the introduction of the measured hysteretic moment-curvature relation into the FE model together with a viscous damping model to account for axial and torsional damping. Using a non-linear TD solution scheme, this model gives a consistent modelling of the structural properties of the umbilical.

It should be noted that viscous damping models normally apply to all modes of deformation for the system, e.g. the Rayleigh damping model, commonly also termed the proportional damping model. Such a model, however, does not allow specification of different damping levels for the different modes of deformations.

Model 2 is numerically challenging and is mainly recommended for calibration of simpler structural models. Model 1 may also be applied as an approximation for dynamic response analyses involving large-amplitude bending. In this case, a low overall viscous damping level (representative for axial/torsional damping) should be applied to give realistic energy dissipation at the dominating response frequency, e.g. peak period in response spectrum.

Several other alternatives are also possible, e.g. viscous models allowing for specification of different damping levels in the different modes of deformation (axial, bending torsional), spatial specification of damping level, etc.

F.4.3 Global modelling considerations

F.4.3.1 General

Numerical approximations typically involve spatial discretization of the umbilical into a finite number of elements as well as time and/or frequency discretization of the dynamic loading. Investigation of convergence in the solution by repeated analyses considering successive refinement of the discretization is the basic principle to verify that the discretization is adequate. The discretization is considered adequate when the change in response between two successive discretizations is acceptable relative to the purpose of the analyses. In this situation, there is no practical gain by further refinement of the discretization.

Guidance to selected generic modelling issues is given in F.4.3.2 to F.4.3.4. Additional guidance on modelling can be found in riser standards/recommended practices such as ISO 13628-11, ISO 13628-2, ANSI/API RP 2RD and DNV OS-F201.

NOTE For the purposes of this provision, API Spec 17J[9] is equivalent to ISO 13628-2 and API RP 2RD[8] is equivalent to ISO 13628-11.

F.4.3.2 Spatial discretization

Special attention should be given to the following issues related to spatial discretization of the umbilical system.

— areas with high curvature, e.g. hog and sag bend;

— contact areas, e.g. touch down, hull supports, bellmouth;

— terminations to fixed structures;

— areas with high load intensities and/or load gradients, e.g. splash zone;

— areas with significant change in cross-sectional properties, e.g. bend stiffener, buoyancy modules, bend limiters;

— areas with change in element lengths; the relative change in length between adjacent elements with uniform cross-sectional properties should not exceed 1:2; a lower relative change can be required in case of non-uniform cross-sectional properties;

— areas with compression, i.e. negative effective tension; element lengths should be selected sufficiently small to avoid Euler buckling within one element, i.e. the mesh should be sufficiently fine to capture potential Euler buckling in the global response model.

F.4.3.3 Frequency discretization

The frequency content of the loading due to, for example, waves and host motions, should be selected to give a physically correct description of the loading. Special attention should be given to possible resonance frequencies of the umbilical system. Irregular analyses considering random-wave loading is recommended for frequency sensitive systems.

Host-motion transfer functions are represented in terms of amplitude and phase angle as function of a number of discrete wave frequencies and directions. The discrete frequencies and directions shall be selected carefully to obtain an adequate description of the host motions. The following recommendations apply.

— The frequencies should be selected to cover the resonance peaks in host-motion transfer functions, e.g. heave, roll and pitch resonance frequencies.

— Possible cancellation frequencies in the host-motion transfer functions should be identified and covered by the discrete representation (relevant, for example, for semi-submersibles and tension leg platforms).

— The frequency range should cover relevant frequencies in the wave-excitation spectrum, the criticality should be evaluated with a basis in possible resonance frequencies in the umbilical system.

— Discretization of wave direction with a spacing in the range of 15° to 30° is normally sufficient to give a good representation of the host motions.

F.4.3.4 Time discretization

Numerical time integration is applied in time-domain analyses to produce discrete-response time series. The choice of the time step is crucial for the stability and accuracy of direct time-integration methods, some aspects are discussed in the following.

— The time step required to obtain a stable numerical solution is, to a large extent, governed by the highest eigenmode present in the discrete structural model. This is because it is necessary to integrate all eigenmodes accurately to obtain a stable solution, including, for example, modes that are of no significance for the response description. The typical time step is in the range of 0,1 s to 0,4 s for numerically well behaved systems.

— Nonlinear analyses in general require a shorter time step to obtain a stable numerical solution when compared with linearized analyses. This is the case, in particular, for numerically sensitive systems, e.g. systems with significant displacement-dependent nonlinearities, such as low-tension problems, including snap-loading, buckling, contact problems and significant nonlinear material behaviour, e.g. moment-curvature hysteresis.

— Quality checks of response-time histories should always be considered to identify possible non-physical noise reflecting an inaccurate numerical solution.

— Study of the convergence considering successive refinements of the time discretization should be performed to determine the required time step to obtain an adequate numerical solution.

Time-domain analyses considering stochastic wave loading typically require the generation of discrete time histories for host motions and wave kinematics according to a specified wave spectrum. The load-time histories are represented in terms of a finite number of harmonic components using a stochastic phase and/or stochastic amplitude to obtain a random-wave realization. The quality of the generated wave-time series should be evaluated to ensure that the desired statistical properties are well represented (typically standard deviation, zero-crossing period, skewness and kurtosis). The repetition period of the generated wave signal should also be assessed.

F.5 Installation analysis

This analysis is used to establish the loadings imposed on the umbilical during installation, including those imposed due to internal monitoring pressure, vessel motion, installation equipment, clamping loads, trenching operations, rock dumping, crushing, seabed stability and pull-in operations.

The analysis shall be used to establish the following parameters, which shall be considered during the design of the umbilical:

- allowable limits in the offset between the touch-down point of the umbilical on the seabed and the vessel as a function of sea-state and current;
- variation of tension and curvature along the umbilical as a function of sea-state and current;
- tension and curvature time-domain plots for a number of points along the umbilical, including the points established as having the maximum values of tension and minimum radii of curvature;
- allowable vessel motions to avoid overstressing the umbilical;
- residual tension from trenching;
- maximum period of time, as a function of sea-state, that the laying vessel can maintain position prior to failure occurring within the umbilical;
- impact forces due to rock dumping;
- lateral deformations due to crushing loads during storage and passage through cable haulers in combination with any internal pressure monitoring and lay tension loads.

The analysis should be performed to define the maximum allowable environmental conditions for all phases of installation for the vessel motions and in the range of weather conditions defined in the metocean criteria provided by the purchaser;

If the installation involves an I-tube or J-tube pull, the maximum pull-in force on the umbilical, taking into account the friction both on the seabed and within the I-tube or J-tube, shall also be determined.

The umbilical design loads, minimum bend radii and allowable crushing load shall be within the limits established by the installation analysis.

Annex G
(informative)

Umbilical full-scale tests

G.1 Umbilical full scale tests

Table G.1 provides guidance to the manufacturer during the preparation of test procedures for full-scale tests. These tests shall be defined by the purchaser as qualification (on prototype length) or verification (on sample of production length) tests. Tests that are noted in Clause 10 are required unless waived by the purchaser if previous test results are applicable for the project.

Table G.1 — Umbilical full scale tests

Umbilical full scale test	Objectives and considerations
Lay-up trial (manufacture of prototype length)	Objectives: — Assess manufacturing feasibility. — Demonstrate feasibility of manufacturing and handling the candidate cross-section. — Confirm predicted properties (e.g. diameter, weight). Considerations: — Incorporate tube-string and termination welding qualification. — If dynamic and static cross-sections differ, consider a prototype length of both.
Combined torsion balance and tension test	Objectives: — Quantify at loads up to the design tensile load the permanent set, residual twist, torque balance, rotation characteristics and axial stiffness of the design. — Address client request to increase the design tensile load to an agreed level above the maximum tensile load to establish the load at which the components within the umbilical cease to function (ultimate tensile strength of the umbilical). — Confirm balance for a deliberate torsion balanced umbilical. — Quantify the force to rotate the umbilical in each radial direction at zero tension and at multiple tension steps. Considerations: — Manner of termination to ensure the internal components are firmly gripped. — Number of load increments up to the maximum tensile load (minimum ten). — Method of recording load, extension and rotation at each load step. — Hold duration at maximum tensile load (minimum 1 h). — Repeating increasing and decreasing load increments (load cycling) to achieve stable elongation and rotation readings (agreed definition for stability). — If dynamic and static cross-sections differ, consider a prototype length of both.

Table G.1 (*continued*)

Umbilical full scale test	Objectives and considerations
Bend stiffness test	Objectives: Confirm theoretical bending stiffness for the umbilical. Considerations: Measure force (load) and deflection in increments to establish curve. The section modulus value obtained for the sample length shall be recorded and graphed at various force/deflection values.
End strength terminations (tension test with terminations)	Objectives: — Demonstrate that the strength of the end terminations are adequate for design tension loads. — Demonstrate that the interaction between elements is as predicted (e.g. no local crushing of weaker elements; elongation of elements is as predicted). Considerations: — Design tension may be different for each end, consider all possible load cases, installation, abandonment, recovery, operation in extreme condition, before establishing design value. — Rate of application of axial load (not to exceed 1 % of the maximum design tension per second). — Test hold duration (minimum 1 h). — Consider test value greater than calculated maximum design value, which includes SF.
Combined tension and bending test	Objectives: Demonstrate that umbilical can meet specified installation or operational (whichever is the greater) tension and bending load combination. Considerations: — Replicate installation design load and installation radius. Utilize representative monitoring pressure in tubes. — Rate of application of axial load (not to exceed 1 % of the maximum installed installation tension per second). — Test hold duration (minimum 1 h). — Evaluate relative movements of elements and deformation of elements as a result of interaction in the B&T configuration. — Compare element ovalization with the results from the crush test.

Table G.1 (*continued*)

Umbilical full scale test	Objectives and considerations
Umbilical squeeze/crush test (installation tensioner simulation)	Objectives: — Confirm allowable crush resistance proposed by umbilical manufacturer. — Record interaction between elements under increasing crush load (local crushing of weaker elements, internal rearrangements, filler deformations, contact pressure points). — Provide purchaser with some guidance on the umbilical integrity after potential crush incidents during reeling, transportation and installation. — Establish integrity of sample at design clamping force. Considerations: — For specific pads, confirm that proposed umbilical/tensioner combination meets project acceptance criteria specified in purchaser's contract. — For non-specific pads, advise installation contractor on umbilical crush resistance for the design of installation tensioner pads and geometry. — If necessary, or if track and pad data are not available, assess multiple options to determine the optimum. — Number of load increments and combination with/without axial load and installation monitoring pressure. — Rate of application of compression load (maximum 5 mm/min) or at a rate representative of the actual loading rate that will be experienced based on the anticipated pay-out speed during deployment. — Measure bundle deformation at design clamping force with known track configuration and pad geometry. — Measure element deformations following application of design clamping force. — Repeat previous measurement at increasing load steps to establish failure load.
Internal/external friction factor assessment	Objectives: Quantify friction factors between components in the cross-section and between bundle and pads. Considerations: — Assess the sensitivity of geometrical position of the bundle in the test rig (clock position) and the track arrangement (2, 3 ,4 number of tracks). — Rate of application of load and hold periods. — Assess the creep behaviour.
Umbilical impact test	Objectives: Determine impact/load energy relationship with consequence. Considerations: Using load steps and an appropriately selected impact object, evaluate the energy required a) to initiate cosmetic damage, b) to cause structural deformation to an element, c) to cause element failure under installation or operating conditions.

Table G.1 (*continued*)

Umbilical full scale test	Objectives and considerations
Dynamic fatigue test	Objectives: — To demonstrate fatigue life and (if run to failure) to quantify margin of SF. — Qualify the umbilical and host interface accessories for dynamic service. — Establish points of wear and magnitude of wear between components. — Establish the fatigue performance of the critical umbilical component that is assumed in the umbilical design. — Confirm that the manufacturer's design methodology, analysis methodologies and software tools are mature and accurate. Considerations: — Replicate the maximum excursion predicted, maximum tension range anticipated and prepare test blocks to accumulate the design fatigue life and further to failure (if specified). — Utilize prototype host interface steelwork and prototype bend stiffener. — Effects of lay length, relative position of bend stiffener and relative position in test rig. — Ensure that the position of any specific butt welds within the sample is known.
Free flooding rate	Objectives: Quantify the flow rate longitudinally through the interstices of the cross-section. Considerations: — Apply water head to one end of the sample, measure water outflow at the other end. — Consider requirement/priority to quantify flow rate longitudinally through the end termination that is “first end” during installation. — Correction for water flow rate at increasing water pressure.
Hydrostatic reduction of cross-section	Objectives: — Evaluate hydrostatic effect on cross-section bundle; diameter reduction and radial deformation as a function of hydrostatic pressure. — Quantify flow rate longitudinally through the cross-section. Considerations: — Effect on individual elements, i.e. tube collapse, cable deformation or insulation water absorption should be studied at the component level. — Internal pressure of tubes NOTE Empty, unpressurized tubes are the most conservative. — Rate of increase of pressure. — Effect of cable deformation/insulation compression on cable properties.
Host pull tube (bend-stiffener latch) interface tests	Objectives: Confirm interface fit and quantify angular, radial or other limitations. Considerations: — Verify or iterate identification markings, visual confirmation methods for engagement, etc., between the mating parts. — Test shall be conducted with applicable installation back tension and an umbilical section representative of the actual umbilical. — Test shall be conducted at incremental angles until worst-case angular misalignment capability of mating system is determined. — ROV (or diver) access to and release or final connection mechanism shall be verified.

Table G.1 (*continued*)

Umbilical full scale test	Objectives and considerations
Repair splice qualification (bundle)	Objectives: Demonstrate feasibility of proposed repair hardware, repair method and necessary tooling. Considerations: — Ensure that the splice is performed in a controlled area with all resources logged. Environment and orientation of ends (horizontal, vertical) should replicate the expected onshore/offshore repair scenario. — Time consumption should be logged to provide an indication of time required to complete the splice. — Verify that repair-splice kit identifies and contains all necessary tooling and repair equipment to perform repair splice. — If the repair splice is expected to be subject to any bending moment, consider performing a combined T&B test on a sample with a repair splice.

G.2 Example procedure detail: Umbilical squeeze/crush test

G.2.1 Purpose

A test shall be performed in order to verify the umbilical's integrity for the specified maximum allowable clamping force at estimated maximum installation tension and zero tension. The test should strive to be as realistic as possible in terms of pad geometry, pad material and number of belts. Alternatively, the test sample may be loaded between two parallel plates in lieu of specific pad geometry.

G.2.2 Test procedure

A sample test procedure is as follows.

a) Perform appropriate acceptance tests to confirm integrity of the test sample.

b) Continuously or before and after each clamping force is applied, pressurize the tubes/hoses to the specified pressure (typically to the recommended installation value).

c) Electric cables, if present, shall be monitored for electrical continuity.

d) Optical fibres, if present, shall be monitored for optical continuity.

e) Tension the umbilical to the specified tension level.

f) Apply each specified clamping force at the agreed rate of compression at different specified locations along the umbilical test sample.

The range of clamping forces should include the calculated allowable as well as a force large enough to be damaging (i.e. cause permanent ovality of tubes, etc.).

After completion of the test, the sample shall be stripped down layer for layer, starting with area subjected to the highest load.

Once an area with no damage has been identified, the maximum allowable clamping force has been identified.

Consideration shall be given to validating the maximum allowable clamping force at multiple locations along the lay length to assess the sensitivity of the cross-sectional orientation to the clamping force.

G.2.3 Acceptance criteria

Acceptance criteria are as follows.

a) No rearrangement of components due to installation crushing loads.

b) No tube ovalization outside allowable limits.

c) No cable deformation outside allowable limits.

NOTE Criteria are agreed between purchaser and manufacturer.

G.2.4 Reporting

The maximum allowable clamping force as identified in the test shall be compared to the maximum allowable as stated in the manufacturer's written specification. Redefine if necessary.

The reduction in umbilical diameter between the load plates shall be recorded as a function of the clamping force applied. The test sample shall be dissected and examined, and the effects of the applied load on the umbilical and the functional components shall be determined and documented.

Annex H
(informative)

Tube material matrix

H.1 General

Table H.1 shows the tube material matrix.

Table H.1 — Tube material matrix

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Type of material	ASTM A789/A789M ferritic/austenitic stainless steel, type 25Cr duplex	ASTM A789/A789M ferritic/austenitic stainless steel, type 25Cr duplex	ASTM A789/A789M ferritic/austenitic stainless steel, type 25Cr super duplex	ASTM A789/A789M ferritic/austenitic stainless steel, type 19Cr lean duplex, type 20Cr lean duplex, type 21Cr lean duplex	ASTM A269 austenitic stainless steel, type 316L
Grade	UNS S32750 UNS S32760 UNS S39274	UNS S32750 UNS S32760 UNS S39274	UNS S32750 UNS S32760	UNS S32001 UNS S32003 UNS S32101	UNS S31603
Chemical composition	Chemical composition according to the relevant UNS codes	An analysis shall be performed per heat in accordance with ASTM A751 to verify that the chemical composition is according to UNS requirements and that min. PRE is achieved.	Chemical composition according to the relevant UNS codes	Chemical composition according to the relevant UNS codes	Chemical composition according to the relevant UNS codes
Mechanical	Values as per the manufacturer's written specification and after client acceptance: — Yield strength — Tensile strength — Yield/tensile strength ratio — Elongation — Hardness	Values as per the manufacturer's written specification and after client acceptance: — Yield strength — Tensile strength — Yield/tensile strength ratio — Elongation — Hardness	Values as per the manufacturer's written specification and after client acceptance: — Yield strength — Tensile strength — Yield/tensile strength ratio — Elongation — Hardness	Values as per the manufacturer's written specification and after client acceptance: — Yield strength — Tensile strength — Yield/tensile strength ratio — Elongation — Hardness	Values as per the manufacturer's written specification and after client acceptance: — Yield strength — Tensile strength — Yield/tensile strength ratio — Elongation — Hardness
Corrosion	The steel tube shall be corrosion-resistant to a marine environment.	The steel tube shall be corrosion-resistant to a marine environment.	The steel tube shall be corrosion-resistant to a marine environment.	The lean duplex alloy tubing is coated or zinc clad for corrosion-resistance in the marine environment. Thickness of the cladding or coating agreed with the purchaser.	The steel tube is not corrosion-resistant to a marine environment.
Compatibility	The fluids used within the tubes shall be demonstrated as compatible with the tube material.	The fluids used within the tubes shall be demonstrated as compatible with the tube material.	The fluids used within the tubes shall be demonstrated as compatible with the tube material.	The fluids used within the tubes shall be demonstrated as compatible with the tube material.	The fluids used within the tubes shall be demonstrated as compatible with the tube material.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Microstructure	The ferrite content shall be within 35 % to 55 % mass fraction. The material shall be essentially free from grain-boundary carbides, nitrides and inter metallic phases.	The ferrite content shall be within 35 % to 55 % mass fraction. The material shall be essentially free from grain-boundary carbides, nitrides and inter metallic phases.	The ferrite content shall be determined in accordance with ASTM E562. Aim for a ferrite band width in the base metal of 45 % to 50 % mass fraction. The acceptable ferrite content range is 35 % to 60 % mass fraction.	The ferrite content shall be determined in accordance with ASTM E562 or ASTM E1245. Aim for a ferrite content of 45 % to 50 % mass fraction. The acceptable ferrite content range is 35 % to 60 % mass fraction mass fraction.	N/A
Surface condition	The tube surface shall be without defects or irregularities exceeding specified reference notch for NDE.	The tube surface shall be without defects or irregularities exceeding specified reference notch for NDE.	The tube surface shall be without defects or irregularities exceeding the thresholds allowed during NDE.	The tube surface shall be without defects or irregularities exceeding the thresholds allowed during NDE. The tube is protected from external corrosion with an extruded external zinc cladding. The surface quality requirements for the zinc cladding or surface coating shall be agreed between purchaser and manufacturer.	The tube surface shall be without defects or irregularities exceeding the thresholds allowed during NDE.
Tube dimension	Tube length, inner diameter, wall thickness, and outer diameter are as specified by the purchaser. It is the purchaser's responsibility to determine the required tubing dimensions based upon the intended service conditions. The permissible variation of wall thickness shall be as per the manufacturer's written specification.	Tube length, inner diameter, wall thickness, and outer diameter are as specified by the purchaser. It is the purchaser's responsibility to determine the required tubing dimensions based upon the intended service conditions. The permissible variation of wall thickness shall be as per the manufacturer's written specification.	Tube length, inner diameter, wall thickness, and outer diameter are as specified by the purchaser. It is the purchaser's responsibility to determine the required tubing dimensions based upon the intended service conditions. The permissible variation of wall thickness shall be as per the manufacturer's written specification.	Tube length, inner diameter, wall thickness, and outer diameter are as specified by the purchaser. It is the purchaser's responsibility to determine the required tubing dimensions based upon the intended service conditions. The permissible variation of wall thickness shall be as per the manufacturer's written specification.	Tube length, inner diameter, wall thickness, and outer diameter are as specified by the purchaser. It is the purchaser's responsibility to determine the required tubing dimensions based upon the intended service conditions. The permissible variation of wall thickness shall be as per the manufacturer's written specification.
Destructive testing					
Chemical composition	An analysis shall be performed per heat in accordance with ASTM A751 to verify that the chemical composition is according to UNS requirements and that min. PRE is achieved. Maximum acceptable content of each element shall be in accordance with manufacturer's written specification. Positive material identification (PMI) shall be performed on each tube.	An analysis shall be performed per heat in accordance with ASTM A751 to verify that the chemical composition is according to UNS requirements and that min. PRE is achieved. Maximum acceptable content of each element shall be in accordance with manufacturer's written specification. Positive material identification (PMI) shall be performed on each tube and filler material.	Upon receipt of the strip, an analysis shall be performed on one strip sample per thickness per heat in accordance with ASTM A751 to verify that the chemical composition is in accordance with UNS requirements and that min. PRE is achieved. Positive material identification (PMI) shall be used to verify the correct grade of strip, filler metal and tubing.	Upon receipt of the strip, an analysis shall be performed on one strip sample per thickness per heat in accordance with ASTM A751 to verify that the chemical composition is in accordance with UNS requirements and that min. PRE is achieved. Positive material identification (PMI) shall be used to verify the correct grade of strip, filler metal and tubing.	Upon receipt of the strip, an analysis shall be performed on one strip sample per thickness per heat in accordance with ASTM A751 to verify that the chemical composition is in accordance with UNS requirements and that min. PRE is achieved. Positive material identification (PMI) shall be used to verify the correct grade of strip, filler metal and tubing.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Tension testing	Tension testing shall be performed in accordance with ASTM A370. The number of specimens tested shall be in accordance with ASTM A789/A789M.	Tension testing shall be performed in accordance with ASTM A370. The number of specimens tested shall be in accordance with ASTM A789/A789M.	Tension testing shall be performed in accordance with ASTM E8/E8M and ASTM A370. Tension tests shall be performed on one sample removed from each end of each tubing mill coil. For strip-splice and orbital-weld samples, testing shall be performed with either a strip-splice weld or orbital weld at approx. the centre of the test specimen. Tension tests shall be performed on two strip-splice weld samples and two orbital-weld samples for each heat/thickness of tubing.	Tension testing shall be performed in accordance with ASTM E8/E8M and ASTM A370. Tension tests shall be performed on one sample removed from each end of each tubing mill coil. For strip-splice and orbital-weld samples, testing shall be performed with either a strip-splice weld or orbital weld at approx. the centre of the test specimen. Tension tests shall be performed on two strip-splice weld samples and two orbital-weld samples for each heat/thickness of tubing.	Tension testing shall be performed in accordance with ASTM E8/E8M and ASTM A370. Tension tests shall be performed on one sample removed from each end of each tubing mill coil. For strip-splice and orbital-weld samples, testing shall be performed with either a strip-splice weld or orbital weld at approx. the centre of the test specimen. Tension tests shall be performed on two strip-splice weld samples and two orbital-weld samples for each heat/thickness of tubing.
Hardness testing	Hardness testing shall be performed in accordance with ASTM A370. The number of specimens tested shall be in accordance with ASTM A789/A789M.	Hardness testing shall be performed in accordance with ASTM A370. The number of specimens tested shall be in accordance with ASTM A789/A789M.	Rockwell or Vickers hardness testing shall be used. Rockwell hardness testing shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Vickers hardness testing shall be performed in accordance with ASTM A1016/A1016M and ASTM E92. Hardness tests shall be performed on both base metal and weld metal regions. Hardness tests shall be performed on two samples from each tubing mill coil, one from each end. Hardness tests shall be performed on two strip-splice welds and two orbital-weld samples for each heat/thickness of tubing.	Rockwell or Vickers hardness testing shall be used. Rockwell hardness testing shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Vickers hardness testing shall be performed in accordance with ASTM A1016/A1016M and ASTM E92. Hardness tests shall be performed on both base metal and weld metal regions. Hardness tests shall be performed on two samples from each tubing mill coil, one from each end. Hardness tests shall be performed on two strip-splice welds and two orbital-weld samples for each heat/thickness of tubing.	Rockwell or Vickers hardness testing shall be used. Rockwell hardness testing shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Vickers hardness testing shall be performed in accordance with ASTM A1016/A1016M and ASTM E92. Hardness tests shall be performed on both base metal and weld metal regions. Hardness tests shall be performed on two samples from each tubing mill coil, one from each end. Hardness tests shall be performed on two strip-splice welds and two orbital-weld samples for each heat/thickness of tubing.
Hardness traverse	—	—	A series of Vicker's hardness test measurements are made on a weld cross-section perpendicular to the axis (direction of travel) of the weld in accordance with ASTM E384. Each traverse shall include the base metal and heat-affected zone on either side of the weld and the weld metal. Testing is performed on two samples for each of the three weld types during the welding procedure qualification testing.	A series of Vicker's hardness test measurements are made on a weld cross-section perpendicular to the axis (direction of travel) of the weld in accordance with ASTM E384. Each traverse shall include the base metal and heat affected zone on either side of the weld and the weld metal. Testing is performed on two samples for each of the three weld types during the welding procedure qualification testing.	A series of Vicker's hardness test measurements are to be made on a weld cross-section perpendicular to the axis (direction of travel) of the weld in accordance with ASTM E384. Each traverse shall include the base metal and heat affected zone on either side of the weld and the weld metal. Testing is performed on two samples for each of the three weld types during the welding procedure qualification testing.
Flattening test	Flattening test shall be performed according to ASTM A1016/A1016M on one tube per lot.	Flattening test shall be performed according to ASTM A1016/A1016M on one tube per lot	N/A	N/A	N/A

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Reverse flattening test	N/A	N/A	Reverse flattening test shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.	Reverse flattening test shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.	Reverse flattening test shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.
Flaring/flange test	Flaring test shall be performed in accordance with ASTM A1016/A1016M. The number of tube specimen and minimum expansion according to ASTM A789/A789M.	Flaring test shall be performed in accordance with ASTM A1016/A1016M. The number of tube specimen and minimum expansion according to ASTM A789/A789M.	Flange tests shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.	Flange tests shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.	Flange tests shall be performed in accordance with ASTM A370 and ASTM A1016/A1016M. Testing shall be performed on samples removed from each end of each tubing mill coil.
Burst test	Tube supplier shall perform burst testing of tubes in accordance with this part of ISO 13628. The minimum required burst pressure shall be two times the DWP.	Tube supplier shall perform burst testing of tubes in accordance with this part of ISO 13628. The minimum required burst pressure shall be two times the DWP.	Tube supplier shall perform burst testing of tubes in accordance with this part of ISO 13628. The minimum required burst pressure shall be two times the DWP.	Tube supplier shall perform burst testing of tubes in accordance with this part of ISO 13628. The minimum required burst pressure shall be two times the DWP.	Tube supplier shall perform burst testing of tubes in accordance with this part of ISO 13628. The minimum required burst pressure shall be two times the DWP.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Corrosion	Pitting corrosion testing shall be performed per lot in accordance with ASTM G48-03, method A, chemical composition, in accordance with the relevant UNS codes. PREN/PREW Test temperature shall be 50 °C and the exposure time shall be 24 h. No visible pitting corrosion attack is acceptable at 20× magnification. Probing with a sharp instrument is required. The mass loss shall be less than 1,0 g/m^2. Should a pitting corrosion test fail, then a propagation test may be performed in strict accordance with the manufacturer's written specification. ASTM G48-03, method B, is not relevant for tubes. Any crevice corrosion testing should be in accordance with manufacturer's written specification.	Pitting corrosion testing shall be performed per lot in accordance with ASTM G48-03, method A, chemical composition, in accordance with the relevant UNS codes. PREN/PREW The exposure time shall be 24 h. No visible pitting corrosion attack is acceptable at 20× magnification. Probing with a sharp instrument is required. The mass loss shall be less than 1,0 g/m^2. Should a pitting corrosion test fail, then a propagation test may be performed in strict accordance with the manufacturer's written specification. ASTM G48-03, method B, is not relevant for tubes. Any crevice corrosion testing should be in accordance with manufacturer's written specification. Test temperature for base material: 50 °C (122 °F) Test temperature for orbital weld: 40 °C (104 °F)	Pitting corrosion testing shall be performed in accordance with ASTM G48-03, method A, chemical composition, in accordance with the relevant UNS codes. PREN/PREW The exposure time shall be 24 in accordance withh. No visible pitting corrosion attack is acceptable at 20× magnification. Probing with a sharp instrument is required. The mass loss shall be less than 1,0 g/m^2. Should a pitting corrosion test fail, then a propagation test may be performed in strict accordance with the manufacturer's written specification. ASTM G48-03, method B, is not relevant for tubes. Any crevice corrosion testing should be in accordance with manufacturer's written specification. Each tubing mill coil shall have two specimens tested from each end of the coil. Tubing mill coils failing to meet the requirements may be heat-treated again and retested. Each heat/thickness of tubing shall have two strip-splice weld and two orbital-weld specimens tested. If strip-splice or orbital-weld specimens fail to meet the requirements, retesting shall be performed. If the retested specimens fail, an investigation shall be performed to determine the cause and appropriate actions required. Test temperature for strip or longitudinal seam weld: 50 °C (122 °F) Test temperature for orbital weld: 40 °C (104 °F)	The lean duplex alloy tubing is coated or zinc clad for corrosion-resistance in the marine environment. Thickness of the cladding or coating is agreed with the purchaser.	Alloy 316L requires some form external cathodic protection in a marine environment.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Microstructure	One micrographic examination is required per heat and shall cover the surfaces and mid-thickness region. Both base metal and weld metal shall be covered. The ferrite content shall be determined and presented in accordance with ASTM E562. The acceptance criterion is a base metal ferrite content of 35 % to 55 % mass fraction. The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates and inter-metallic phases. If inter-metallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval. Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.	One micrographic examination is required per heat and shall cover the surfaces and mid-thickness region. Both base metal and weld metal shall be covered. The ferrite content shall be determined and presented in accordance with ASTM E562. The acceptance criteria are — a base metal ferrite content within 35 % to 55 % mass fraction; — a weld metal ferrite content within 35 % to 60 % mass fraction. The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates and inter-metallic phases. If inter-metallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval. Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.	One micrographic examination is required per heat and shall cover the surfaces and mid-thickness region. Both base metal and weld metal shall be covered. The ferrite content shall be determined and presented in accordance with ASTM E562. The acceptance criteria are — a base metal ferrite content within 35 % to 55 % mass fraction; — a weld metal ferrite content within 35 % to 60 % mass fraction. The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates and inter-metallic phases. If inter-metallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval. Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.	One micrographic examination is required per heat and shall cover the surfaces and mid-thickness region. Both base metal and weld metal shall be covered. The ferrite content shall be determined and presented in accordance with ASTM E562. The acceptance criteria are — a base metal ferrite content within 35 % to 55 % mass fraction; — a weld metal ferrite content within 35 % to 60 % mass fraction. The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates and inter-metallic phases. If inter-metallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval. Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.	N/A

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Non destructive examination (NDE)					
Dimensional check (OD and WT)	The whole length of all the tubes shall be examined to detect dimensional deviations (WT and OD). The WT shall be measured by ultrasonic examination in a helix along the tube. The OD shall be measured by laser in at least two perpendicular levels or by ultrasonic examination in a helix along the tube.	The whole length of all the tubes shall be examined to detect dimensional deviations (WT and OD). The WT shall be measured by ultrasonic examination in a helix along the tube. The OD shall be measured by laser in at least two perpendicular levels or by ultrasonic examination in a helix along the tube.	Wall thickness is controlled during the strip manufacture. Strip width, gauge, crown and chamber shall conform to the tolerances specified in ASTM A240 and ASTM A480. Strip shall be suitable in all respects for the manufacturing of welded tubing on a continuous mill. Strip shall be free of slivers, laminations, gouges, scratches and other injurious defects. Permissible variation in the nominal outside diameter, OD_{nom}, and nominal wall thickness, t_{nom}, of 26Cr tubing shall be as specified in the manufacturer's specification. The wall thickness and outside diameter shall be measured on samples removed from each end of each tubing mill coil.	Wall thickness is controlled during the strip manufacture. Strip width, gauge, crown and chamber shall conform to the tolerances specified in ASTM A240 and ASTM A480. Strip shall be suitable in all respects for the manufacturing of welded tubing on a continuous mill. Strip shall be free of slivers, laminations, gouges, scratches and other injurious defects. Permissible variation in the nominal outside diameter, OD_{nom}, and nominal wall thickness, t_{nom}, of the lean duplex tubing shall be as specified in the manufacturer's specification. The wall thickness and outside diameter shall be measured on samples removed from each end of each tubing mill coil.	Wall thickness is controlled during the strip manufacture. Strip width, gauge, crown and chamber shall conform to the tolerances specified in ASTM A240 and ASTM A480. Strip shall be suitable in all respects for the manufacturing of welded tubing on a continuous mill. Strip shall be free of slivers, laminations, gouges, scratches and other injurious defects. Permissible variation in the nominal outside diameter, OD_{nom}, and nominal wall thickness, t_{nom}, of the austenitic tubing shall be as specified in the manufacturer's specification. The wall thickness and outside diameter shall be measured on samples removed from both ends of each tubing mill coil.
Straightness	The tubes shall be of a sufficient straightness to permit rolling the tube by hand on a flat surface.	N/A	N/A	N/A	N/A
Tube end squareness	The tube ends shall be square cut to within 0,08 mm total indicator reading and free from burrs.	N/A	N/A	N/A	N/A
Eddy current examination	Calibration shall be performed in accordance with ASTM A1016/A1016M. Each tube shall be 100 % examined in accordance with ASTM E426.	Calibration shall be performed in accordance with ASTM A1016/A1016M. Each tube shall be 100 % examined in accordance with ASTM E426.	Eddy current testing shall be performed in accordance with ASTM A1016/A1016M and ASTM E309. In-process testing shall be performed on the tubing mill. Final testing shall be performed on a separate off-mill testing line. Both the in-process and final testing shall be performed using high-and low-frequency coils.	Eddy-current testing shall be performed in accordance with ASTM A1016/A1016M and ASTM E309. In-process testing shall be performed on the tubing mill. Final testing shall be performed on a separate off-mill testing line. Both the in-process and final testing shall be performed using high-and low-frequency coils.	Eddy current testing shall be performed in accordance with ASTM E426. In-process testing shall be performed on the tubing mill. Final testing shall be performed on a separate off-mill testing line. Both the in-process and final testing shall be performed using high-and low-frequency coils.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
In-line sigma phase detection	Multiple techniques are used to demonstrate that detrimental levels of inter-metallic phase are not present. The method used for in-line detection of inter-metallic phases shall be calibrated and qualified using samples with a known level of such phases. The qualification shall include correlation with test results from corrosion tests, mechanical tests and metallographic examinations. The calibration and qualification procedures shall be subject to purchaser's approval.	Multiple techniques are used to demonstrate that detrimental levels of inter-metallic phase are not present. The method used for in-line detection of inter-metallic phases shall be calibrated and qualified using samples with a known level of such phases. The qualification shall include correlation with test results from corrosion tests, mechanical tests and metallographic examinations. The calibration and qualification procedures shall be subject to purchaser's approval.	Multiple techniques are used to demonstrate that detrimental levels of inter-metallic phase are not present. The method used for in-line detection of inter-metallic phases shall be calibrated and qualified using samples with a known level of such phases. The qualification shall include correlation with test results from corrosion tests, mechanical tests and metallographic examinations. The calibration and qualification procedures shall be subject to purchaser's approval.	N/A	N/A
Ultrasonic examination	Calibration shall be performed in accordance with ASTM A1016/A1016M and each tube shall be 100 % examined circumferentially and axially according to ASTM E213. Notch examination shall include both inside and outside of the tube. The reference standard for calibration shall have at least four artificial U-, V- or square-shaped defects (notches). There shall be a longitudinal and a transversal notch on both internal and external tube surface.	Calibration shall be performed in accordance with ASTM A1016/A1016M and each tube shall be 100 % examined circumferentially and axially according to ASTM E213. Notch examination shall include both inside and outside of the tube. The reference standard for calibration shall have at least four artificial U-, V- or square-shaped defects (notches). There shall be a longitudinal and a transversal notch on both internal and external tube surface.	In-process UT of the longitudinal seam weld shall be performed in accordance with ASTM A1016/A1016M and ASTM E273. In-process UT shall be performed on the tubing mill. Final UT shall consist of full volumetric examination of the entire tubing circumference in accordance with ASTM A1016/A1016M, ASTM E213, and ASTM E1001. Final UT may be performed on the tubing mill or on a separate off-mill testing line. If final UT is performed on the tubing mill, in-process UT is not required. The final UT shall be performed using both shear-wave and longitudinal-wave transducers. The longitudinal-wave transducers shall be used to detect base metal defects and to verify achievement of the minimum wall thickness.	In-process UT of the longitudinal seam weld shall be performed in accordance with ASTM A1016/ A1016M-04a, paragraph 25, and ASTM E273. In-process UT shall be performed on the tubing mill. Final UT shall consist of full volumetric examination of the entire tubing circumference in accordance with ASTM A1016/ A1016M-04a, paragraph 25, ASTM E213 and ASTM E1001. Final UT may be performed on the tubing mill or on a separate off-mill testing line. If final UT is performed on the tubing mill, in-process UT is not required. The final UT shall be performed using both shear-wave and longitudinal-wave transducers. The longitudinal-wave transducers shall be used to detect base metal defects and to verify achievement of the minimum wall thickness.	N/A

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
X-Ray examination of strip splice and orbital welds	N/A	X-ray examination shall be performed on all orbital welds (OW). The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively. A minimum of either three straight shots at 60° apart or two elliptical shots shall be taken for all orbital welds. Any relevant indication in the orbital weld is cause for rejection and the weld shall be removed Repair of orbital welds is not allowed. Any OW with relevant indications shall be removed and replaced with an orbital weld. A log of all rejected welds shall be maintained.	X-ray examination shall be performed on all orbital welds (OW). The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively. A minimum of either three straight shots at 60° apart or two elliptical shots shall be taken for all orbital welds. Any relevant indication in the orbital weld is cause for rejection and the weld shall be removed Repair of orbital welds is not allowed. Any OW with relevant indications shall be removed and replaced with an orbital weld. A log of all rejected welds shall be maintained. Repair of the longitudinal seam welded is not allowed.	X-ray examination shall be performed on all orbital welds (OW). The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively. A minimum of either three straight shots at 60° apart or two elliptical shots shall be taken for all orbital welds. Any relevant indication in the orbital weld is cause for rejection and the weld shall be removed Repair of orbital welds is not allowed. Any OW with relevant indications shall be removed and replaced with an orbital weld. A log of all rejected welds shall be maintained. Repair of the longitudinal seam welded is not allowed.	X-ray examination shall be performed on all orbital welds (OW). The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively. A minimum of either three straight shots at 60° apart or two elliptical shots shall be taken for all orbital welds. Any relevant indication in the orbital weld is cause for rejection and the weld shall be removed Repair of orbital welds is not allowed. Any OW with relevant indications shall be removed and replaced with an orbital weld. A log of all rejected welds shall be maintained. Repair of the longitudinal seam welded is not allowed.
FAT	N/A	A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel. The tubing shall be pressurized to a minimum of 1,5 times the DWP and held for 4 h minimum. Reels shall be tested indoors with dry paper beneath them. Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.	A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel. The tubing shall be pressurized to a minimum of 1,5 times the DWP and held for 4 h minimum. Reels shall be tested indoors with dry paper beneath them. Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.	A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel. The tubing shall be pressurized to a minimum of 1,5 times the DWP and held for 4 h minimum. Reels shall be tested indoors with dry paper beneath them. Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.	A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel. The tubing shall be pressurized to a minimum of 1,5 times the DWP and held for 4 h minimum. Reels shall be tested indoors with dry paper beneath them. Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.
Marking	All tubes shall have equi-spaced markings at an interval of 0,5 m. The marking shall include supplier, grade, UNS number, OD, WT, heat number, lot number and tube number.	All tubes shall have equi-spaced markings at an interval of 0,5 m. The marking shall include supplier, grade, UNS number, OD, WT, heat number, lot number and tube number.	The tubing shall be marked welded tubing with the tubing supplier's name, and order number; ASTM specification number; material grade; heat number; nominal dimensions (outside diameter, wall thickness and inside diameter); and day and date of manufacture as specified in ASTM A789/A789M.	The tubing shall be marked welded tubing with the tubing supplier's name, and order number; ASTM specification number; material grade; heat number; nominal dimensions (outside diameter, wall thickness and inside diameter); and day and date of manu-facture as specified in ASTM A789/A789M.	The tubing shall be marked welded tubing with the tubing supplier's name, and order number; ASTM specification number; material grade; heat number; nominal dimensions (outside diameter, wall thickness and inside diameter); and day and date of manufacture as specified in ASTM A789/A789M.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Visual inspection	Surface discontinuities may be removed by grinding. The remaining tube dimensions shall nevertheless be within the limits given in ASTM A789/A789M. Any depression formed during grinding shall be blended smoothly into the adjacent area. Any repaired area shall be subjected to the following testing: — ultrasonic wall thickness measurement; — outer diameter measurement. All tubes shall be checked for correct marking. A positive material identification (PMI) shall be performed on each tube.	Surface discontinuities may be removed by grinding. The remaining tube dimensions shall nevertheless be within the limits given in ASTM A789/A789M. Any depression formed during grinding shall be blended smoothly into the adjacent area. Any repaired area shall be subjected to the following testing: — ultrasonic wall thickness measurement; — outer diameter measurement. All tubes shall be checked for correct marking. A positive material identification (PMI) shall be performed on each tube. Dimensional and visual examination of all orbital welds shall be performed after removal of excess filler metal, but before x-ray examination is performed. The outside diameter of orbital welds shall be measured to verify compliance with the permissible variations in nominal outside diameter as per the manufacturer's specification. The outside surface of all orbital welds shall be visually examined to verify that a smooth, curved surface is maintained in accordance with the requirements of ASTM A789/A789M.	Surface discontinuities may be removed by grinding. The remaining tube dimensions shall nevertheless be within the limits given in ASTM A789/A789M. Any depression formed during grinding shall be blended smoothly into the adjacent area. Any repaired area shall be subjected to the following testing: — ultrasonic wall thickness measurement — outer diameter measurement. All tubes shall be checked for correct marking. A positive material identification (PMI) shall be performed on each tube. Dimensional and visual examination of all orbital welds shall be performed after removal of excess filler metal, but before x-ray examination is performed. The outside diameter of orbital welds shall be measured to verify compliance with the permissible variations in nominal outside diameter as per the manufacturer's specification. The outside surface of all orbital welds shall be visually examined to verify that a smooth, curved surface is maintained in accordance with the requirements of ASTM A1016/ A1016M-04a, paragraph 13.	Surface discontinuities may be removed by grinding. The remaining tube dimensions shall nevertheless be within the limits given in ASTM A789/A789M. Any depression formed during grinding shall be blended smoothly into the adjacent area. Any repaired area shall be subjected to the following testing: — ultrasonic wall thickness measurement; — outer diameter measurement. All tubes shall be checked for correct marking. A positive material identification (PMI) shall be performed on each tube. Dimensional and visual examination of all orbital welds shall be performed after removal of excess filler metal, but before x-ray examination is performed. The outside diameter of orbital welds shall be measured to verify compliance with the permissible variations in nominal outside diameter as per the manufacturer's specification. The outside surface of all orbital welds shall be visually examined to verify that a smooth, curved surface is maintained in accordance with the requirements of ASTM A1016/ A1016M-04a, paragraph 13.	Surface discontinuities may be removed by grinding. The remaining tube dimensions shall nevertheless be within the limits given in ASTM A789/A789M. Any depression formed during grinding shall be blended smoothly into the adjacent area. Any repaired area shall be subjected to the following testing: — ultrasonic wall thickness measurement; — outer diameter measurement. All tubes shall be checked for correct marking. A positive material identification (PMI) shall be performed on each tube. Dimensional and visual examination of all orbital welds shall be performed after removal of excess filler metal, but before x-ray examination is performed. The outside diameter of orbital welds shall be measured to verify compliance with the permissible variations in nominal outside diameter as per the manufacturer's specification. The outside surface of all orbital welds shall be visually examined to verify that a smooth, curved surface is maintained in accordance with the requirements of ASTM A1016/ A1016M-04a, paragraph 13.
General	The tube manufacturer is required to establish specifications for controlling each process during tube manufacturing.	The tube manufacturer is required to establish specifications for controlling each process during tube manufacturing.	The tube manufacturer is required to establish specifications for controlling each process during tube manufacturing.	The tube manufacturer is required to establish specifications for controlling each process during tube manufacturing.	The tube manufacturer is required to establish specifications for controlling each process during tube manufacturing.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Delivery	The tubes shall be packed in such a way that the material is received in an undamaged condition and in accordance with this specification. The packing method shall be suitable for long-term outdoor storage and in accordance with the manufacturer's written specification.	The tubing shall be spooled and level-wound onto metal utility cable reels as specified by the purchaser. Back tension shall be applied during the spooling operation. No gaps in the level winding are allowed. All inadvertent gaps shall be filled. The tubing ends shall be accessible. The reel drum and flanges shall be fitted with a protective barrier (card board, plastic layer or wood) to avoid direct contact between the tubing and the metal reel. The reel drum diameter shall be such that the bending strain on the reeled tubing does not exceed 2 %. Reference is made to 7.5.2.8.	The tubing shall be spooled and level wound onto metal utility cable reels as specified by the purchaser. Back tension shall be applied during the spooling operation. No gaps in the level winding are allowed. All inadvertent gaps shall be filled. The tubing ends shall be accessible. The reel drum and flanges shall be fitted with a protective barrier (card board, plastic layer or wood) to avoid direct contact between the tubing and the metal reel. The reel drum diameter shall be such that the bending strain on the reeled tubing does not exceed 2 %. Reference is made to 7.5.2.8.	The tubing shall be spooled and level wound onto metal utility cable reels as specified by the purchaser. Back tension shall be applied during the spooling operation. No gaps in the level winding are allowed. All inadvertent gaps shall be filled. The tubing ends shall be accessible. The reel drum and flanges shall be fitted with a protective barrier (card board, plastic layer or wood) to avoid direct contact between the tubing and the metal reel. The reel drum diameter shall be such that the bending strain on the reeled tubing does not exceed 2 %. Reference is made to 7.5.2.8.	The tubing shall be spooled and level wound onto metal utility cable reels as specified by the purchaser. Back tension shall be applied during the spooling operation. No gaps in the level winding are allowed. All inadvertent gaps shall be filled. The tubing ends shall be accessible. The reel drum and flanges shall be fitted with a protective barrier (card board, plastic layer or wood) to avoid direct contact between the tubing and the metal reel. The reel drum diameter shall be such that the bending strain on the reeled tubing does not exceed 2 %. Reference is made to 7.5.2.8.

Table H.1 (*continued*)

Characteristic	Requirement description/reference				
	Seamless 25Cr super duplex straight lengths	**Seamless 25Cr super duplex coils**	**Seam welded 25Cr super duplex coils**	**Seam welded lean duplex coils**	**Seam welded austenitic coils (316L stainless steel)**
Heat treatment	Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, it is necessary to build a strong emphasis into the process control. A verification check of the heat treatment process shall be performed by the use of a thermocouple inside a tube. If the recorded annealing temperatures or cooling time are outside the manufacturer's written specification, the tubes heat-treated after the last accepted verification shall be subject to a non-conformance report. The frequency of such verification shall be in accordance with the manufacturer's written specifications. The process shall be qualified within the tolerances set for the important process parameters. These parameters are typically annealing- and cooling-zone temperatures or inlet and outlet temperatures in the cooling medium, speed of the tubes throughout the heat-treatment process and the number of tubes in the process. These parameters shall be measured and recorded continuously during the entire process. Repeating the heat treatment process is acceptable as long as the re-heat-treated tubes are considered as a separate lot.	Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, it is necessary to a build strong emphasis into the process control. A verification check of the heat-treatment process shall be performed by the use of a thermocouple inside a tube. If the recorded annealing temperatures or cooling time are outside the manufacturer's written specification, the tubes heat treated after the last accepted verification shall be subject to a non-conformance report. The frequency of such verification shall be in accordance with the manufacturer's written specifications. The process shall be qualified within the tolerances set for the important process parameters. These parameters are typically annealing- and cooling-zone temperatures or inlet and outlet temperatures in the cooling medium, speed of the tubes throughout the heat-treatment process and number of tubes in the process. These parameters shall be measured and recorded continuously during the entire process. Repeating the heat treatment process is acceptable as long as the re-heat treated tubes are considered as a separate lot.	Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, it is necessary to build a strong emphasis into the process control. Continuous monitoring/ recording of heat-treatment conditions and testing of the strip shall be performed by the strip supplier to ensure that the strip is free of detrimental levels of inter-metallic phases. Heat treatment of the strip splice and longitudinal seam welds is performed using equipment to record the tubing travel speed and temperature versus time. The equipment shall be calibrated to a standard traceable to the National Institute of Standards and Technology (NIST). A chart documenting the time-temperature-speed history shall be recorded for each mill tubing coil. The strip splice weld and the longitudinal seam weld shall be heat treated with a non-oxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.	Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity an, as such, it is necessary to build a strong emphasis into the process control. Heat treatment shall comply with ASTM A789/A789M unless otherwise agreed to between the supplier and purchaser. This is not a concern because lean duplex is not expected to form detrimental levels of inter-metallic phases under the heat-treatment time and temperature conditions encountered during manufacturing. It is not necessary to monitor the strip, strip-splice weld (if autogenous), longitudinal seam weld or orbital weld (if autogenous) for the presence of detrimental levels of an inter-metallic phase because it is not expected to form under the heat-treatment time and temperature conditions encountered during manufacturing. The strip-splice weld and the longitudinal seam weld shall be heat-treated with a non-oxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.	Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, it is necessary to build a strong emphasis into the process control. The strip-splice weld and the longitudinal seam weld shall be heat treated with a non-oxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.
Certification	A material test certificate shall accompany each delivery to minimum requirements as specified in EN 10204:2004, 3.1, stating the quantity, type of material and all test results in accordance with this part of ISO 13628.	A material test certificate shall accompany each delivery to minimum requirements as specified in EN 10204:2004, 3.1, stating the quantity, type of material and all test results in accordance with this part of ISO 13628.	The tubing supplier shall furnish a certificate of compliance that the material has been manufactured and tested in accordance with the requirements of the manufacturer's specification.	The tubing supplier shall furnish a certificate of compliance that the material has been manufactured and tested in accordance with the requirements of the manufacturer's specification.	The tubing supplier shall furnish a certificate of compliance that the material has been manufactured and tested in accordance with the requirements of the manufacturer's specification.

Annex I
(informative)

Tube-wall thickness example calculation

I.1 General

This annex presents a "simplified" tube-wall thickness calculation, based on the design methodology described in Clause 7. The calculations are given in SI units in I.2 and in USC units in I.3.

The following assumptions are made.

a) The tube is in static application only, no dynamic amplification is considered.

b) No shear stresses are considered.

c) No bending stresses are considered.

d) No contact stresses are considered.

e) No tolerances are considered; nominal dimensions are used.

f) The tube is suspended in sea water.

g) The tube is vertically suspended.

h) The tube is sea-water filled.

I.2 SI units

I.2.1 Input details

The following values are used:

— design working pressure: $p_{DW} = 68{,}95$ MPa

— tube outer diameter: $D = 14{,}9$ mm

— tube-wall thickness: $t = 1{,}0$ mm

— design water depth: $d_w = 2\,000$ m

— density of tube: $\rho_t = 7\,840$ kg/m^3

— density of seawater: $\rho_w = 1\,025$ kg/m^3

— yield stress of tube (0,2 % proof): $f_y = 670$ MPa

— yield stress utilization factor: $\eta = 0{,}96$

— pressure test factor: $F_{PT} = 1{,}5$

I.2.2 Design calculation

Calculate the maximum design pressure, p_i, as given in Equation (I.1):

$$\begin{aligned} p_i &= F_{PT} \times p_{DW} \\ &= 103,421 \text{ MPa} \end{aligned} \tag{I.1}$$

Calculate the external pressure, p_e, at design water depth, d_w, as given in Equation (I.2):

$$\begin{aligned} p_e &= \rho_w \times g \times d_w \\ &= 20,104 \text{ MPa} \end{aligned} \tag{I.2}$$

NOTE The maximum working pressure considers the umbilical tube subjected to a positive internal pressure in a closed system.

Calculate the hoop stress, σ_{hi}, on the tube inner wall due to design pressure as given in Equation (I.3):

$$\begin{aligned} \sigma_{hi} &= \frac{p_i \times \left[D^2 + (D - 2t)^2 \right] - p_e \times 2D^2}{D^2 - (D - 2t)^2} \\ &= 561,952 \text{ MPa} \end{aligned} \tag{I.3}$$

Calculate the hoop stress, σ_{he}, on the tube outer wall due to design pressure and design water depth as given in Equation (I.4):

$$\begin{aligned} \sigma_{he} &= \frac{p_i \times 2 \times (D - 2t)^2 - p_e \times \left[D^2 + (D - 2t)^2 \right]}{D^2 - (D - 2t)^2} \\ &= 478,634 \text{ MPa} \end{aligned} \tag{I.4}$$

Calculate the radial stress, σ_{ri}, on tube inside wall due to maximum design pressure as given in Equation (I.5):

$$\begin{aligned} \sigma_{ri} &= -p_i \\ &= 103,421 \text{ MPa} \end{aligned} \tag{I.5}$$

Calculate the radial stress, σ_{re}, on the tube outer wall due to design pressure and design water depth as given in Equation (I.6):

$$\begin{aligned} \sigma_{re} &= -p_e \\ &= -20,104 \text{ MPa} \end{aligned} \tag{I.6}$$

NOTE The axial stress in the tube varies with water depth, internal pressure and umbilical configuration. It is necessary that this be taken into account when analysing the stresses in the tube wall at various locations along the umbilical configuration.

The axial stress, σ_a, is calculated as given in Equations (I.7) to (I.12) for a tube hang-off for a single suspended tube. No dynamic amplification is considered and no umbilical load share is considered.

Calculate the cross-sectional area, A, of the tube, with no lay configuration adjustment as given in Equation (I.6):

$$A = \frac{\pi}{4} \times \left[D^2 - (D - 2t)^2 \right] \\ = 43{,}668 \text{ mm}^2 \tag{I.7}$$

Calculate the self-weight, W, of the tube filled with seawater as given in Equation (I.8):

$$W = \frac{\rho_t \times A \times 1\,\text{m}}{1\,\text{m}} \times \left(1 - \frac{\rho_W}{\rho_t} \right) \\ = 2{,}92 \text{ N/m} \tag{I.8}$$

Calculate the maximum tube tension, T, at hang-off as given in Equation (I.9):

$$T = W \times d_w \times g \\ = 5{,}837 \text{ kN} \tag{I.9}$$

Calculate the tensile stress, σ_{at}, at hang-off due to tube self-weight as given in Equation (I.10):

$$\sigma_{at} = T/A \\ = 133{,}665 \text{ MPa} \tag{I.10}$$

Calculate the axial stress due to end cap load at design pressure as given in Equation (I.11):

$$\sigma_{aec} = p_i \times \frac{(D - 2t)^2}{D^2 - (D - 2t)^2} \\ = 309{,}539 \text{ MPa} \tag{I.11}$$

Calculate the equivalent Von Mises stress, σ_e (σ_h, σ_r, σ_a) as a function of hoop, radial, and axial stresses, as given in Equation (I.12):

$$\sigma_e(\sigma_h, \sigma_r, \sigma_a) = \sqrt{\frac{(\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_a)^2 + (\sigma_a - \sigma_h)^2}{2}} \tag{I.12}$$

I.2.3 Design check

I.2.3.1 As part of the simplified analysis, two locations are considered for the design check, the umbilical hang-off and the umbilical at maximum water depth.

I.2.3.2 Assumptions for the umbilical hang-off location are as follows.

a) Maximum umbilical tension is at hang-off location.

b) No bending is applied.

c) Torsional stresses are negligible.

d) External pressure is negligible.

Maximum hoop stress: $\sigma_h = \sigma_{hi}$

Maximum radial stress: $\sigma_{\text{r}} = \sigma_{\text{ri}}$

Maximum axial stress: $\sigma_{\text{a}} = \sigma_{\text{at}} + \sigma_{\text{aec}}$

Von Mises stress: $\sigma_{\text{e}}\left(\sigma_{\text{h}}, \sigma_{\text{r}}, \sigma_{\text{a}}\right) = 614{,}663\ \text{MPa}$

I.2.3.3 Assumptions for the maximum water depth location are as follows.

a) The umbilical tension at maximum water depth is zero.

b) No bending is applied.

c) Torsional stresses are negligible.

d) External pressure is maximum at maximum water depth.

Maximum hoop stress: $\sigma_{\text{h}} = \sigma_{\text{ho}}$.

Maximum radial stress: $\sigma_{\text{r}} = \sigma_{\text{re}}$.

Maximum axial stress: $\sigma_{\text{a}} = \sigma_{\text{aec}}$.

Von Mises stress: $\sigma_{\text{e}}\left(\sigma_{\text{h}}, \sigma_{\text{r}}, \sigma_{\text{a}}\right) = 439{,}316\ \text{MPa}$.

I.2.3.4 The umbilical tube shall satisfy the criterion that the utilization stress, σ_{ut}, shall be less than or equal to the maximum calculated Von Mises stress as given in Equation (I.13):

$$\begin{aligned}\sigma_{\text{ut}} &= \eta \times f_{\text{y}} \\ &= 643{,}2\ \text{MPa}\end{aligned} \tag{I.13}$$

If the maximum Von Mises stress is lower than the utilization stress, the wall thickness should be altered to the point where both stresses are equal.

NOTE This is an iterative process.

I.3 Calculations in USC units

I.3.1 Input details

The following values are used:

— design working pressure: $p_{\text{DW}} = 10\ 000\ \text{psi}$

— tube outer diameter: $D = 0{,}587\ \text{in}$

— tube-wall thickness: $t = 0{,}039\ \text{in}$

— design water depth: $d_{\text{w}} = 6\ 562\ \text{ft}$

— density of tube: $\rho_{\text{t}} = 489{,}435\ \text{lb/ft}^3$

— density of seawater: $\rho_{\text{w}} = 63{,}989\ \text{lb/ft}^3$

— yield stress of tube (0,2 % proof): $f_y = 97{,}175$ ksi

— yield stress utilization factor: $\eta = 0{,}96$

— pressure test factor: $F_{PT} = 1{,}5$

I.3.2 Design calculation

Calculate the maximum design pressure, p_i, as given in Equation (I.14):

$$\begin{aligned} p_i &= F_{PT} \times p_{DW} \\ &= 15 \text{ ksi} \end{aligned} \tag{I.14}$$

Calculate the external pressure, p_e, at design water depth, d_w, as given in Equation (I.15):

$$\begin{aligned} p_e &= \rho_w \times g \times d_w \\ &= 2{,}916 \text{ ksi} \end{aligned} \tag{I.15}$$

NOTE The maximum working pressure considers the umbilical tube subjected to a positive internal pressure in a closed system.

Calculate the hoop stress, σ_{hi}, on the tube inner wall due to design pressure as given in Equation (I.16):

$$\begin{aligned} \sigma_{hi} &= \frac{p_i \times \left[D^2 + (D - 2t)^2 \right] - p_e \times 2D^2}{D^2 - (D - 2t)^2} \\ &= 82{,}412 \text{ ksi} \end{aligned} \tag{I.16}$$

Calculate the hoop stress, σ_{he}, on the tube outer wall due to design pressure and design water depth as given in Equation (I.17):

$$\begin{aligned} \sigma_{he} &= \frac{p_i \times 2 \times (D - 2t)^2 - p_e \times \left[D^2 + (D - 2t)^2 \right]}{D^2 - (D - 2t)^2} \\ &= 70{,}328 \text{ ksi} \end{aligned} \tag{I.17}$$

Calculate the radial stress, σ_{ri}, on the tube inside wall due to maximum design pressure as given in Equation (I.18):

$$\begin{aligned} \sigma_{ri} &= -p_i \\ &= -15 \text{ ksi} \end{aligned} \tag{I.18}$$

Calculate the radial stress, σ_{re}, on the tube outer wall due to design pressure and design water depth as given in Equation (I.19):

$$\begin{aligned} \sigma_{re} &= -p_e \\ &= -2{,}916 \text{ ksi} \end{aligned} \tag{I.19}$$

NOTE The axial stress in the tube varies with water depth, internal pressure and umbilical configuration. It is necessary that this be taken into account when analysing the stresses in the tube wall at various locations along the umbilical configuration.

The axial stress, σ_a, is calculated as given in Equations (I.20) to (I.25) for a tube hang-off for a single suspended tube. No dynamic amplification is considered and no umbilical load share is considered.

Calculate the cross-sectional area, A, of the tube, with no lay configuration adjustment as given in Equation (I.20):

$$A = \frac{\pi}{4} \times \left[D^2 - (D - 2t)^2 \right] = 0{,}067 \text{ in}^2 \quad \text{(I.20)}$$

Calculate the self-weight, W, of the tube filled with seawater as given in Equation (I.21):

$$W = \frac{\rho_t \times A \times 1 \text{ ft}}{1 \text{ ft}} \left(1 - \frac{\rho_w}{\rho_t} \right) = 0{,}198 \text{ lb/ft} \quad \text{(I.21)}$$

Calculate the maximum tube tension, T, at hang-off as given in Equation (I.21):

$$T = W \times d_w \times g = 1{,}302 \text{ kip} \quad \text{(I.22)}$$

Calculate the tensile stress, σ_{at}, at hang-off due to the tube self-weight as given in Equation (I.23):

$$\sigma_{at} = T/A = 19{,}387 \text{ ksi} \quad \text{(I.23)}$$

Calculate the stress due to end cap load at design pressure:

$$\sigma_{aec} = p_i \times \frac{(D - 2t)^2}{D^2 - (D - 2t)^2} = 45{,}459 \text{ ksi} \quad \text{(I.24)}$$

Calculate the maximum equivalent Von Mises stress, σ_e (σ_h, σ_r, σ_a), as a function of hoop, radial, and axial stresses as given in Equation (I.25):

$$\sigma_e(\sigma_h, \sigma_r, \sigma_a) = \sqrt{\frac{(\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_a)^2 + (\sigma_a - \sigma_h)^2}{2}} \quad \text{(I.25)}$$

I.3.3 Design check

I.3.3.1 As part of the simplified analysis, two locations are considered for the design check, the umbilical hang-off and the umbilical at maximum water depth.

I.3.3.2 Assumptions for the umbilical hang-off location are as follows.

a) Maximum umbilical tension is at hang-off location.

b) No bending applied.

c) Torsional stresses are negligible.

d) External pressure is negligible.

Maximum hoop stress: $\sigma_{h} = \sigma_{hi}$

Maximum radial stress: $\sigma_{r} = \sigma_{ri}$

Maximum axial stress: $\sigma_{a} = \sigma_{at} + \sigma_{aec}$

Von Mises stress: $\sigma_{e}\left(\sigma_{h}, \sigma_{r}, \sigma_{a}\right) = 89{,}925 \text{ ksi}$

I.3.3.3 Assumptions for the maximum water depth location are as follows.

a) The umbilical tension at maximum water depth is zero.

b) No bending is applied.

c) Torsional stresses are negligible.

d) External pressure is maximum at maximum water depth.

Maximum hoop stress: $\sigma_{h} = \sigma_{ho}$.

Maximum radial stress: $\sigma_{r} = \sigma_{re}$.

Maximum axial stress: $\sigma_{a} = \sigma_{aec}$.

Von Mises stress: $\sigma_{e}\left(\sigma_{h}, \sigma_{r}, \sigma_{a}\right) = 64{,}511 \text{ ksi}$.

I.3.3.4 The umbilical tube shall satisfy the criterion that the utilization stress, σ_{ut}, shall be less than or equal to the maximum calculated Von Mises stress as given in Equation (I.26):

$$\begin{aligned}\sigma_{ut} &= \eta \times f_{y} \\ &= 93{,}288 \text{ ksi}\end{aligned} \quad \text{(I.26)}$$

If the maximum Von Mises stress is lower than the utilization stress, the wall thickness should be altered to the point where both stresses are equal.

NOTE This is an iterative process.

Annex J
(informative)

Buckling of metallic tubes

J.1 Displacement controlled bending

In order to avoid buckling, individual umbilical tubes (prior to assembly) may be bent to a maximum bending strain, ε_d, as given in Equation (J.1), provided that the bending curvature is limited by a well-defined geometric constraint and the tube is not subjected to an axial compressive force, pressure or dynamic load:

$$\varepsilon_d \leqslant \eta_\varepsilon \times \varepsilon_c \quad \text{(J.1)}$$

where

η_ε is the utilization factor, see Table J.1;

ε_c is the characteristic strain capacity, equal to $\frac{t_2}{2 \times D}$;

where

D is the nominal outer diameter;

t_2 is the wall thickness from Table 7.

Table J.1 — Utilization factors

Condition	η_ε
Manufacture	0,70

Be aware that the utilization factor in Table J.1 is not specifically validated for umbilical tubes.

The strain cycles imposed in the reeling, handling and installation shall be checked against the materials' fatigue properties.

A certain back tension is required in order to give the tube a firm support against the reel drum.

Reference is made to low-cycle fatigue testing in 7.5.8.4.

J.2 Collapse

The criterion for p_e, the external pressure, as expressed in Equation (J.2), may be used to avoid collapse due to net external pressure:

$$p_e - p_{min} \leqslant \eta_c \times p_c \quad \text{(J.2)}$$

where

p_{min} is the minimum internal pressure that is continuously sustained;

η_c is the utilization factor, see Table J.2;

p_c is the collapse capacity, equal to $\dfrac{p_p \times p_{el}}{\sqrt{p_p^2 + p_{el}^2}} \times g$;

where

p_{el} is the elastic collapse capacity, equal to $\dfrac{2 \times E}{1-\nu^2} \times \left(\dfrac{t_2}{D}\right)^3$;

p_{pl} is the plastic collapse capacity, equal to $\sigma_{SMY} \times \dfrac{2 \times t_2}{D}$

where σ_{SMY} is the specified minimum yield stress;

$$g = \sqrt{\frac{1 + \left(p_p / p_{el}\right)^2}{O^{-2} + \left(p_p / p_{el}\right)^2}} \text{; where } O = \sqrt{1 + \left(0{,}5 \times f_O \times D/t_2\right)^2} - 0{,}5 \times f_O \times D/t_2$$

where

D is the nominal outer diameter;

t_2 is the wall thickness from Table 7;

f_O is the ovality from manufacturing and installation, equal to $\dfrac{D_{max} - D_{min}}{D}$; the minimum value for the ovality is 0,005, however, the measured or calculated ovality value should be used, if available.

E is Young's modulus;

ν is Poisson's ratio.

Table J.2 — Utilization factors

Condition	η_c
Normal operation	0,62
Installation	0,75

Be aware that the utilization factors in Table J.2 have not been specifically validated for umbilical tubes.

It is assumed that temperature derating is insignificant and that the tubes are fully annealed to remove any effects from cold working during manufacturing. Otherwise, the value of SMYS should be reduced accordingly.

J.3 Propagating buckling

The condition in Equation (J.3) may be used to avoid propagating a buckle:

$$p_e - p_{min} \leqslant \eta_c \times p_{pr} \quad (J.3)$$

where

p_e is the external pressure;

p_{min} is the minimum internal pressure that is continuously sustained;

η_c is the utilization factor, see Table J.2;

p_{pr} is the characteristic propagation buckling strength, equal to $24 \times \sigma_{SMY} \times \left(\frac{t_2}{D}\right)^{2,4}$;

where

D is the nominal outer diameter;

t_2 is the wall thickness from Table 7.

It is assumed that temperature derating is insignificant and that the tubes are fully annealed to remove any effects from cold working during manufacturing. Otherwise the value of SMYS should be reduced accordingly.

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