

Specification for Subsea Umbilicals

API SPECIFICATION 17E
FIFTH EDITION, JULY 2017

EFFECTIVE DATE: JANUARY 15, 2018



AMERICAN PETROLEUM INSTITUTE

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Foreword

This standard was developed as an API recommended practice under the jurisdiction of the API Upstream Segment Executive Committee on Drilling and Production Operations.

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This is the Fifth Edition.

API Subcommittee 17 documents consist of the following:

- Recommended Practice 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*
- Recommended Practice 17B, *Recommended Practice for Flexible Pipe*
- Specification 17D, *Specification for Subsea Wellhead and Christmas Tree Equipment*
- Specification 17E, *Specification for Subsea Umbilicals*
- Standard 17F, *Specification for Subsea Production Control Systems*
- Recommended Practice 17G, *Recommended Practice for Completion/Workover Riser Systems*
- Recommended Practice 17H, *Remotely Operated Tools and Interfaces on Subsea Production Systems*
- Specification 17J, *Specification for Unbonded Flexible Pipe*
- Specification 17K, *Specification for Bonded Flexible Pipe*
- Specification 17L1, *Specification for Flexible Pipe Ancillary Equipment*
- Recommended Practice 17L2, *Recommended Practice for Flexible Pipe Ancillary Equipment*
- Recommended Practice 17N, *Recommended Practice for Subsea Production System Reliability and Technical Risk Management*
- Standard 17O, *Standard for Subsea High Integrity Pressure Protection Systems (HIPPS)*
- Recommended Practice 17P, *Design and Operation of Subsea Production Systems—Subsea Structures and Manifolds*
- Recommended Practice 17Q, *Recommended Practice for Subsea Equipment Qualification—Standardized Process for Documentation*
- Recommended Practice 17R, *Recommended Practice for Flowline Connectors and Jumpers*

- Recommended Practice 17S, *Recommended Practice for Design, Testing and Operation of Subsea Multiphase Flow Meters*
- Recommended Practice 17U, *Recommended Practice for Wet and Dry Thermal Insulation of Subsea Flowlines and Equipment*
- Recommended Practice 17V, *Recommended Practice for Subsea Safety*
- Recommended Practice 17W, *Recommended Practice for Subsea Capping Stacks*
- TR 17TR1, *Evaluation Standard for Internal Pressure Sheath Polymers for High Temperature Flexible Pipes*
- TR 17TR2, *The Ageing of PA-11 in Flexible Pipes*
- TR 17TR3, *An Evaluation of the Risks and Benefits of Penetrations in Subsea Wellheads Below the BOP Stack*
- TR 17TR4, *Subsea Equipment Pressure Ratings*
- TR 17TR5, *Avoidance of Blockages in Subsea Production Control and Chemical Injection Systems*
- TR 17TR6, *Attributes of Production Chemicals in Subsea Production Systems*
- TR 17TR8, *High-pressure High-temperature Design Guidelines*
- TR 17TR10, *Subsea Umbilical Termination (SUT) Design Recommendations*
- TR 17TR11, *Pressure Effects on Subsea Hardware during Flowline Pressure Testing in Deep Water*
- TR 17TR12, *Consideration of External Pressure in the Design and Pressure Rating of Subsea Equipment*

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalogue of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards

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Introduction

This document is based on API Specification 17E, Fourth Edition, which superseded previous versions of API 17E and API RP 17I, First Edition.

It is important that users of this document be aware that further or differing requirements can be needed for individual applications. This document 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 document and provide details.

Within this document, "shall" is used to state that a provision is mandatory; "should" is used to state that a provision is not mandatory, but is recommended as good practice; and "may" is used to state that a provision is optional.

Système International (SI) units are identified first when cited in the document. United States Customary (USC) units may be given in parentheses after the SI units.

Specification for Subsea Umbilicals

1 Scope

This document 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 document applies to umbilicals containing components, such as electrical cables, optical fibers, thermoplastic hoses, and metallic tubes, either alone or in combination.

This document applies to umbilicals for static or dynamic service, with surface–surface, surface–subsea, and subsea–subsea routings.

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

This document applies only to tubes with the following dimensions:

- wall thickness, $t < 6$ mm (0.2 in.);
- internal diameter, ID < 50.8 mm (2 in.).

NOTE Tubular products with dimensions greater than these can be regarded as pipeline/line pipe, and therefore designed and manufactured according to a recognized pipeline/line pipe standard.

This document does not apply to a tube or hose rated lower than 7 MPa (1015 psi).

This document applies to electrical cables for rated voltages from 1kV ($U_m = 1.2$ kV) up to 30kV ($U_m = 36$ kV).

If a product is supplied bearing the API Monogram and manufactured at a facility licensed by API, the requirements of Annex A apply.

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.

API RP 17H, *Remotely Operated Tools and Interfaces on Subsea Production Systems*

ASTM A240/A240M, *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/A480M, *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 and Knoop Hardness of Metallic Materials*

ASTM E213, *Standard Practice for Ultrasonic Testing of Metal Pipe and Tubing*

ASTM E273, *Standard Practice for Ultrasonic Testing 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 G48-11, *Standard Test Methods for Pitting And Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferritic Chloride Solution*

DNV-OS-H205, *Lifting Operations (VMO Standard—Part 2–5)*

DNV-RP-B401, *Cathodic Protection Design*

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

IEC S-97-682, *Standard for Utility Shielded Power Cables Rated 5 Through 46 kV*

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 fibers — Part 1-1: Measurement methods and test procedures — General and guidance*

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

IEC 60794-1-21, *Optical fiber cables - Part 1-21: Generic specification — Basic optical cable test procedures — Mechanical test methods*

IEC 62230, *Electric cables — Spark-test method*

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

ISO 10619-2:2011, *Rubber and plastics hoses and tubing — Measurement of flexibility and stiffness — Part 2: Bending tests at sub-ambient temperatures*

ITU-T G.652, *Characteristics of a single-mode optical fibre cable*

ITU-T G.654, *Characteristics of a cut-off shifted single-mode optical fibre cable*

ITU-T G.976, *Test methods applicable to optical fiber 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

accidental load

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

3.1.2

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 centerline 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.

NOTE 3 Increasing the level of safety generally increases the allowable bend radius and decreases the allowable tensile load, i.e. moves the capacity curves toward origin.

NOTE 4 Increasing the internal pressure generally increases the allowable bend radius and decreases the allowable tensile load, i.e. moves the capacity curves toward origin.

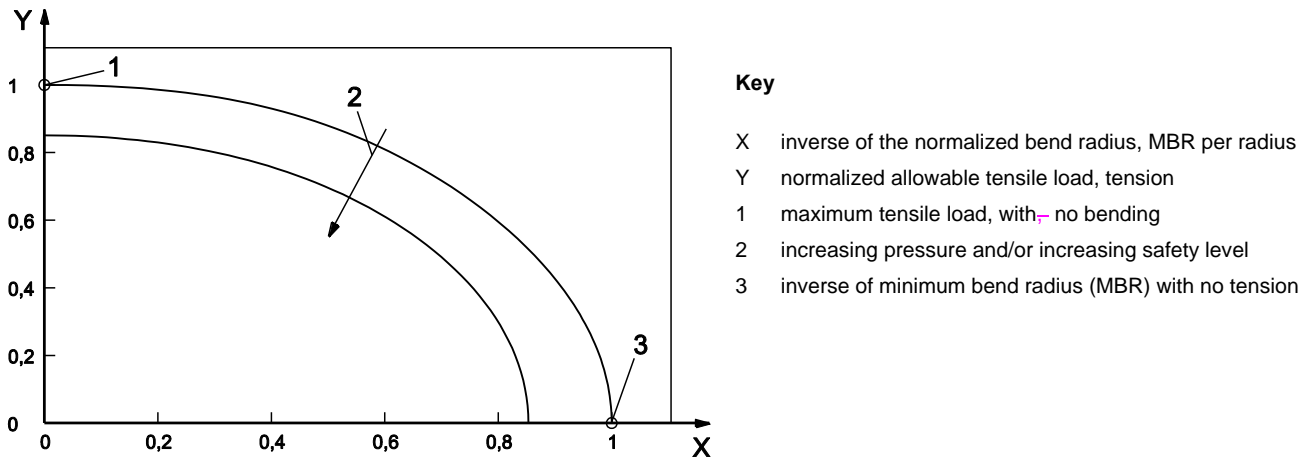


Figure 1—Capacity Curves

3.1.3 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 varies depending on internal pressure and condition, i.e. safety level.

3.1.4 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.

3.1.5 bend restrictor

Device for limiting the bend radius of the umbilical by mechanical means.

NOTE 1 A bend restrictor typically is comprised of a series of interlocking metallic or molded rings, applied over the umbilical.

NOTE 2 It is sometimes referred to as a bend limiter.

3.1.6 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 molded device, sometimes reinforced, depending on the required duty, applied over the umbilical. It is sometimes referred to as a bend strain reliever (BSR).

3.1.7 bird-caging

Phenomenon whereby armor wires locally rearrange with an increase and/or decrease in pitch-circle diameter as a result of accumulated axial and radial stresses in the armor layer(s).

3.1.8 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 fiber cables.

3.1.9 capacity curve

Curve that defines the relationship between the allowable curvature and allowable tension for an internal pressure condition.

See Figure 1.

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

3.1.10 carousel

Storage container that can be rotated by a drive about a vertical axis.

3.1.11 caterpillar

Device that holds the umbilical between belts or pads and that transfers axial linear motive power to the umbilical.

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

3.1.12 characterization data

Data relating to a component or an umbilical giving an indication of performance but not giving specific acceptance/rejection criteria.

3.1.13 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.

3.1.14 core

Generic term used to describe an individual electrically insulated conductor.

3.1.15 crab lay

Installation deployment activity whereby the installation vessel moves sideways along, or at the end of, the installation route.

3.1.16 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.

3.1.17 deep water

Water depth generally ranging from 610 m (2000 ft) to 1830 m (6000 ft).

3.1.18 design life

Service life multiplied by an appropriate factor that is equal to, or greater than, one.

3.1.19
design pressure
DP

Maximum pressure at which a hose or tube is rated.

3.1.20
design tensile load

Maximum tensile load multiplied by an appropriate factor that is equal to, or less than, one.

3.1.21
dynamic analysis

Analysis of an umbilical system that will be subject to dynamic excitation during installation or operation to ensure that the system is designed, installed, and operated safely and reliably.

3.1.22
dynamic application

Time-dependent excitation applied while in service.

3.1.23
end termination

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

3.1.24
environmental load

Load induced by external forces caused directly or indirectly by all environmental parameters acting on the umbilical, including those induced by waves, currents, winds, and vessel motion.

3.1.25
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.

3.1.26
filler

Item wholly or partially filling the voids between the **functional components** (3.1.27) 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.

3.1.27
functional component

Hoses, tubes, and electric/optical fiber cables included within an umbilical that are required to fulfill the operational service needs.

3.1.28
functional load

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.

3.1.29
functional specification

Document that specifies the features, characteristics, process conditions, boundaries, and exclusions defining the performance of a product or service, including quality assurance requirements.

3.1.30**high collapse resistance hose
HCR hose**

Type of thermoplastic hose that contains a feature that enables it to resist collapse at greater water depths than a thermoplastic hose of equivalent bore and pressure rating.

3.1.31**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.

3.1.32**hydrogen scavenger**

Gel material applied inside the tube (metal or polymer) holding the optical fiber to absorb hydrogen ions that prevent the fiber from “darkening” and from reducing transmission capabilities.

3.1.33**lay-up**

Operation of helically assembling (SZ where appropriate) electrical cores or optical fibers into a cable, or hoses, tubes, electric cables, and optical fiber cables, into a bundle or sub-bundle.

NOTE Sometimes referred to as “cabling.”

3.1.34**lay angle**

Angle between the axis of a spiral-wound element (e.g. armor wires) and a line parallel to the longitudinal axis of the umbilical.

3.1.35**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.

3.1.36**low-voltage (LV) cable**

Electrical cable with extruded solid insulation for rated voltages up to 1.8/3 (3.6) kV (AC) for use in subsea umbilical applications.

3.1.37**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 document

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

3.1.38**maximum tensile strength**

Maximum axial load an umbilical, with zero curvature, can withstand without infringing the stress criterion or suffering loss of performance.

See Figure 1, and 3.1.9.

3.1.39**medium-voltage (MV) cable**

Electrical cable with extruded solid insulation for rated voltages from 3.6/6 (7.2) kV up to 18/30 (36) kV (AC) for use in subsea umbilical applications.

3.1.40**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.

3.1.41**metocean data**

Data describing meteorological, environmental, and oceanographic conditions for a particular offshore area.

NOTE At a minimum, metocean data typically include information on wind, waves, currents, tides, temperatures (air and seawater), and sea ice.

3.1.42**minimum bend radius****MBR**

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 3.1.9.

3.1.43**prototype**

Separate length of an umbilical or component manufactured prior to the main production for which the intention is to perform qualification testing.

3.1.44**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 armors 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 armoring 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.

3.1.45**qualification**

Activity undertaken to prove that a prototype umbilical component or prototype umbilical can withstand the manufacturing process and that the design requirements for the component or umbilical have been fulfilled.

3.1.46**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.

3.1.47**service life**

Specified time during which the umbilical system is capable of meeting the functional requirements.

3.1.48**S-N data**

Data obtained by plotting cyclic stress level versus number of cycles to failure.

3.1.49**splice**

To join together component lengths or sub-components to achieve the required production length.

3.1.50**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 treated as a dynamic application.

3.1.51**subsea termination interface**

Mechanism that forms the transition between the umbilical and the subsea termination.

NOTE 1 The interface is comprised typically of an umbilical armor termination and/or a mechanical anchoring device for the tubes, bend stiffener/limiter, and tube or hose-end fittings.

NOTE 2 If the umbilical contains electric cables/fiber optics, penetrator(s) and/or connectors may also be incorporated.

3.1.52**subsea umbilical termination**

Mechanism for mechanically, electrically, optically, and/or hydraulically connecting an umbilical or jumper bundle to a subsea system.

3.1.53**tensile armor**

Structural layer consisting of, for example, steel wires, fiber-reinforced plastic rods, etc., that is used to sustain tensile loads in the umbilical.

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

3.1.54**turret**

Cylindrical single-point mooring system geostationary with the seabed, allowing rotation of the vessel in response to environmental conditions.

3.1.55**ultimate tensile strength**

Load at which the weakest component of the umbilical bundle fails when the axial load is applied with the umbilical in a straight condition.

3.1.56**ultra-deep water**

Water depths exceeding 1830 m (6000 ft) that can necessitate the consideration of design and/or technology alternatives.

3.1.57**umbilical**

Group of functional components, such as electric cables, optical fiber 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 armoring may be included for strength, protection, or weight considerations.

3.1.58**umbilical joint**

Means of joining together two lengths of umbilical to effect a repair or to achieve the required production length.

3.1.59**umbilical system**

Umbilical, complete with end terminations and other ancillary equipment.

3.1.60**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 fibers.

3.1.61**verification**

Activity undertaken to document that an umbilical component or manufactured umbilical meets the specified design requirements or predicted properties.

3.1.62**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
CRA	corrosion-resistant alloy
DC	direct current
DP	design pressure (mathematical symbol: DP)
FAT	factory acceptance test
FD	frequency domain
FE	finite element
FEM	finite element modeling
HCR	high collapse resistance
ID	inside diameter (mathematical symbol: d)
LTD	linearized time domain
LV	low voltage
MBR	minimum bending radius at zero tensile load
MV	medium voltage
NDE	nondestructive examination
NTD	nonlinear time domain
OD	outside diameter (mathematical symbol: D)
OTDR	optical time-domain reflectometer/reflectometry
PMI	positive material identification
PRE	pitting resistance equivalent
RAO	response amplitude operator

ROV	remotely operated vehicle
SF	safety factor
SMYS	specified minimum yield strength
TDR	time-domain reflectometry
TVE	true volumetric expansion
U_0	rated power-frequency voltage between conductor and earth or metallic screen, for which the cable is designed
U	rated power-frequency voltage between conductors, for which the cable is designed
U_m	maximum value of the “highest system voltage” for which the equipment may be used (See IEC 60038)
UT	ultrasonic testing
UV	ultraviolet
VIM	vortex-induced motions
VIV	vortex-induced vibration
WPS	welding procedure specification
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) where applicable, have electric cables capable of transmitting power and signals with the required characteristics;
- e) where applicable, have optical fibers capable of transmitting signals at the required wavelengths within the attenuation specified;
- f) where applicable, 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;
- i) for dynamic umbilicals, the dynamic section of the umbilical shall be fabricated in one continuous length.

4.1.2 End Terminations and Ancillary Equipment

End terminations and ancillary equipment shall, at 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) Cathodic protection 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.

NOTE 1 Functional requirements neither specifically required nor specified by the purchaser, but that 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 2 An example of a project functional specification can be found in Annex B.

5 Safety, Design, and Testing Philosophy

5.1 Application

Section 5 shall apply to umbilical systems, including umbilicals, terminations, and auxiliary equipment that are built in accordance with this document.

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 policies 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 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.

NOTE The consequences include consequences of such events for people, environment, subsea system, and financial interests.

5.4 Fundamental Requirements

5.4.1 General

The following fundamental requirements shall apply:

- a) The materials and products shall be used as specified in this document or in the relevant material or product specification.
- b) Adequate supervision and quality control shall be provided during manufacture and fabrication.
- c) 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.
- d) The umbilical shall be adequately maintained, including inspection and preservation when applicable.
- e) The umbilical shall be operated in accordance with the design basis and the installation and operating manuals.
- f) Design reviews shall be carried out where all contributing and affected disciplines (professional sectors) are included to identify and solve any problems.
- g) 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. At 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.

5.4.2 Quality Assurance

Equipment manufactured in accordance with this document shall conform to a certified quality assurance program. The manufacturer shall develop written specifications that describe how the quality assurance program is to be implemented.

5.5 Design Philosophy

5.5.1 Design Principles

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

- a) The umbilical system shall satisfy functional and operational requirements as given in the design basis.
- b) 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.
- c) The umbilical system shall permit simple and reliable installation, retrieval, and reinstallation, and be robust with respect to use.
- d) The umbilical system shall provide adequate access for replacement and repair.
- e) Design of structural details and selection of materials shall address the effects of corrosion, aging, erosion, and wear.
- f) 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:

- a) specifications supplied by the purchaser as specified in Annex B (e.g. functional requirements, field data, host data);
- b) procedures for load-effect analyses for the umbilical and associated components (see Annex C); and
- c) load-case matrices, as specified in Annex B (e.g. temporary conditions, installation, extreme conditions, fatigue conditions).

5.6 Testing

5.6.1 General

All tests specified in this document 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 program in relation to the project schedule.

See B.2.9 for guidance on the responsibility of identifying the need for qualification testing. Guidance on the recommended testing program is given in Annex D and Annex J.

5.6.2 Qualification Testing

NOTE Qualification testing refers to tests performed on a prototype component or prototype umbilical to prove that it can withstand the manufacturing process, environment, and 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 B.2.9.

For umbilicals and/or components that 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.

The manufacturer shall document the track record for, and 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. If such analysis is performed, it shall be carried out according to the requirements of this document (see Section 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, midline connectors, and ancillary equipment, if applicable.

5.6.3 Verification Testing

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

The scope of verification testing shall be specified by the purchaser based on the purchaser's risk profile and the manufacturer's design/testing statistics (see B.2.9).

NOTE Guidance on the possible testing program is given in Annex D and Annex J.

5.6.4 Factory Acceptance Testing

Factory acceptance testing shall be 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.

NOTE Factory 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.

Acceptance tests for common components shall be performed as specified in Annex D.

Acceptance tests shall also be carried out for the end terminations, 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 document. The requirement for analysis shall result from a risk evaluation for the umbilical. The factors that shall be evaluated 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. In addition to operational load cycles, the cycles shall include reeling, handling, construction, installation, and 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 evaluated 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.

Assessment of creep in electrical cables from the effects of axial tension shall be undertaken.

See Annex E for guidance on fatigue testing.

6.2 Loads

6.2.1 Load Classification

Loads shall be classified as functional, environmental (external), or accidental.

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, heat generated from the operation of MV power conductors, 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) wind;
- j) subsea landslides;
- k) UV radiation.

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 or displacement 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 B.

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 shall apply to the permanent operational state of the umbilical, considering functional and environmental loads. Design conditions with a 10^{-2} annual exceedance probability (i.e. 100-year return period) shall be applied.
- b) Abnormal operation: This shall apply to the permanent operational state of the umbilical, considering functional, environmental, and accidental loads. Combined design conditions with an annual exceedance probability between 10^{-2} and 10^{-4} shall be evaluated.
- c) Temporary conditions: This shall apply 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 exceedance 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.

NOTE 1 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 exceedance probability higher than 10^{-2} should be considered to be normal operation.

NOTE 2 Load combinations with an annual exceedance 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	<p>Probability of exceedance according to season and duration of the temporary period.</p> <p>If more information is not available, the following return period values may be applied for temporary conditions:</p> <ul style="list-style-type: none"> — a 100-year return period if duration is in excess of six months; — a 10-year return period for the actual seasonal environmental condition if duration is in excess of three days but less than six months. — For temporary conditions with a duration less than three days or operations that can be terminated within a three-day window, an extreme load condition may be specified, and startup /shutdown of the operation is then based on reliable weather forecasts. 	Annual exceedance probability of 10^{-2}	<p>Annual exceedance probability of 10^{-2} to 10^{-4}</p> <p>If combined with accidental loads, the environmental load may be established so that the combined annual exceedance probability is 10^{-4}.</p>
Accidental	As appropriate to the actual temporary condition	Not applicable	Individual considerations. Annual exceedance probability $\geq 10^{-4}$.

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 and 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 VIM 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 a 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.

Unless more precise information is available, calculation of fatigue stresses should 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.

Fatigue calculations shall be performed using material properties that are adjusted to take into consideration the impact of elevated operating temperatures and thermal aging that may result from the operation of MV power conductors within the umbilical, or from other heat sources that may be present.

6.3 Load Effect Analysis

6.3.1 General

The manufacturer shall design the umbilical according to the specified loads and environmental conditions. The output of the analyses shall be used to demonstrate that the umbilical is suitable for installation and operational regimes during its specified 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 Section 5.

All load-effect analyses shall be based on accepted physical/numerical principles for modeling 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

- a) verified against closed-form analytical solutions;
- b) 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
- c) 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 neighboring 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 to 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 fatigue analyses, for example) 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 analysis 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 dynamic analysis, with the use of discrete modeling, 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:

- a) The global response model shall include the complete umbilical system, considering accurate modeling of stiffness, mass, damping, and hydrodynamic load effects along the umbilical, in addition to top and bottom boundary conditions. If a regular-wave-based approach is used, this shall be validated by using an irregular-wave, time-domain-based analysis approach.
- b) Appropriate drag and inertia coefficients for the selected method shall be applied. Effects of marine growth shall be included, if applicable. Recognized principles shall be applied to assess possible drag magnification due to VIV.
- c) The global cross-sectional properties shall be representative of the stiffness and damping properties of the actual umbilical cross-section.
- d) The umbilical shall be modeled 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 C, Appendix F of DNV OS-F201, or equivalent may be applied.
- e) 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 modeling 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.
- f) Any use of simplified modeling and/or analysis techniques shall be verified by more advanced modeling and/or analyses for representative (critical) load cases.

For further details, see Annex C.

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 Section 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 evaluated 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 section 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 behavior 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. In most cases, VIV analyses are 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 API 2RD, DNV RP-F204, or other recognized industry standards.

The internal frictional stresses between components within the umbilical should be accounted for in VIV analysis.

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 evaluated 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 B (see Table B.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 a 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 neighboring risers that can interfere with each other. It is the responsibility of the purchaser to ensure that there is sufficient distance in instances where neighboring risers are delivered by different manufacturers.

The interference analyses are essentially global load-effect analyses with due regard to the modeling of hydrodynamic interaction. Industry standards, such as those 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 evaluated.

Hence, the engineering efforts required to qualify an umbilical system for structural impact are substantially more demanding compared to those 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 eigenmodes with due regard to boundary conditions and multi-span scenarios.

Umbilicals are normally more tension-dominated than pipelines due to the low bending stiffness. Hence, effective as-laid tension is important for the prediction of participating modes. The uncertainty in the tension can be large, prompting uncertainty 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. In general, the pull-in analysis should be comprised of:

- a) an estimation of the friction force due to the weight of the umbilical;
- b) an estimation of the friction force due to the bends around corners, if relevant;
- c) an estimation of the required pulling force due to bending of the umbilical, if relevant;
- d) an estimation of reverse pull-in analysis for contingency scenarios or for future removal and/or abandonment.

NOTE 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. The contributions from friction forces and bending of the umbilical should be added together in a conservative manner.

Computer analyses by use of a general-purpose FE code should be applied in the case of complex pull-in scenarios. Such analyses should be performed as nonlinear static analyses. The load application shall represent the actual pull-in scenario. Due regard shall be given to the modeling of constraints and contact forces from the supporting structure (e.g. bend geometry with appropriate friction-force modeling). 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 envisioned during manufacture, load-out, recovery, repair, and installation, and for the operational conditions throughout the design life.

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

NOTE 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:

- a) capacity curves in terms of tension versus curvature at a specific pressure, if applicable;
- b) assessment of maximum allowable crushing loads;
- c) stresses and strains used for fatigue calculations;
- d) 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 C.3 for an overview of fatigue-analysis strategies.

Local stress analysis shall be conducted in order to obtain accurate internal friction-induced stresses, as well as the stresses and strains on the components from other loads.

The 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. For electrical cables, the effects of creep shall be assessed.

6.3.9.2 Modeling 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 taken into account in the analysis:

- a) deterioration of material properties and degradation as a result of aging 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, armor wires, electrical conductor, fillers, bend stiffeners, polymers);

- d) contact pressure and friction among different umbilical components;
- e) effects of environmental conditions, (e.g. UV radiation, temperature, ozone, long-term exposure to seawater, marine growth, and permeated fluids);
- f) cumulative effects of strain on the electrical cable, armor wires, metallic tubes, and fibers throughout the manufacturing processes; handling; and installation operations;
- g) strain on the optical fibers;
- h) assessment of lateral deformations and stress/strain on the individual components due to crushing loads during storage and installation;
- i) effects of elevated temperature from any heat sources that may be present in all or part of the umbilical.

NOTE 1 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 Section 5 and Section C.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 evaluated, 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 as they would be assembled in the umbilical.

The load-sharing analysis shall be based on nominal dimensions. Dimensional tolerances, including effects from corrosion and wear, shall be taken into account in the stress and fatigue analysis.

Tolerances shall be taken into account 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.

Friction can influence the global damping and stiffness behavior. Therefore, it shall be included 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, this shall be taken into account as part of the fatigue calculation.

Terminations of dynamic umbilicals in operation should be given special consideration. Due to high bending gradients, end effects can occur as a result of the helically layered umbilical structure. The stress amplification shall be evaluated or documented by testing (qualification or verification testing according to Section 5) 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 3-D structural analysis models can be used to adjust the test program to simulate the real loading conditions.

6.4 Electrical System Analysis

NOTE The purpose of the electrical analysis is to ensure that the specified MV power conductors are suitable for safe operation at the specified power transfer requirements, and that their arrangement within the umbilical cross-section results in acceptable electrical system performance for the required range of operating voltages and frequencies in the various environmental conditions throughout the design life.

The analyses shall establish:

- a) the conductor cross-sectional area or verify the size-specified by purchaser;
- b) minimum conductor insulation thickness required to meet system operating voltages;
- c) characteristic electrical parameters of the MV conductors within the umbilical, such as resistance, inductance, and capacitance, and derived characteristics, such as series impedance;
- d) expected voltage drop in the MV power conductors.

In addition to determining the electrical characteristics and performance of the MV conductors within the umbilical, analysis shall be performed to establish the levels of induced voltages between multiple MV power circuits, and between the MV power circuits and any LV power/signal cables and any other electrically conductive materials within the umbilical.

The following shall be taken into account in the analysis:

- a) operating conditions when no ground fault is present, but also when a single power phase experiences a fault to ground;
- b) materials selection, including corrosion of metallic elements, cathodic attack, and delamination of bonded elements;
- c) Analysis of power transfer performance of electrical circuit(s) shall be performed under the range of operating voltages (including maximum voltage, nominal transmission voltage, and megavolt amps (MVA) power transmission) and frequencies;
- d) Analysis shall be conducted throughout the range of operating temperatures that will impact the resistance of the conductors.

The electrical analysis should be based on analytical or numerical (FE) methods that are validated by physical testing.

6.5 Thermal Analysis

Thermal analysis shall be conducted for umbilicals subjected to elevated temperatures, internal or external to the umbilical, when specified by the purchaser. The analysis should evaluate the steady state temperature distribution throughout the cross-section of the umbilical.

The manufacturer shall demonstrate that temperatures in the umbilical are within all materials limits at the specified environmental and loading conditions.

The output of this analysis may result in reductions in material strength, fatigue performance, chemical compatibility or reduced corrosion resistance which shall be taken into consideration in the umbilical design.

The following shall be taken into account in the analysis:

- a) Environmental operating conditions that represent the highest degree of thermal input to the umbilical system;

NOTE 1 These conditions may only occur for short periods of time, and a transient analysis method may be proposed to take such temporary conditions into account.

- b) Evaluation of various locations throughout the umbilical system to ensure the highest operating temperatures have been identified;
- c) Maximum electrical loading as determined by the electrical system analysis, including induced voltages and currents into the LV electrical cables and non-current-carrying conductive components; and

d) Expected range of operating frequencies.

NOTE 2 The analysis may consider thermal conductivity of the umbilical materials allowing axial heat transfer along the umbilical, convective heat transfer within the umbilical, and in the environment adjacent to the umbilical as appropriate.

NOTE 3 The thermal analysis may be based on analytical or numerical (FE) methods.

6.6 Installation Analysis

All transport, load transfer, lifting, and 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 shall 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.

6.7 Fatigue Life

The umbilical shall be designed with fatigue life that is equal to or greater than 10 times the service life.

NOTE 1 The service life is determined on a project-specific basis.

NOTE 2 Qualification or verification testing may 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.

NOTE 1 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.

NOTE 2 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 the end terminations, midline connectors, and ancillary equipment shall be verified by testing, if applicable.

Verification and acceptance tests that shall be performed during and on completion of component manufacture specified in this section are summarized in Annex D.

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 checkpoints), 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, at a minimum, contain the following information:

- a) plan(s) and process flow description/diagram;
- b) project-specific quality plan;
- c) manufacturing process;
- d) manufacturer(s) of functional components and any supplier quality plans;
- e) 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) ability to be used in the manufacturing process;
- d) in-service repair;
- e) degradation related to the seawater environment and service fluids.

NOTE EEMUA Publication 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.

NOTE The use of the terms “signal” or “power,” with respect to cable descriptions, are customer-specific and relate only to how they are used in service.

7.2.2 Operating Voltages

The operating voltages shall be defined using U_0 , U , and U_m .

Cables included in this standard shall be defined as low voltage (LV) or medium voltage (MV).

7.2.3 Low-voltage Cables

Low voltage cables shall follow the basic design requirements of IEC 60502-1, which covers the 0.6/1 (1.2) kV and 1.8/3 (3.6) kV.

NOTE 1 Other voltage combinations for LV cable may be used, provided they fall within this range.

NOTE 2 Most low-voltage cables likely take the form of multicore cables, such as pairs, triads, or quads.

7.2.4 Medium Voltage Cables

Medium-voltage cables shall follow the basic design requirements of IEC 60502-2, which covers 3.6/6 (7.2) kV; 6/10 (12) kV; 8.7/15 (17.5) kV; 12/20 (24) kV; and 18/30 (36) kV, with additional consideration for submarine applications.

NOTE Other voltage combinations for MV cable may be used, provided they fall within this range. In addition to IEC 60502-2, other industry standards exist that govern power-cable design, including those written by ICEA and IEEE.

Medium-voltage cables usually shall be supplied as individual cores, or as a unit containing three cores.

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 Section 4.

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

NOTE Some cables may include screening and/or armoring, 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 multicore cable, the construction shall ensure that the cores can be readily separated for termination purposes and do not adhere or 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.

Where necessary, the designs shall take into consideration the effects and mitigation of gas and liquid 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 conductor shall comply with the relevant conductivity and material requirements of IEC 60228, Class 2.

The minimum nominal cross-sectional area shall be 2.5 mm² (0.004 in²); however, the conductor sizing shall be suitable for both the operating conditions and testing requirements.

The nominal cross-sectional area for the conductor shall meet the functional requirements of Section 4. The relationship between conductor size, strand count, and stiffness should be considered.

When selecting conductor size, consideration should be given to the minimum recommended size based on the insulation thickness.

NOTE Where conductors are used in MV cables, a semiconducting screen may be present on top of the conductor. This would be simultaneously applied as part of the insulation extrusion.

7.2.5.4 LV Cable 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.

Other 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.

When polyethylene is used as insulation material, the minimum thickness for EPR defined in IEC 60502-1 shall be used.

During the material selection process, consideration shall be given to the operating temperature.

The minimum allowable insulation thickness shall be as specified in IEC 60502-1 (or alternatively, as stated in the manufacturer's written specification).

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

The insulated conductors shall be identified either by color 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 colors employed shall be cited in the manufacturer's written specification.

Coding shall be stable under heat aging, and shall not cause a failure to satisfy the requirements of Section 4.

Embossed printing shall not be permitted.

7.2.5.5 MV Cable 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 60502-2.

During the material selection process, consideration shall be given to the operating temperature and maximum continuous temperature of the conductor.

The minimum allowable insulation thickness shall be as stated in IEC 60502-2 for the chosen material.

NOTE Most MV cables require conductor and insulation screening with a semiconducting layer extruded simultaneously with the insulation layer. The only exception is a 3.6/6 (7.2) kV cable with the material selection and thicknesses defined in IEC 60502-2.

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

In a multicore cable, fillers or extruded filling shall be included in the interstices to achieve a circular consolidated arrangement. Viscous filling compounds may also be included to reduce internal voids and minimize water ingress.

Any filler and binder tape materials shall be compatible with other materials in the cable. In particular, the effect on electrical insulation shall be evaluated. 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 LV Cable 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 (0.0005 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 MV Cable Screening

All MV cables (with the exception of 3.6/6 (7.2) kV cables referenced in 7.2.5.5) shall contain a screen, either individually or collectively, comprising of a metallic layer in combination with the semiconducting insulation screening.

The construction of the screen shall be as described in IEC 60502-2. In addition to these requirements, other nonmetallic or semiconducting tapes may be present to inhibit longitudinal water penetration.

The area of metallic screen, combined with any grounding wires, shall be capable of withstanding the required short-circuit current rating.

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.

7.2.5.10 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 seawater 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.

NOTE 1 MV cables may be supplied where the metallic screens are shared amongst the cables of a three-phase system and the only sheath is an overall sheath over the triad.

NOTE 2 To assist with identification in the final umbilical, the sheath may be of a specific color.

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.

7.2.5.11 Armor/reinforcement

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

The armor of individual MV cables used in AC systems shall contain nonmagnetic material.

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

7.2.5.12 Cable Identification

The cables shall be marked along the complete length at regular intervals not exceeding 1 m (3.28 ft). At a minimum, the marking shall include:

- a) the manufacturer;
- b) a unique component reference, e.g. "Cable 3";
- c) the batch number;
- d) conductor size;
- e) voltage rating;
- f) description, e.g. single, pair, quad;
- g) for MV cables, the individual phases within a triad shall be uniquely identified.

NOTE For MV cables, color identification is not part of the insulation process, but may be applied to the outer sheath or as a colored tape or filament included in the structure.

7.2.6 Performance Requirements

7.2.6.1 LV Cable Performance

A low-voltage cable is specified by its conductor material, conductor size, voltage rating, and number of cores, and if it is shielded and/or armored.

The performance of a LV cable shall be defined by a number of DC measurements and AC characteristics, which include:

- a) DC conductor resistance;
- b) insulation resistance (DC): minimum acceptable value is 1000 M Ω .km @ 1000 V (DC).
 - 1) The following AC requirements are usually specified at particular frequencies or frequency range:
 - i) AC resistance;
 - ii) capacitance;
 - iii) inductance;
 - iv) attenuation;
 - v) characteristic impedance;

- vi) cross-talk (as applicable).

7.2.6.2 MV Cable Performance

A medium-voltage cable is specified by its conductor material, conductor size, and voltage rating.

The performance of a MV cable shall be comprised of DC measurements and some AC characteristics measured at a specific frequency (usually operation), which include:

- a) DC conductor resistance
- b) AC resistance

7.2.7 Structural Analysis

Taking into account the data generated from the umbilical structural analysis specified in 6.3, structural analysis 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.

Multistranded 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.
- 1) In MV cables where extruded semiconducting layers are present below and/or above the insulation material, these shall be co-extruded with the insulation layer.
 - 2) Where semiconductive insulation screening is present, the insulation shall be extruded as one continuous length without defects, and shall be subject to inspection without continuous spark-testing during the extrusion process, in accordance with the manufacturer's written specification.
 - 3) For the extrusion of LV cable insulation without a semiconductive screen layer, 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 conductor insulation, for both LV and MV cables, 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 cabling operations, the conductors shall not be subject to tensile and compressive loadings that introduce kinks or reduction in conductor or strand cross-sectional area.

Fillers may be simultaneously introduced when cores are being assembled into a multicore cable.

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 Fillers

7.2.8.4.1 Belted Filling

Belted fillers are created by extruding material around and between the laid-up cores to provide a circular arrangement upon which to apply a screening or sheathing layer.

The application of a belted extrusion should not adversely affect or degrade the insulation material. Once applied, the belting layer shall be capable of being removed from the insulated cores without sticking to the conductor insulation.

In some cases, a belted extrusion may be applied simultaneously with an outer sheathing layer, in which case the outer layer should also be capable of being removed from the belting without sticking.

7.2.8.4.2 Other Fillers

NOTE Other fillers may be used that include round or shaped nonmetallic elements and different types of viscous filling compounds that are usually introduced during core lay-up. The viscous filling compounds may be applied either by flooding the laid-up cores and wiping off the surplus, or by pumping the material into the closing die where the cores are brought together during assembly. Drain wire(s) may also be included along with fillers, where required.

7.2.8.5 Tape Screening

In LV multicore cables, plain metal tapes shall not be applied over the laid-up cores without a nonmetallic layer between them.

For LV cable screens containing a composite metallic layer on polymer substrate, the inclusion of drain wire(s) shall be such that electrical continuity is maintained when adding a new roll of screen tape.

NOTE For MV cables, semiconducting tape(s) may also be applied immediately below the metal tape(s).

7.2.8.6 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.

7.2.8.7 Armoring/Reinforcement

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

7.2.9 LV Cable 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 7.2.9.12.

If a splice is being provided in the cable, 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, with 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, with 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 town-mains or 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 hours, and then insulation-resistance tested while still under pressure. The value of the insulation resistance shall not be less than the value defined in 7.2.6.1.

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.

NOTE 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 town-mains or potable water. An initial insulation-resistance test shall be performed. 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 hours, 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 five minutes, 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 shall be 5 kV or three times U_0 , whichever is greater.

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 $2.5 \times U_0 + 2\text{kV}$. The voltage shall be applied between conductor and water. It shall be increased at the rate defined in 7.2.9.8 and maintained at the full value for five minutes without breakdown of the insulation.

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 deemed suitable.

7.2.9.8 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 seconds, or less than 100 % in 60 seconds. The initial applied voltage shall not be greater than 500 V.

7.2.9.9 Inductance

A sample of completed electric cable, with a minimum length of 10 m (32.8 ft), shall be measured for inductance. The inductance of each selected pair of cores 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 7.2.6.1, which shall include limits for deviation between actual and specified values.

7.2.9.10 Capacitance

A sample of completed electric cable, with a minimum length of 10 m (32.8 ft), shall be measured for capacitance. The capacitance of each selected pair of cores 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 conform to the requirements specified in 7.2.6.1, which shall include limits for deviation between actual and specified values.

7.2.9.11 Attenuation

A sample of completed electric cable, with a minimum length of 10 m (32.8 ft), shall be evaluated for attenuation. The attenuation of each selected pair of cores shall be measured or derived at the frequencies specified in the manufacturer's written specification. The values, either measured or determined, shall be in accordance with the requirements specified in 7.2.6.1, which shall include limits for deviation between actual and specified values.

7.2.9.12 Characteristic impedance

A sample of completed electric cable, with a minimum length of 10 m (32.8 ft), shall be used for the determination of characteristic impedance. The characteristic impedance of each selected pair of cores in the cable shall be measured or derived at the frequencies specified in the manufacturer's written specification.

The values, either measured or determined, shall be in accordance with the requirements specified in 7.2.6.1, which shall include limits for deviation between actual and specified values.

7.2.10 MV Cable Verification/Qualification Testing

7.2.10.1 General

Testing shall be performed on samples of the particular cable to qualify the design as being fit for purpose.

If a splice is being provided in the cable, this shall also be subjected to the same suite of tests identified below for qualification testing.

For MV cables, these should be performed in accordance with IEC 60502-2 in the section relating to “Type” tests where applicable in the list below.

NOTE In most cases, the MV cable is a single core; however, the cable may contain more than one core, in which case it would require each core of the cable sample to be tested.

The following tests, with the exception of visual and dimensional (a), Tan δ measurement (f), and resistivity of semi-conducting screens (j), shall be performed on the same sample having a minimum length of 10 m (33 ft):

- a) visual and dimensional;
- b) DC conductor resistance;
- c) partial discharge (with sensitivity of 5 pC or better);
- d) bending test followed by partial discharge;
- e) tan δ measurement for cables rated 6/10 (12) kV and above;
- f) heating cycle test followed by partial discharge;
- g) impulse test followed by a voltage test;
- h) voltage test;
- i) resistivity of semiconducting screens;
- j) tests performed on separate cable samples include:
 - 1) tensile strength characterization test of unspliced and spliced (if splicing is required) conductor;
 - 2) testing of water-blocking method for specified water depth (where this feature is included);
 - 3) accelerated water-treeing test in accordance with ICEA S-97-682;
 - 4) hyperbaric electrical testing at specified water depth (similar to LV cables).

NOTE Other tests may be performed based on a specific cable design or particular purchaser requirements.

7.2.10.2 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.

7.2.10.3 DC Conductor Resistance

A DC conductor resistance test shall be performed on a sample of each insulated conductor, being at least 10 m (32.8 ft) long. 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, where applicable.

7.2.10.4 Partial Discharge

A partial discharge test shall be performed on a sample of each insulated conductor in accordance with IEC 60502-2.

The discharge magnitude shall not exceed 5 pC.

7.2.10.5 Bending Test

This shall be performed on the sample that was previously used for partial discharge testing.

The sample shall be bent around a former following the conditions specified in IEC60502-2, for the particular type of cable.

Following completion of the bending test, a partial discharge test shall be repeated, as in 7.2.10.4.

7.2.10.6 Tan δ Measurement

This test shall only apply to cables rated 6/10 (12) kV and above.

The test method shall be as described in IEC 60502-2.

7.2.10.7 Heating Cycle Test

This shall be performed on the sample that was previously used for the bending test.

The test method shall be as described in IEC 60502-2

7.2.10.8 Impulse Test

This shall be performed on the same sample previously used for the heating cycle test

The test method shall be as described in IEC60502-2

7.2.10.9 Voltage Test

This shall be performed on the sample that was previously used for the impulse test.

The test method shall be as described in IEC60502-2.

7.2.10.10 Resistivity of Semiconducting Screens

A sample of semiconducting screen shall be prepared from a 150 mm (6 in) sample of cable.

The resistivity of the nonmetallic screening layers (semiconducting) in the completed insulated core shall not exceed the following values:

- a) conductor screen: 1000 Ω m
- b) insulation screen: 500 Ω m

7.2.10.11 Tensile Strength Characterization Test of Conductor

This shall be performed on a sample of the electrical conductor. If the electrical cable is to be spliced, a spliced sample shall also undergo testing.

7.2.10.12 Testing of Water-blocking Method

Testing shall be performed on one sample each of unspliced and spliced cable to qualify the water-blocking properties of the cable, with test conditions to be agreed with the purchaser.

7.2.10.13 Accelerated Water-treeing Test

Samples of the insulated conductor shall undergo an accelerated water-treeing test in accordance with ICEA S-97-682.

NOTE This is considered a type test, and only needs to be performed to qualify the extrusion equipment and material used for the insulation for all cables using that equipment and material.

7.2.10.14 Hyperbaric Electrical Testing at Specified Water Depth

Hyperbaric testing on unspliced and spliced cable samples (number of samples and length of sample to be agreed with purchaser) shall be performed at the design water depth, with measurements of OD before and after hyperbaric testing and electrical continuity testing before, during, and after testing. Cable samples shall be partially discharge tested after testing. Cable samples shall be dissected after testing to determine if conductor and conductor insulation are still within original manufacturing tolerances.

7.2.11 LV Cable Acceptance Testing

7.2.11.1 General

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

7.2.11.2 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.

7.2.11.3 Spark Testing

All cores shall be spark-tested during insulation extrusion.

Other cable sheathing layers should be subjected to spark testing, provided the extrusion is applied directly over a screen or metallic armor 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 IEC 602230 for the insulation and sheath thicknesses.

7.2.11.4 DC Conductor Resistance

This test shall be performed on the complete conductor lengths at the following manufacturing stages, at 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.

Where applicable, any metallic screen layer should be checked and should be continuous over the full cable length.

7.2.11.5 Insulation Resistance

This test shall be performed on the completed insulated conductor lengths in accordance with the procedure and acceptance value specified in 7.2.6.1 after having been immersed in town mains or potable water for 22 hours. For acceptance testing of these insulated conductors, the hydrostatic pressure and duration shall be stated in the manufacturer's written specification.

NOTE 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.

7.2.11.6 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.

NOTE 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.

7.2.11.7 Inductance

On completion of cable manufacture, the inductance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.2.9.9 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.

7.2.11.8 Capacitance

On completion of cable manufacture, the capacitance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.2.9.10 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.

7.2.11.9 Attenuation

On completion of cable manufacture, the attenuation characteristics shall be measured or derived in accordance with the procedure and acceptance values specified in 7.2.9.11 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.

7.2.11.10 Characteristic Impedance

On completion of cable manufacture, the characteristic impedance shall be established in accordance with the procedure 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; or
- b) on the completed length, provided the overall length does not introduce spurious results.

7.2.11.11 Cross-talk

For cables containing independent conductor pairs that require minimized 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.

7.2.11.12 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.

7.2.11.13 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 7.2.9.3;
- b) insulation resistance as specified in 7.2.9.4.

7.2.12 MV Cable Acceptance Testing

7.2.12.1 General

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

7.2.12.2 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.

7.2.12.3 Spark Testing

Only cores without a semiconducting insulation screen shall be spark-tested during the insulation extrusion.

Other cable sheathing layers should be subjected to spark testing, provided the extrusion is applied directly over a screen or metallic armor 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 IEC 62230 for the insulation and sheath thicknesses.

7.2.12.4 DC Conductor Resistance

This test shall be performed on the complete conductor lengths at the following manufacturing stages, at 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 where applicable, i.e. assembly angle or twist.

7.2.12.5 Partial Discharge Test

This shall only be performed on cable lengths containing semiconducting screening layers.

Partial discharge testing shall be performed on each length of manufactured cable in accordance with IEC 60502-2.

The discharge magnitude shall not exceed 10 pC.

7.2.12.6 High Voltage

This shall be performed on each length of manufactured cable in accordance with IEC 60502-2.

Testing shall be made using AC voltage at power frequency, at the routine test voltages specified in IEC 60202-2.

No breakdown of the insulation shall occur.

7.2.12.7 Capacitance

On completion of cable manufacture, the capacitance shall be measured at the transmission frequency with respect to ground, unless otherwise stated in the manufacturer's written specification:-

- 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.

7.2.12.8 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 shall not constitute acceptance/rejection criteria.

7.2.12.9 Metallic Screen Integrity

The metallic screen layer shall be checked, and:

- a) at a minimum, should be continuous over the full cable length;
- b) not exceed a value stated in the manufacturer's written specification.

7.2.12.10 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 7.2.12.4;
- b) Insulation resistance as specified in 7.2.11.5.

7.3 Hoses

7.3.1 General

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

7.3.2 Hose Sizing

All hoses shall be referenced by nominal bore and DP.

NOTE See Annex F for preferred hose bore sizes and DP.

Tolerances on nominal bore shall not exceed the values given in Table 3, and the IDs and ODs of the hose shall be concentric within the limits in Table 4.

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

Table 3—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)

Table 4—Concentricity

Nominal Bore		Concentricity (full indicated reading)	
mm	(in)	mm	(in)
≤ 25.4	(1.0)	1.0	(0.039)
> 25.4	(1.0)	1.5	(0.059)

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.

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 radiation, 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.

NOTE Multilayer 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, an internal support may be incorporated.

For high collapse-resistant (HCR) 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 suitable material, compatible with both external environment and inner fluid.

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 fiber, applied around the liner.

7.3.3.4 Sheath

The sheath shall be comprised of a continuous, seamless and circular extrusion, which is 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 a minimum, 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) DP;
- 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 makeup.

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., 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

The required ratio of proof and burst pressures to the DP for thermoplastic hoses shall meet the requirements of Table 5, in accordance with ISO 7751.

Table 5—Ratios of Test Pressure to DP

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 DP ratings and/or larger bore sizes than those specified in Annex F, lower burst-pressure ratios, which shall be in accordance with the manufacturer's written specification, may be acceptable. These hoses for higher 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 DP 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 Section 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 color 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 taken into account 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 fibers 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 reel surfaces shall be smooth, such that the fiber 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 buildup 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 that has already been 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.

NOTE 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:

- a) internal diameter;
- b) diameter over reinforcement;
- c) external diameter;
- d) hose concentricity;
- e) liner wall thickness.

The manufacturer's written specification shall include a dimensional specification for the hose, clearly stating the values and manufacturing tolerances for 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 DP.

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.

NOTE 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 center 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 construction material 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 $55\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($131\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$). Compatibility of the test fluid with the hose liner shall be confirmed prior to commencement of the test. The test pressure shall be $1.33 \times \text{DP}$, and the hose shall withstand a minimum of 200,000 cycles without any signs of leakage or failure.

NOTE For hoses greater than 25.4 mm (1 in.) nominal bore, design pressures higher than those specified in Table F.1, 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 10619-2:2011, method B, where the test temperature is $-40\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($-40\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$). The sample shall fail the test if any signs of leakage, distortion, or cracking are apparent.

NOTE Tests previously conducted in accordance with the superseded ISO 4672:1997 remain valid for purposes of qualification and do not need to be re-performed.

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 G. 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 center of the test arrangement.

Hydrostatic pressure cycling between zero and $1.5 \times DP$ 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 seconds. On completion of 10 cycles, the pressure shall be held constant at $1.5 \times DP$ for a minimum of 10 minutes. 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 $40\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ ($104\text{ }^{\circ}\text{F} \pm 1.8\text{ }^{\circ}\text{F}$) 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, 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 DP at a rate of one cycle per hour. The pressurization and depressurization periods shall each be of a duration of 5 minutes \pm 10 seconds, and the dwell time at zero pressure shall be 10 minutes \pm 10 seconds.

At specified time intervals, samples of hose shall be removed from one of the test assemblies, and the remaining hose re-terminated and reintroduced 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.

NOTE 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 days, 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.

At 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.

Acceptance criteria for visual and dimensional inspection shall be defined by the manufacturer and agreed with purchaser prior to the start of manufacture.

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, suitably filtered to allow the final system cleanliness, as defined in the manufacturer's written specification:

- a) specified system control fluid;
- b) proprietary storage fluid;
- c) town-mains or potable water; 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) deionized water.

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, 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, 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 minutes. 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 minutes.

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 G.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 $1.5 \times DP$, shall be performed on all hoses following delivery and prior to lay-up.

7.4 Optical-fiber Cable

7.4.1 General

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

7.4.2 Fiber Type

The fiber type shall be of either single-mode or multimode design in accordance with ITU-T G.652 or ITU-T G.654, or as specified by purchaser. The design shall be as given in the manufacturer's written specification.

7.4.3 Fiber Construction

7.4.3.1 Core

The optical-fiber 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 color coding as a means of individual fiber identification. The material used for coating, including color, 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, e.g. terminations.

7.4.4.2 Fiber Package

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

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

NOTE Tensile protection can be by means of a central strength member and/or external armoring 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 armoring.

7.4.4.3 Sheathing

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

7.4.4.4 Armor/reinforcement

Tensile, axial stiffness and crush protection, in addition to that provided by the fiber package, can be achieved by means of external armoring, 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

NOTE 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 fiber type;
- d) the number of fibers;
- 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-fiber 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 document is not applicable to the design of optical-fiber terminations for subsea use.

7.4.6 Performance Requirements

7.4.6.1 Optical Attenuation

The optical attenuation for each fiber at specified wavelengths shall meet the requirements given by the purchaser in accordance with Section 4.

7.4.6.2 Fiber Strain

The umbilical and optical-fiber cables shall be designed so that potentially damaging residual strain levels are not imposed on the optical fibers. Excessive compression causes increased fiber attenuation, and excessive strain causes latent defects and early failure. The optical-fiber package shall be designed and tested so that the residual strain levels fall in a range from 0.05 % to 0.25 % for any individual fiber, irrespective of fiber over-length.

7.4.7 Jointing

7.4.7.1 Cable Jointing

If production lengths dictate, optical-fiber cable lengths may be joined together. The joint shall be either a cable splice incorporating fiber 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 fibers 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 fibers.

7.4.7.2 Fiber Splicing

Jointing of the fibers 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 1750 MPa (100 ksi to 250 ksi)].

The splice region shall be suitably protected and the optical performance, after splicing, shall meet the requirements of Section 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 Fiber Manufacture

Fibers 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, IEC 60793-2, ITU-T-G.650.1, ITU-T G650.2, ITU-T G.652, ITU-T G.654, and ITU-T G.655.

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

7.4.9.2 Fiber-package Construction

The individual fibers shall be assembled into the fiber 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 Armoring/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 shall be 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 and in line with current industry standards, each optical-fiber 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 fibers 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-fiber cables shall be verified in accordance with IEC 60794-1-21 or in accordance with ITU-T G.976.

7.4.10.5 Environmental Resistance

The environmental resistance of the optical-fiber 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-fiber 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 fibers 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 fiber change that can compromise the design life of the system.

7.4.10.7 Fiber Splicing

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

7.4.11 Acceptance Testing

7.4.11.1 General

Acceptance tests 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 and in line with current industry standards, each optical-fiber cable shall be 100 % visually examined and shall be free from damage, kinks, or irregularities. Cable lay-up, carrier tube fabrication, sheathing, and armoring 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 fiber 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 fibers following delivery, prior to lay-up. Attenuation values shall meet the requirements of Section 4.

7.5 Metallic Tubes

7.5.1 General

Metallic tubes shall be capable of continuous operation while 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 DP.

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 F.

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

7.5.2.2 Wall Thickness

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

NOTE 1 The equations for calculating the tube wall thickness are given in 7.5.2.6 through 7.5.2.8.

Collapse and buckling of the tubes shall be evaluated for the maximum operational water depth. Collapse and buckling can be evaluated using equations in Annex H unless otherwise agreed with the purchaser.

The calculations for the wall thickness, t_x , where x is 1, 2, or 3, for use in the stress calculations, shall be per Table 6.

Table 6—Wall Thickness for Stress Calculations

Condition	Pressure Containment	Combined Loading	Fatigue
Operation	$t_1 = t_{\text{nom}} - t_{\text{fab}} - t_{\text{corr}}$	$t_2 = t_{\text{nom}} - t_{\text{corr}}$	$t_3 = t_{\text{nom}} - 0.5 \cdot t_{\text{corr}}$
Pressure test and installation	$t_1 = t_{\text{nom}} - t_{\text{fab}}$	$t_2 = t_{\text{nom}}$	$t_3 = t_{\text{nom}}$
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).			

NOTE 3 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 6.2.5.3.

7.5.2.3 Diameter

NOTE 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 SMYS

Specified minimum yield strength (SMYS) in the final delivered tube condition shall be used as material strength/yield stress in calculations. The effect of temperature on SMYS shall be evaluated for the normal and abnormal operational loading cases.

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 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 (7).

7.5.2.7 Test Pressure

The tubes shall be designed to withstand a minimum test pressure ratio of $1.5 \times DP$.

A minimum test pressure of $1.5 \times DP$ shall be used for the stress calculations. Any nominal overpressurization 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):

$$p_i = DP \times 1.5 \quad (1)$$

where DP is the design pressure.

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):

$$\sigma_e \leq \eta_\sigma \times \text{SMYS} \quad (2)$$

where

η_σ is the utilization factor obtained from Table 7;

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

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 evaluated:

- pressure containment where only internal pressure is acting;
- combined loading, where direct functional and/or environmental forces are acting in addition to internal pressure.

Table 7—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 H can apply.

For pressure-containment load cases, the following stress components should be evaluated.

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)

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

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 6, Wall Thickness for Stress Calculations.

For calculation of stress at a certain water depth, the effect of pressure head shall be considered.

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

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

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

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

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

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

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

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

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

For pressure-containment calculations (internal pressure only), the axial stress is equal to the pressure-induced end-cap stress, σ_a , which shall be calculated as follows:

$$\sigma_a = p_i \times \left[\frac{(D - 2 \times t)^2}{D^2 - (D - 2 \times t)^2} \right] \quad (8)$$

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

For combined load cases, the following stress components shall be evaluated as applicable:

- a) hoop stress due to internal pressure and/or external pressure; see Equations (4) and (5);
- b) radial stresses due to internal pressure; see Equations (6) and (7);
- c) axial stresses due to the end-cap load, direct tensile load, and bending;
- d) shear stresses due to torque.

NOTE Contact stresses can exist between components, and the effects of these contact stresses should be considered.

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

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.

See Annex H for equations for collapse and buckling.

Special care shall be taken when the tube is subject to a large net external pressure, combined with bending, that may 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 Section 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):

$$f_0 = \frac{D_{\max} - D_{\min}}{D} \times 100 \quad (9)$$

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 evaluated:

- a) mechanical properties;
- b) hardness;
- c) ductility;
- d) fatigue resistance;
- e) weldability;
- f) corrosion resistance.

NOTE A matrix for tube materials that are acceptable for use in subsea umbilicals is included in Annex I. 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 exceeds 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 material-specific considerations shall be made, when applicable:

- a) certain steels that can be susceptible to both localized corrosion and environmentally assisted cracking under conditions when water, oxygen, and chloride are present in the fluid, e.g. for water injection, requiring an application-specific consideration of the corrosion resistance;
- b) effect of corrosion on fatigue life;
- c) limited resistance of austenitic stainless steels to corrosion in seawater;
- d) ensuring electrical continuity for providing corrosion protection to all necessary components;
- e) possible galvanic corrosion effects between different materials in direct electrical contact in a saline conducting environment;
- f) sacrificial barrier-coating thickness (zinc cladding) on tubes to achieve the required design life.

7.5.4 Corrosion/erosion Protection

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.

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.

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 in order to achieve the final production length or as a result of affecting 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). In particular, this applies to material subjected to significant work hardening during fabrication, installation, and operation. Parameters for consideration are:

- a) material susceptibility (including effects from manufacture and welding);
- b) ingress of seawater (with regards to hydrogen charging from cathodic protection);
- c) cathodic potential (with regards to hydrogen charging from cathodic protection);
- d) stress and strain level,
- e) 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, at a minimum, in accordance with ASTM A1016/A1016M, ASTM A789/A789M, or equivalent.

If tubes are oversheathed with a thermoplastic polymer, unique component reference may be achieved by means of color coding or unique reference.

7.5.6.3 Tube Manufacturer's Documentation

The quality plan shall contain the information listed in this section, 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 7.5.2.2. The manufacture shall be carefully controlled and monitored. The manufacturing process shall ensure that raw material, as well as 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 8.

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

If one or more tests in the verification testing 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 shall be performed.

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

- a) qualification activities in accordance with Section 5;
- b) metal-making process, casting process, alloying practice, rolling or working condition, and heat treatment, including target values and proposed allowable variation in process parameters;
- c) target values for chemical composition and PRE;
- d) material traceability, handling, and tube tracking procedure;
- e) tube forming process;
- f) method for cold expansion/sizing/finishing, target, and maximum sizing ratio;
- g) final heat-treatment condition and mechanical properties;
- h) NDE procedures, including acceptance criteria;
- i) list of specified mechanical and corrosion tests;
- j) dimensional control procedures;
- k) tube number allocation;
- l) alignment and joint design for welding and production WPS;
- m) welding, inspection, and nondestructive weld testing procedures, including acceptance criteria;
- n) production destructive weld testing, including disposition for failed tests;
- o) pressure test and cleaning/flushing procedures;
- p) marking, coating, and protection procedures;
- q) 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 the steel 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 color 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, at 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 corrosion protection 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, at 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 ingress.

7.5.7 Tube Welding

7.5.7.1 General

The following requirements shall be 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 nondestructive 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. The party that shall perform contingency offshore repair jointing 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, and position, as well as

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.

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

7.5.7.2 Weld Qualification

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.

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

- a) heat input parameters outside the allowable range;
- b) gas composition;
- c) weld consumables.

NOTE 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.

7.5.7.3 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.
- c) prevention of swarf ingress into the tube;
- d) surface cleaning (mechanical and/or chemical) of the tube adjacent to the end being welded;
- e) tube- and weld-head alignment for welding of the tube ends;
- f) gas purging, if required;
- g) radial and axial alignment of the weld gap within specified tolerances;
- h) secure and accurate location of the welding system relative to the tube;
- i) control of ambient environment;

- j) control of welding equipment parameters.

7.5.7.4 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 datasheet. The datasheet shall give guaranteed limits and/or minimum values for composition and mechanical properties, determined under defined reference conditions. The datasheet 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 datasheets.

7.5.7.5 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.

7.5.7.6 Production Weld Testing

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

- a) destructive or nondestructive 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).

7.5.7.7 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, 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.

7.5.7.8 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 reconstitution 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 Section 5 and Table 8. The required tests vary with material grade (see Annex I).

Table 8—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 I	Annex I	V and A	V and A
Macro-examination	—	Annex I	Annex I	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	—	7.5.7.2	—	V	V
NDE examination	—	7.5.8.12	7.5.8.12	V and A	V and A
Burst	—	7.5.8.13	—	V	V
Pressure	—	—	7.5.8.14	A	A
^a Qualification testing requirements in accordance with Section 5. ^b In some cases, it is necessary to evaluate high-cycle fatigue. This is not typically performed by the tube supplier and is 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.					

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

- destructive or nondestructive examination;
- 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).

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.

— Acceptance criteria for visual and dimensional inspection shall be defined by the manufacturer and agreed with the purchaser prior to the start of manufacture.

7.5.8.3 Dimensional Tolerances

The dimensional tolerances for the tubes shall be in accordance with Table 9. Alternative tolerances may be agreed upon by the UMBILICAL manufacturer and the purchaser provided the criteria in 7.5.2 are satisfied.

Table 9—Dimensional Tolerances

Characteristic That Shall Be Tested	Recommended Tolerance	Extent of Testing %
Outer diameter ^a	$\pm 0.3 \% D^b$ or ± 0.13 mm, whichever is greater	100
Out-of-roundness ^c	$1.0 \% D^b$	100
Tube wall thickness	$\pm 10 \% t^d$	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 caliper or calibrated nondestructive testing device.		

The tolerance to wall thickness is included in the design equations for pressure containment and collapse (see Annex H), and the values stated in Table 9 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 9 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 9 are in line with the most stringent requirements of ASTM A789, but leave out the discontinuities specified in ASTM A789.

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 uniaxial 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 pass/fail criteria shall be agreed upon between the purchaser and the umbilical 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 I 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 I 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 I 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 I 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 I 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 I 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 I for tube material applicability.

7.5.8.12 Nondestructive Examination

All tubes shall be subject to non-destructive examination (NDE) in accordance with ASTM A1016/A1016M or equivalent, and 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 tubes. 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:

- a) tube dimensions;
- b) pore geometry;
- c) pore location within the weld;
- d) number of pores.

Consideration shall be given to the sensitivity, calibration, and limitations of any NDE method employed such that unacceptable defects shall be located and defective tubes identified and segregated for further examination and possible corrective action.

See Annex I for tube material applicability.

7.5.8.13 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, 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 $2 \times DP$.

7.5.8.14 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 $1.5 \times DP$ for a minimum of four hours 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, suitably filtered to allow the achievement of the final system cleanliness, as defined in the manufacturer's written specification:

- a) specified system control fluid;
- b) proprietary storage fluid;
- c) town-mains or potable water; 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) deionized water.

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, 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, 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 partly 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

NOTE The purchaser may consider additional requirements for ancillary equipment; these can be found in API 17L1 and API 17L2.

The design shall be carried out in accordance with the philosophy in Section 5 and the relevant parts of Section 6 and Section 7.

Terminations and ancillary equipment should be designed for the predicted loads experienced by the component. The safe working load for terminations and ancillary equipment may be different from the limit states of the umbilical.

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

The design shall also take into consideration temperature effects during transport and installation, installation method, and possible repair and intervention situations 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 nonmetallic 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. Cathodic protection shall be in accordance with the requirements of DNV-RP-B401, *Cathodic Protection Design*.

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 Section 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 or wet storage, the requirement for pressure relief during retrieval shall be evaluated and additional corrosion protection allowance considered. If temporary cable end sealing is used, a double watertight barrier should be included.

8.3 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 shall 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.

8.4 Cable Terminations

For electric/optical fiber 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 seawater 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 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 block to stop water penetration and incorporate a gas-blocking feature to minimize gas permeation into the pigtail 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.

Both ends of each cable component shall have matched identification prior to terminating the cable to ensure its continuity.

Cable termination that serves a temporary function, such as cable seal inside the pull-in head, shall be designed to satisfy the environment to which the termination will be exposed prior to permanent termination.

Termination design for MV cable shall consider the type of power to be transmitted (AC or DC), as it may require different connector design.

Cable termination shall be designed to achieve intended functions of each component within cable, to include armor and semiconductor shield. This requirement may be critical for MV cable that is designed for AC application.

Cable termination shall be rated equal or higher than the cable within the umbilical. If that is not achievable, the cable shall be de-rated to the lowest-rated component in the system to avoid overvoltage applied during system testing.

Accurate cable dimension data shall be used to design boot seal that provides interface between the cable or hose conduit and the connector.

The materials utilized in the termination assembly shall be compatible with both seawater and the selected dielectric fluid.

8.5 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 shall 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-fiber 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 generally 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 utilization factor shall be 0.59 (equal to $1/1.7$).

A proof test shall be carried out at a load approved by the purchaser. A 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-OS-H205 or an approved code proposed by the contractor.

8.6 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 safe and controlled manner with containment, and facilitate functional testing.

The hang-off system design shall ensure adequate strength and fatigue of all components (pull-in head, connections, valves, tube termination, etc.) for the hang-off structure.

8.7 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 armor 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.

8.8 Subsea Umbilical Connection

A subsea umbilical termination shall be used to connect the umbilical mechanically and functionally to the subsea system.

NOTE Suitable handling facilities may be included, if required, for use during load-out and installation. These are 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, with the exception of fittings or flanges at the umbilical interface, shall have been subjected to hydrostatic pressure testing prior to connection to the umbilical. The test pressure of the terminated umbilical may now be limited by the components within the termination.

8.9 Bend Restrictors

NOTE 1 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 shall lock at a specified bend radius to assist in handling and maintain the umbilical position when in service.

NOTE 2 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).

NOTE 3 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.

NOTE 4 Overall size, mass, and center of gravity are required for handling purposes.

NOTE 5 Materials of construction can be metallic or thermoplastic, depending on functional requirements.

The design of the bend restrictor shall take into account the size, mass, and center 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 evaluated in the design.

The bend restrictor shall be mechanically protected during handling.

NOTE 6 For umbilicals with a large center tube, the termination interface can result in large free spans.

8.10 Bend Stiffeners

8.10.1 General

NOTE 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.

8.10.2 Dynamic Bend Stiffeners

NOTE 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, as should operational temperature.

Documentation of overall size, mass, and center of gravity shall be 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.

8.10.3 Static Bend Stiffeners

NOTE Static bend stiffeners are used to provide an increase in bending stiffness at the point of attachment to a termination. In the case of armored 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 the risk of snagging during handling, deployment, or recovery.

8.11 Ancillary Equipment

8.11.1 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 suitable bend protection at each end, and shall be of compact size to facilitate reeling, storage, and installation requirements.

The joining of the electric cables, optical fibers, 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.

8.11.2 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 that 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.

8.11.3 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 a "clamped" or similar type of connection 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 the amount of buoyancy provided, effects of water depth, allowable clamping pressure onto the umbilical, interface geometry between the clamp and umbilical, potential change in umbilical diameter with tension, or effects of long-term creep.

8.11.4 Centralizers

NOTE 1 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.

NOTE 2 These devices usually are split in two halves, which allow for ease of fitting during installation.

NOTE 3 Designs may include an inner segmented or split clamp that is firmly attached to the umbilical and has 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 the clamping pressure to attach the inner clamp around the umbilical.

8.11.5 Vortex-induced Vibration Strakes

NOTE 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 the 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.

8.11.6 Riser-tube Seals

NOTE 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.

8.11.7 Tie-back Clamps

NOTE 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.

8.11.8 Temporary Hold-back Clamps

NOTE 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 appurtenance to the umbilical itself.

These shall be designed 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.

8.11.9 Bellmouth

NOTE 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.

8.11.10 Riser Clamps

NOTE 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 Section 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-fiber 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 Section 4, the design requirements of Section 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.

For umbilicals containing MV cables, additional consideration shall be given to the following:

- a) The cross-section shall be arranged to minimize coupling between the MV power circuits.
- b) The cross-section shall be arranged to minimize electromagnetic inductance into non-current-carrying conductive components and LV electrical cables, with consideration given to each potential operating scenario for the MV power circuits at maximum transmission power.

- c) Lay direction, lay angles, and lay lengths of the circuits shall be designed to minimize induced voltage from each three-phase circuit to any other three-phase circuit in the umbilical.
- d) The cross-section arrangement shall be designed to prevent permanent deformation of the MV electrical cables, in order to avoid uneven voltage stress within the cable, with consideration of the crushing forces on the bundle during manufacture, reeling, installation, and service.
- e) The cross-section arrangement shall take into account the temperatures generated within the bundled umbilical from the power circuit(s) and be designed to ensure the individual umbilical components are not exposed to temperatures beyond their design limits for the specified service life.

9.6 Lay-up

Individual functional components (electric cables, optical-fiber 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-fiber 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 oversheathed 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 armored, an inner sheath shall be applied over the taped bundle to provide mechanical protection, increase bundle stability, and provide bedding for the armor wires. The sheath construction shall be:

- a) for static applications: either a continuously extruded thermoplastic material or a layer of helically applied synthetic fiber 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 armor wire and the bundle. The material purity, thickness of the sheath, and 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 armoring process (if applicable) and to ensure that the bundle components can move freely and independently of each other during bending and flexing.

9.9 Armoring

Umbilicals that contain electrical conductors and/or optical fibers, but that do not include load-bearing tubes, shall be armored or shall include a suitable strain member. For umbilicals that are torque-balanced and/or are subjected to high-tensile loading, the armoring shall consist of two or more contra-helically applied layers of steel armor wires (if required, other suitable materials that provide the specified performance may be used). The armor 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 armoring may also serve to provide ballast to achieve the necessary stability during dynamic operation. For multilayer armor 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 armor 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 armoring packaging.

NOTE EN 10257-2 and ASTM A411 provide specifications for suitable steel wires.

For an umbilical that contains 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 armor layer for mechanical protection of the components, or ballasting of the umbilical, shall be evaluated as part of the design performance analysis.

If required, thermoplastic filler rods may be used in place of armor 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 color 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 having a minimum character height of 25.4 mm (1.0 in).

Other key locations that could be relevant for marking on the umbilical outer sheath may include:

- a) buoyancy module locations;
- b) centralizer positions;

- c) clamping locations;
- d) touch-down point.

10 Umbilical Manufacture and Test

10.1 Umbilical Manufacture

10.1.1 General

Manufacturing operations shall be done according to the 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, armoring, 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 mentioned above, 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

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 an 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 Armoring

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 armor wire to confirm that the material properties are within the specified limits.

Armor wires shall be wound uniformly onto armor 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 armor 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 armor layers, if used, shall be applied at uniform tension. The tension applied to the armor 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 armor 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 armor. Care shall be taken to ensure that the sheathed bundle is not stretched and that the sheath is not disturbed during this process.

If armor-wire welds are included in an armoring layer, they shall be staggered and shall be made in accordance with the manufacturer's written specification. Armor-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 Section 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) tensioner slip test;
- n) buoyancy module slip test (if applicable);
- o) repair splice qualification (bundle);
- p) elevated temperature test for umbilicals exposed to elevated temperatures.

The objectives of all full-scale tests are described in Annex J 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 the 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.

NOTE 1 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.

NOTE 2 Optical fibers may be subject to light-signal monitoring (optical continuity) where sensible and practical, or to measurement made before or after the test.

For tests that require tensile-loading of the umbilical and termination, 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 both prior to and after fitment of end terminations, unless otherwise agreed by the purchaser.

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 partially completed components 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 LV Electric Cable

On completion of umbilical manufacture, LV electrical cores shall be subject to the following FATs:

- a) DC-conductor resistance, as specified in 7.2.11.4;
- b) insulation resistance, as specified in 7.2.11.5;
- c) High-voltage DC, as specified in 7.2.11.6;
- d) transmission-in line characteristic, as specified in 7.2.11.7, 7.2.11.8, 7.2.11.9, and 7.2.11.10;

- e) Cross-talk, as specified in 7.2.11.11 and from cable to cable when required by system design;
- f) Time-domain reflectometry, as specified in 7.2.11.12.

Inductance, capacitance, and impedance characteristics shall be measured only if the overall length is sufficiently short so as not to introduce spurious results.

11.4 MV Electric Cable

MV electrical cores shall be subject to the following FATs on the completed length:

- a) DC-conductor resistance, as specified in 7.2.12.4;
- b) insulation resistance, as specified in 7.2.11.5;
- c) partial discharge, as specified in 7.2.12.5;
- d) high-voltage AC, as specified in 7.2.12.6;
- e) screen integrity, as specified in 7.2.12.9;
- f) time-domain reflectometry, as specified in 7.2.12.8.

For umbilicals that contain multiple MV cables or a combination of MV and LV cables, additional testing may be requested by the purchaser to measure the effects of interference between different conductors and circuits.

11.5 Optical-fiber Cables

On completion of umbilical manufacture, the optical-fiber cables shall be subject to an optical time-domain reflectometry test as specified in 7.4.11.3.

11.6 Trial Termination Fit-up

Trial assembly of all temporary and permanent termination hardware shall be undertaken.

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 $1.5 \times DP$ over a minimum period of four hours; however, a longer period may be required as agreed between the 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 1 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 G. 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.
 - 1) The highest-possible flow rate shall be used that does not result in the hose being subject to a pressure greater than the DP 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 minutes, using the procedure specified in ISO 4406. The cleanliness levels shall meet or exceed the value(s) specified in the manufacturer's written specification.

NOTE 2 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 DP may result due to limitations in flushing equipment capacity.

NOTE 3 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 $1.25 \times DP$ for a minimum of four hours;
- b) flow test in accordance with the procedure of 11.7 b);
- c) fluid cleanliness in accordance with the procedure of 11.7 d).

11.9 Functional Component 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.

11.10 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.

12 Storage

12.1 General

Upon satisfactory completion of all umbilical FATs, the umbilical shall be stored on a carousel, reel, or 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 or 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 outermost layer of the umbilical shall be within the flange diameter of the reel. The end termination may protrude with end-user approval. 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. Reel and carousel location shall be subjected to a risk assessment and appropriate mitigation.

12.2 Protection of Underminated Umbilical Components

12.2.1 Electrical Cables

Electrical cores shall be capped and sealed to prevent water ingress.

12.2.2 Optical-fiber Cables

Optical-fiber 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, the ends shall be protected to ensure cleanliness of the internal surface. Hoses/tubes may be preserved with an appropriate fluid.

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, against typical installation pad materials;
- b) maximum tensile strength;

- c) ultimate tensile strength;
- d) axial stiffness;
- e) bending stiffness;
- f) mass (weight) in air (when hoses/tubes are filled with the installation fluid);
- g) weight in water (when hoses/tubes are 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, operation, and storage conditions (plus capacity curve for installation conditions);
- m) load-torque characteristics (torque-balance);
- n) maximum crush load per unit length based on a defined pad configuration, shape, and material;
- 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 DPs;
- 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;
- x) required tooling for installation of ancillary equipment.

13.2 Route Information

The 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;
- i) repair joint dimensions and fitting procedure.

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 API 17H.

13.4 Host Facility Information

The purchaser shall provide the relevant details of the platform(s). These include, at 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 the I- or J-tube and surrounding area, including any obstructions over the 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.

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, at 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-hour 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 is loaded 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;
- m) equipment requirements and responsibilities for post-load-out testing.

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 D summarizes the tests specified in the main body of this document.

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 for LV cables and 7.2.10.3 for MV cables, and shall be within $\pm 2\%$ 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 for LV cables and 7.2.10.3 for MV cables and compared with those obtained during the FAT. Any changes shall be evaluated.

14.5.2.3 Time-Domain Reflectometry Test

A TDR test shall be carried out only in the event of an unexplained CR or IR fault being encountered. The test shall be in accordance with 7.2.11.12 for LV cables and 7.2.12.8 for MV cables.

14.5.3 Optical-fiber Cables

An OTDR trace shall be obtained for each fiber 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 $1.1 \times DP$, 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 $1.1 \times DP$ for a minimum of four hours, shall be carried out on each tube that is in the umbilical. The test duration may be reduced, subject to all parties' agreement, but should not be less than one hour.

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 the allowable bend radius based on the manufacturer's capacity curve for the umbilical.

14.8.4 Lifting the Umbilical

If the umbilical is to be lifted 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 onboard 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 for LV cables and 7.2.10.3 for MV cables.

14.9.3 Optical-fiber Cables

The attenuation of the fibers shall be monitored at regular intervals, as agreed with the purchaser, during the load-out operation using an OTDR. Should there be any change in attenuation or any apparent discontinuity in the fiber, 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 (1015 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 armor 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 transpoiled 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. For delivery on reel, umbilical contractor shall provide sufficient information regarding umbilical reel (estimated weight, center of gravity, allowable location to anchor securing chains and ratings, or acceptable location to weld stopper plates) in advance in order for the transportation contractor to proceed to proper lifting and seafastening activities.

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) TDR (only in the event of an unexplained CR or IR fault being encountered).
- b) optical fibers (see 14.5.3): OTDR;
- c) hydraulic (see 14.5.4):
 - 1) hose pressure/decay test,
 - 2) tube pressure test.

NOTE The umbilical load-out can potentially be the time at which the umbilical is handed over to the installation contractor or to an end user, and as such, can be a significant contractual event. It is thus in the best interest of all parties to conduct a series of post load-out tests to ensure the integrity of the umbilical.

15 Installation Operations

15.1 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 avoids infringement of the allowable bend radius and that avoids 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 overboarded in a safe manner without the possibility of damage and hold-ups due to sharp edges, rough surfaces, and obstructions.

The installer shall carry backup equipment onboard the vessel whenever this is practicable, and shall ensure that suitable spares are available at all times for the rapid repair of all essential items.

15.2 Pre-installation Survey

15.2.1 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.

15.2.2 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 or environmentally sensitive areas, 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 the 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.

15.2.3 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.

15.3 I-tube or J-tube Pull-in Operations

15.3.1 General

NOTE In the course of installing umbilicals, it is usually necessary to carry out I- or J-tube pull-in operations.

15.3.2 Preparatory Work

Prior to initiating the pull-in, a number of activities shall be carried out in order to ensure that the operation can be completed successfully, including:

- 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 be checked against the expected loads it will handle.

The messenger wire should not be considered as the pull-in cable.

15.3.3 Weather Window for Pull-in

The availability of a suitable weather window shall be established prior to initiating operations. The required window shall take into account 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 overboarding chute in one location without causing damage to the deployed umbilical due to localized flexing at the point of overboarding. Provision shall be made to avoid extended duration of point loading/flexing of the umbilical.

15.3.4 Initiation of Pull-in Operations

Following successful completion of the host-facility preparatory activities described in 15.3.2, 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 regulatory requirements that pertain to operations on the host facility, including obtaining the necessary permits.

15.3.5 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.

15.3.6 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.

15.3.7 First End Pull-in

The pull-in head shall be overboarded 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 is not dragged excessively along the seabed or subjected to overbending.

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 what was 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.

15.3.8 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 armor 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.

15.3.9 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 may be 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.

15.3.10 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.

15.3.11 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.

15.4 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.

15.5 Lay Route

The umbilical lay route shall be shown on umbilical route alignment charts. These charts shall show the waypoints, 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.

15.6 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 overboarding 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.

15.7 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 onboard 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, 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 a 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.

15.8 Control and Monitoring of Length Laid

Umbilical length paid out shall be monitored against the distance traveled along the planned route in order to:

- a) detect whether excessive umbilical length is being laid, and
- b) 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 (kilometer 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 the completion of lay are given in 15.12.

15.9 Integrity Monitoring During Lay

15.9.1 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.

15.9.2 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 7.2.11.4 for LV cables and 7.2.12.4 for MV cables.

NOTE Certain termination arrangements can preclude this test from being carried out (e.g. inductive couplers).

15.9.3 Optical-fiber Cables

Each optical fiber 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 fiber problem investigated.

15.9.4 Hoses/Tubes

Each hose/tube shall be pressurized to a gauge pressure of a minimum of 7.0 MPa (1015 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 behavior 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.

15.9.5 Visual Inspection

The umbilical shall be examined visually during deployment for signs of distortion, kinking, surface damage, bird-caging of armor 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 may not be apparent until sufficient water depth is achieved.

15.9.6 In-line Termination

In the case of a midpoint 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 midpoint 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 the purchaser and manufacturer.

NOTE For deepwater service, it can be necessary to increase this pressure to minimize the number of times it may be 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:
 - 1) DC resistance,
 - 2) insulation resistance,
 - 3) TDR;
- c) optical: ODTR.

15.10 Burial Operations

15.10.1 General

Ploughing or trenching, if required, shall be performed as a single-pass operation. If the required burial depth is not achieved, 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 (164 ft) of any subsea facility.

15.10.2 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.

At 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.

15.10.3 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.

15.11 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 toward the final waypoint 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.

15.12 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; however, 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 maneuvering 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.

15.13 Pull-in of Subsea Termination with Mating Plates

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 affected after pull-in.

The angular orientation of the termination with respect to the subsea structure is particularly critical.

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. 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.

15.14 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.

15.15 Buoyancy Attachments

The contractor's installation procedures shall address:

- a) adequate access area on the installation vessel to install buoyancy attachments prior to overboarding umbilical;
- b) umbilical marking for buoyancy attachments;
- c) visual confirmation during installation that the proper configuration of the umbilical is achieved (i.e. lazy wave) and no elements have slipped during installation;
- d) final configuration verification as part of the post lay/installation survey.

15.16 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.

15.17 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.

15.18 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:

- a) video survey of the entire length of the umbilical route;
- b) identification of the positions of any unburied or unsupported lengths of the umbilical.

The installer shall carry out suitable remedial work if required. 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.

15.19 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,
 - 3) TDR (only in the event of an unexplained CR or IR fault being encountered).
- b) optical fibers (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 should be compared against a similar system test arrangement (for example, between similar functions in the same umbilical).

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.

15.20 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,
 - 3) TDR (only in the event of an unexplained CR or IR fault being encountered).
- b) optical fibers (see 14.5.3): OTDR;
- c) hydraulic, for which the test pressure for the post-hook-up hydraulic tests shall be $1.0 \times DP$ for control lines, and $1.1 \times DP$ for chemical lines (see 14.5.4):
 - 1) hose proof-pressure/decay test,
 - 2) tube pressure test.

15.21 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.

15.22 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.

15.23 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.

15.24 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 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)

API Monogram Program

Use of the API Monogram by Licensees

A.1 Scope

A.1.1 Applicability

This annex is normative (mandatory) for products supplied bearing the API Monogram and manufactured at a facility licensed by API; for all other instances it is not applicable.

A.1.2 General

The API Monogram® is a registered certification mark owned by the American Petroleum Institute (API) and authorized for licensing by the API Board of Directors. Through the API Monogram Program, API licenses product manufacturers to apply the API Monogram to products which comply with product specifications and have been manufactured under a quality management system that meets the requirements of API Q1. API maintains a complete, searchable list of all Monogram licensees on the API Composite List website (www.api.org/compositelist).

The application of the API Monogram and license number on products constitutes a representation and warranty by the licensee to API and to purchasers of the products that, as of the date indicated, the products were manufactured under a quality management system conforming to the requirements of API Q1 and that the product conforms in every detail with the applicable standard(s) or product specification(s). API Monogram program licenses are issued only after an on-site audit has verified that an organization has implemented and continually maintained a quality management system that meets the requirements of API Q1 and that the resulting products satisfy the requirements of the applicable API product specification(s) and/or standard(s). Although any manufacturer may claim that its products meet API product requirements without monogramming them, only manufacturers with a license from API can apply the API Monogram to their products.

Together with the requirements of the API Monogram license agreement, this annex establishes the requirements for those organizations that wish to voluntarily obtain an API license to provide API monogrammed products that satisfy the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program requirements.

For information on becoming an API Monogram Licensee, please contact API, Certification Programs, 1220 L Street NW, Washington, DC 20005 or call (202) 682-8145 or by email at certification@api.org.

A.2 Normative References

In addition to the referenced standards listed earlier in this document, this annex references the following standard:

API Specification Q1, *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry*

For Licensees under the Monogram Program, the latest version of this document shall be used. The requirements identified therein are mandatory.

A.3 API Monogram Program: Licensee Responsibilities

A.3.1 Monogram Program Requirements

For all organizations desiring to acquire and maintain a license to use the API Monogram, conformance with the following shall be required at all times:

- a) quality management system requirements of API Q1;
- b) API Monogram Program requirements of API Q1, Annex A;
- c) requirements contained in the API product specification(s) to which the organization is licensed;
- d) requirements contained in the API Monogram Program License Agreement.

A.3.2 Control of the Application and Removal of the API Monogram

Each licensee shall control the application and removal of the API Monogram in accordance with the following:

- a) products that do not conform to API specified requirements shall not bear the API Monogram;
- b) each licensee shall develop and maintain an API Monogram marking procedure that documents the marking/monogramming requirements specified by this annex and any applicable API product specification(s) and/or standard(s). The marking procedure shall:
 - 1) define the authority responsible for application and removal of the API Monogram and license number;
 - 2) define the method(s) used to apply the Monogram and license number;
 - 3) identify the location on the product where the API Monogram and license number are to be applied;
 - 4) require the application of the date of manufacture of the product in conjunction with the use of the API Monogram and license number;
 - 5) require that the date of manufacture, at a minimum, be two digits representing the month and two digits representing the year (e.g. 05-12 for May 2012) unless otherwise stipulated in the applicable API product specification(s) or standard(s);
 - 6) define the application of all other required API product specification(s) and/or standard(s) marking requirements.
- c) only an API licensee shall apply the API Monogram and its designated license number to API monogramable products;
- d) the API Monogram and license number, when issued, are site specific and subsequently the API Monogram shall only be applied at that site-specific licensed facility location;
- e) the API Monogram may be applied at any time appropriate during the production process but shall be removed in accordance with the licensee's API Monogram marking procedure if the product is subsequently found to be out of conformance with any of the requirements of the applicable API product specification(s) and/or standard(s) and API Monogram Program.

For certain manufacturing processes or types of products, alternative API Monogram marking procedures may be acceptable. Requirements for alternative API Monogram marking are detailed in the API Monogram Program Alternative Marking of Products License Agreement, available on the API Monogram Program website at http://www.api.org/products-and-services/api-monogram-and-apiqr/apply-renew#tab_documents.

A.3.3 Design and Design Documentation

Each licensee and/or applicant for licensing shall maintain current design documentation as identified in API Q1 for all of the applicable products that fall under the scope of each Monogram license. The design document information shall provide objective evidence that the product design meets the requirements of the applicable and most current API product specification(s) and/or standard(s). The design documentation shall be made available during API audits of the facility.

In specific instances, the exclusion of design activities is allowed under the Monogram Program, as detailed in Advisory #6, available on API Monogram Program website at http://www.api.org/products-and-services/api-monogram-and-apiqr#tab_advisories.

A.3.4 Manufacturing Capability

The API Monogram Program is designed to identify facilities that have demonstrated the ability to manufacture equipment that conforms to API specifications and/or standards. API may refuse initial licensing or suspend current licensing based on a facility's level of manufacturing capability. If API determines that an additional review is warranted, API may perform additional audits (at the organization's expense) of any subcontractors to ensure their conformance with the requirements of the applicable API product specification(s) and/or standard(s).

A.3.5 Use of the API Monogram in Advertising

An API Monogram licensee shall not use the API Monogram and/or license number on letterheads, buildings or other structures, websites, or in any advertising without an express statement of fact describing the scope of Licensee's authorization (license number and product specification). The Licensee should contact API for guidance on the use of the API Monogram other than on products.

A.4 Product Marking Requirements

A.4.1 General

These marking requirements shall apply only to those API Licensees wishing to mark applicable products in conjunction with the requirements of the API Monogram Program.

A.4.2 Product Specification Identification

Manufacturers shall mark products as specified by the applicable API specifications or standards. Marking shall include reference to the applicable API specification and/or standard. Unless otherwise specified, reference to the API specifications and/or standards shall be, as a minimum, "API [Document Number]" (e.g. API 6A or API 600). Unless otherwise specified, when space allows, the marking may include use of "Spec" or "Std", as applicable (e.g. API Spec 6A or API Std 600).

A.4.3 Units

Products shall be marked with units as specified in the API specification and/or standard. If not specified, equipment shall be marked with U.S. customary (USC) units. Use of dual units [USC units and metric (SI) units] may be acceptable, if such units are allowed by the applicable product specification and/or standard.

A.4.4 Nameplates

Nameplates, when applicable, shall be made of a corrosion-resistant material unless otherwise specified by the API specification and/or standard. Nameplate shall be located as specified by the API specification and/or standard. If the location is not specified, then the licensee shall develop and maintain a procedure detailing the location to which the nameplate shall be applied. Nameplates may be attached at any time during the manufacturing process.

The API Monogram and license number shall be marked on the nameplate, in addition to the other product marking requirements specified by the applicable product specification and/or standard.

A.4.5 License Number

The API Monogram license number shall not be used unless it is marked in conjunction with the API Monogram. The license number shall be used in close proximity to the API Monogram.

A.5 API Monogram Program: Nonconformance Reporting

API solicits information on products that are found to be nonconforming with API specified requirements, as well as field failures (or malfunctions), which are judged to be caused by either specification and/or standard deficiencies or nonconformities against API specified requirements. Customers are requested to report to API all problems with API monogrammed products. A nonconformance may be reported using the API Nonconformance Reporting System available at <http://compositelist.api.org/ncr.aspx>.

Annex B (informative)

Information Provided in a Purchaser's Functional Specification

B.1 General

This annex provides guidelines for information being provided in a purchaser's functional specification for an umbilical system, which references this document 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 that 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 B.2 and B.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.

B.2 Information

B.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.

B.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.

B.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 document should be clearly stated.

B.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.

B.2.5 Specific Purchaser Requirements

B.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, mass, or diameter restrictions, and minimum bend radius if these are likely to impact the shipment and/or installation equipment;
- 2) for dynamic umbilicals, this should address, in addition, the following:
 - i) minimum submerged weight/diameter ratio per meter of length (with units), 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).

B.2.5.2 Component Characteristics and Design Criteria

This document defines acceptance criteria for hoses and metallic tubes, and gives guidance on the design of terminations.

Table B.1 shows an overview of the different umbilical components and their design criteria. Table B.1 includes references to the section that defines these criteria. For components where no reference is available, the design criteria are subject to agreement.

Table B.1—Design Criteria for Umbilical Components

Component	Strength Contribution	Design Criteria	Reference
Power cables	<ul style="list-style-type: none"> Can make a significant contribution to tensile strength Compressive (radial) strength contribution is significant 	<ul style="list-style-type: none"> Deformation Fatigue Temperature 	None
Control cables	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> Deformation Fatigue Temperature 	None
Optical signal cable	<ul style="list-style-type: none"> 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 	<ul style="list-style-type: none"> Deformation Fatigue Temperature Elongation Over-length Axial stiffness 	None
Hoses	High in static Low in dynamic	<ul style="list-style-type: none"> Burst Collapse 	7.3 and Annex F
Metallic tubes	High	<ul style="list-style-type: none"> Yielding Buckling Collapse Ovality Fatigue 	7.5
		<ul style="list-style-type: none"> Wear 	None
Fillers	Low	<ul style="list-style-type: none"> Wear Degradation Aging Case-by-case basis 	None
Coating/ Sheathing	Low	<ul style="list-style-type: none"> Thickness Out-of-roundness Max strain level Wear Depend on reason for applying sheathing 	None
Tapes	Low	<ul style="list-style-type: none"> Axial strength Aging 	None
Terminations	Low	—	—
Armoring	High	<ul style="list-style-type: none"> Yielding Buckling Fatigue 	None
Steel wire	High	<ul style="list-style-type: none"> Yielding Fatigue 	None

B.2.6 One-off Functional Requirements

A functional or set of functional requirement(s) that is (are) necessary to meet only once should be stated if necessary for the installation or operation of the umbilical/umbilical system.

B.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.

B.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, overboarding 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.

B.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 B.2.

Table B.2—Activities and Responsibilities

Activities	Responsible Party	
	Purchaser	Manufacturer
Provide design basis and system information	X	—
Provide list of chemicals/fluids that 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 document	—	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 verification and 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, installation, and operation	X	—
^a Unless otherwise specified. ^b The evaluation of the manufacturer's historical project statistics and their relevance for a given project, and hence the project's need for verification and qualification testing, shall be approved by the purchaser.		

B.3 Design Basis Document

B.3.1 General

The design basis should, at a minimum, include

- system information (e.g. system description, function 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-side 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;

- h) tolerances on umbilical length;
- i) design load cases, as referenced in Section 6 (e.g. accidental, ballasted, traverse).

B.3.2 Dynamic Applications

For dynamic applications, the design basis should, at a minimum, include:

- a) geotechnical data (e.g. friction factors, seabed stiffness);
- b) 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;
- c) vessel motion transfer functions;
- d) water depth at vessel and maximum water depth (bathymetry);
- e) vessel schematic, including:
 - 1) umbilical hang-off location (coordinates),
 - 2) vertical top departure angle,
 - 3) horizontal departure angle (azimuth),
 - 4) size of I- or J-tube, ID, MBR;
- f) vessel RAOs;
- g) definition of rotational response (e.g. deg/m, rad/m, rad/rad, deg/ft, etc.);
- h) definition of phase angles (e.g. degree or radians or other; phase lead or phase lag);
- i) definition of vessel heading relative to waves and current (e.g. does a 180° heading represent head seas or following seas?);
- j) hang-off location(s) in vessel coordinate system (see above).

NOTE Static umbilicals are treated as dynamic during the temporary state of installation.

Annex C

(informative)

Load-effect Analysis

C.1 Structural Analysis

C.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 behavior 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 shall be taken 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 behavior 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 behavior 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.

C.1.2 Overview of Structural Analysis Methods

Methods for the structural analysis of umbilicals cover the range from simple analytical methods to advanced FE analysis. With regard to structural behavior, the applied assumptions inherent in these models depend on the applied loading.

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 behavior may be classified into:

- a) analytical equations, basically assuming that there are no gaps between structural components;
- b) computerized methods that handle the umbilical as a set of concentric layers, and where gap and radial effects are handled by iterative procedures that consider geometry, kinematics, and material properties; contact pressures on each layer are assumed to have a uniform distribution, which means the local crush-load effects from contact pressures shall be evaluated separately;
- c) 2-D or 3-D 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 shall be evaluated separately.

With respect to the response to external loads, such as installation crush loads, the available models may be classified into:

- a) analytical models based on a conservative assumption of load sharing between components;
- b) FEM methods, including full contact formulation taking the inherent geometric and material properties into account.

The response in bending is more complicated since relative displacements can occur. The physical behavior in bending can be divided into the following two regimes:

- stick regime, where plane surfaces remain plane as in traditional beam theory; this behavior 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 toward the tensile side of the umbilical.

The above behavior gives rise to friction stresses, 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, as is the imposed friction stress. In such cases, the behavior is governed by elastic bending and the associated stresses can be calculated by analytical methods based on differential geometry. For high tensions, the friction contribution during fatigue calculations shall be evaluated, 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;
- 3-D FEM methods formulating all relevant physical effects, including arbitrary curvature profiles, and where the full equilibrium equation is solved for each component.

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 shall be given 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 shall be documented either by structural testing or by applying models where such effects are included.

Table C.1 gives a summary of the different approaches that may be used.

Table C.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 consists 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 are handled on an individual-component level	3-D 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.		

C.1.3 Calibration of Structural Analysis Methods

The structural analytical methods shall be calibrated by testing. Such tests may be classified as given in Table C.2.

Table C.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	<p>a) Axial and torsion stiffness test measuring:</p> <ul style="list-style-type: none"> – 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. <p>b) Strain-gauge testing where strain gauges are placed on individual components and the strains are measured for the above load conditions.</p>
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	<p>a) Bending stiffness testing where the moment curvature relationship is measured: By designing the test setup 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.</p> <p>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.</p>
To verify the stress and fatigue model	Fatigue testing, where the umbilical is exposed to combined loading in terms of tension, torsion, and curvature.

C.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, at a minimum, when evaluating the need for and the extent of qualification testing:

- a) maximum tension and curvature;
- b) maximum component stress level from tension and curvature;
- c) contact pressure between components;
- d) cross-section lay-out and lay angle;
- e) material properties in terms of mechanical and corrosion performance.

Any qualified analytical method qualified in accordance with C.3 may be used to assess stresses from tension and curvature, as well as the contact pressure.

C.3 Fatigue Analysis Strategies

C.3.1 Alternative Strategies

Alternative strategies for fatigue analysis may be applied as illustrated in Figure C.1.

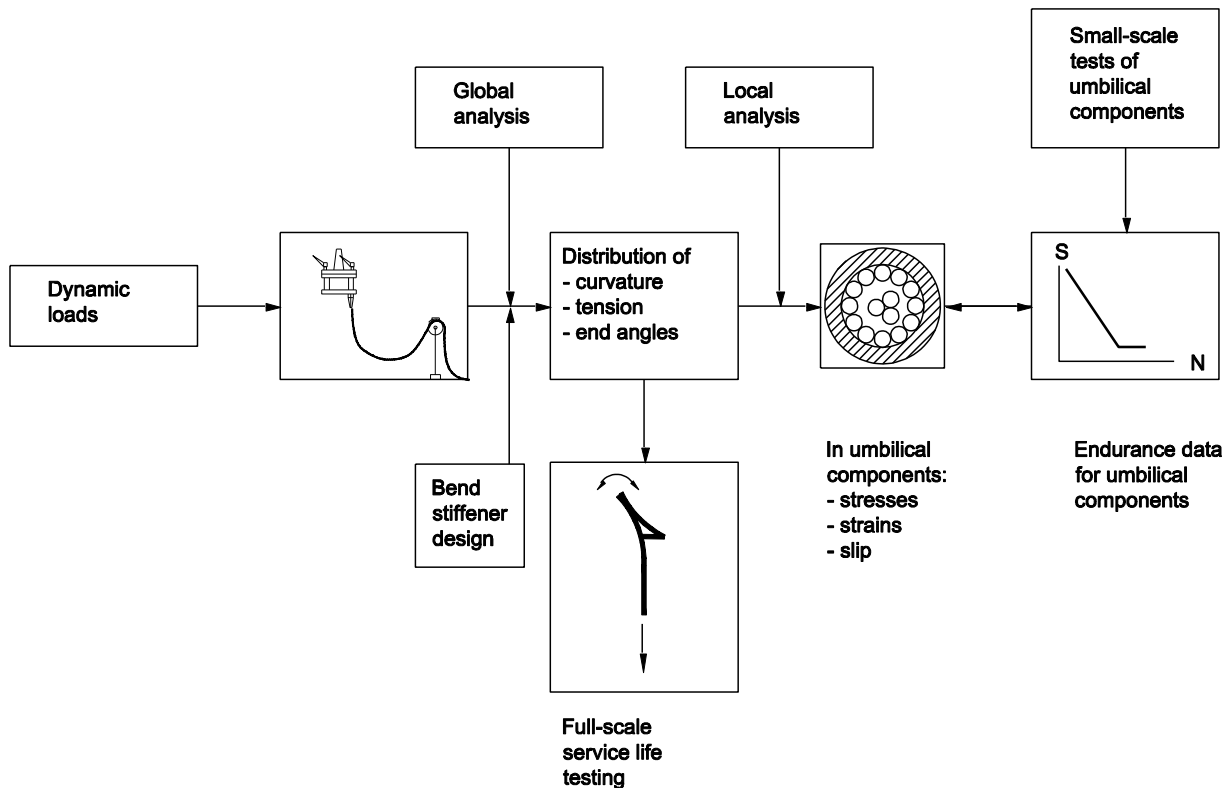


Figure C.1—Schematic Presentation of Fatigue Analysis Strategies

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:

- a) use the results from global analysis as a basis for a full-scale prototype test in order to simulate the service life of the umbilical;

- b) 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. The scaling factor can vary as a function of curvature and shall cover the relevant curvature ranges. In cases where end effects are handled by a 3-D formulation, relevant load histories of tension and end angles from global analyses are required.

C.3.2 Procedures

Different procedures may be applied to calculate the fatigue damage using the methods described in C.3.1. Among these are:

- a) global analysis based on the regular wave approach, where the classes of curvatures and tension responses are applied as input to local stress analyses;
- b) 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:
 - 1) 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 direct calculation of the fatigue damage by time-series processing, and
 - 2) 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.
 - i) The response classes may be obtained by alternative strategies:
 - I) 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,
 - II) 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,
 - III) if the tension variation effect has the same order of magnitude as the curvature effect, the time-series processing shall be based on selecting either tension or curvature as a master quantity to obtain classes of simultaneous tension and curvature variations;
 - 3) joint distribution procedures, which also apply if the tension and end-angle approach is used.

C.3.3 Positions

In general, the different positions in the umbilical cross-section and along the umbilical shall be investigated to ensure that the worst-case location is identified. With regard to handling the effect of environmental load direction, different assumptions may be applied.

- a) 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.
- b) 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 3-D description of the umbilical stress and fatigue model in order to distribute the fatigue over the cross-section. The curvature shall be described about two axes and the angle variation shall be described in 3-D.

C.4 Global Load Effect Analysis Methodology

C.4.1 General

The purpose of global load effect analysis 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 (coordinates, 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).

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 C.3.

Table C.3—Dynamic FE Analysis Techniques

Method	Nonlinearity	
	Environmental Load	Structure
Nonlinear time domain (NTD)	Morrison loading Integration to actual surface elevation	Geometric stiffness Nonlinear cross-section Seafloor contact Contact surface (e.g. bellmouth) Large 3-D rotations
Linearized time domain (LTD)		Linearized at static equilibrium position
Frequency domain (FD)	Linearized at static equilibrium position (stochastic linearization in case of irregular excitation)	

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 used as the primary method of analysis for umbilicals. The nonlinear time-domain approach should allow unlimited translations and rotations in 3-D 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.

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” refers to a deterministic, harmonic wave with a given period and amplitude. “Irregular wave” refers to a stochastic wave generated from a given wave spectrum. One or combinations of the following methods should be applied:

- a) irregular-wave analysis in the time domain;
- b) regular-wave analysis in the time domain;
- c) irregular-wave analysis in the frequency domain.

Wave-period variation should be considered for regular- and irregular-wave analyses to identify the most unfavorable 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:

- a) statistical variation of the wave period;
- b) eigenvalues of the umbilical system;
- c) peaks in host motion transfer function;
- d) 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 modeling and/or analysis technique be verified by more advanced modeling and/or analyses. In particular, the validation, as specified in Table C.4, should be considered for representative (critical) load cases. For further details, see DNV OS-F201:2001, Appendix D.

Table C.4—Validation Analysis Method 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

C.4.2 Cross-sectional Modeling in Global Analyses

As outlined in C.1 through C.3, the umbilical can have rather complex global cross-sectional characteristics of bending due to the stick/slip behavior caused by the contact forces and friction between the components of the umbilical. Globally, this results in 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.

- a) Different structural damping properties are related to axial, torsional, and bending deformation of the umbilical.
- b) The axial and torsional stiffness may be regarded as constant for a given tension in the umbilical.
- c) 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.

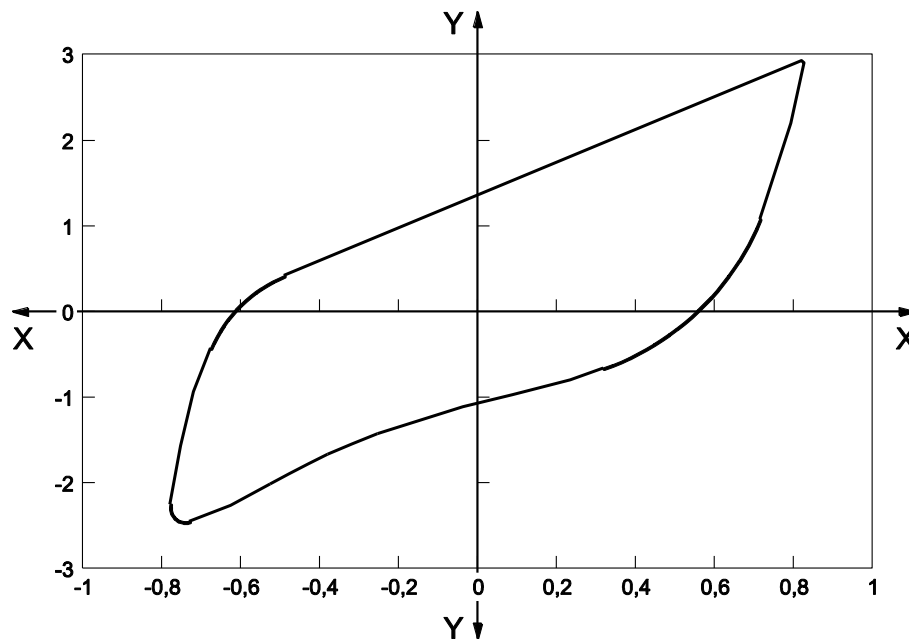
- d) A pronounced moment-curvature hysteresis is observed for large-amplitude bending due to slippage between the components, see Figure C.2. The characteristics of the bending hysteresis are governed by the material properties of the layers and the friction between the layers.
- e) The umbilical behaves 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 only be regarded as 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.

It can be concluded that the damping and stiffness properties in bending is a strongly nonlinear 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.

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 modeling alternatives may be applied:

- i. An equivalent viscous damping model is recommended for small-amplitude vibrations, e.g. VIV and free-spanning analyses. The structural damping 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 and FD formulations
- ii. 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 nonlinear TD solution scheme, this model gives a consistent modeling of the structural properties of the umbilical.



Key

X curvature, $(1/m) \times 10$

Y bending moment, expressed in kilonewton-meters

Figure C.2—Representative Example of Measured Bending Hysteresis

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 referred to as 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.

C.4.3 Global Modeling Considerations

C.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 modeling issues is given in C.4.3.2 to C.4.3.4. Additional guidance on modeling can be found in riser standards/recommended practices, such as API 17J, API 2RD, and DNV OS-F201.

C.4.3.2 Spatial Discretization

Special attention should be given to the following issues related to spatial discretization of the umbilical system:

- a) areas with high curvature, e.g. hog and sag bend;
- b) contact areas, e.g. touch-down, hull supports, bellmouth;
- c) terminations to fixed structures;
- d) areas with high load intensities and/or load gradients, e.g. splash zones;
- e) areas with significant change in cross-sectional properties, e.g. bend stiffener, buoyancy modules, bend limiters;
- f) areas with changes 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 nonuniform cross-sectional properties;
- g) 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.

C.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 analysis considering random-wave loading is recommended for frequency sensitive systems.

Host-motion transfer functions are represented in terms of amplitude and phase angle as functions 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:

- a) The frequencies should be selected to cover the resonance peaks in host-motion transfer functions, e.g. heave, roll, and pitch-resonance frequencies.
- b) 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).
- c) 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.
- d) Discretization of wave direction with spacing in the range of 15° to 30° is normally sufficient to give a good representation of the host motions.

C.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:

- a) 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 all eigenmodes must be integrated 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 seconds to 0.4 seconds for numerically well behaved systems.
- b) Nonlinear analyses generally requires 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 behavior, e.g. moment-curvature hysteresis.
- c) Quality checks of response-time histories should always be considered to identify possible nonphysical noise reflecting an inaccurate numerical solution.
- d) 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.

C.4.3.5 Irregular Wave Modeling

Irregular wave modeling includes the following:

- a) The number of wave components and their frequencies should be selected such that an appropriate integration method of the wave spectrum produces accurate calculations of wave elevation standard deviation, peak period, zero-crossing period, and spectral moments up to the fourth moment. The accuracy should be demonstrated by sensitivity runs that show convergence of the above mentioned parameters.
- b) The frequency of the wave components should be selected with sufficient resolution to accurately capture the resonant responses of the umbilical system in the entire wave frequency range defined in the metocean

criteria. Sensitivity runs with finer frequency spacing should be performed to demonstrate convergence of key global umbilical responses (such as tension and curvature) and capturing of distinct umbilical-response peaks.

- c) The frequencies of the wave components should be selected in a manner that avoids repetition of the wave record within the simulation duration. Repetition should be diagnosed by computing the autocorrelation function of the wave elevation record and showing that this function is a very small percentage of the wave elevation standard deviation for time lags longer than a few wave cycles.
 - 1) The analysis should include multiple realizations and utilize reasonable extreme values.

C.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 determined during the design of the umbilical:

- a) 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;
- b) variation of tension and curvature along the umbilical as a function of sea state and current;
- c) 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;
- d) allowable vessel motions to avoid overstressing the umbilical;
- e) residual tension from trenching;
- f) maximum period of time, as a function of sea state, that the laying vessel can maintain position prior to failure occurring within the umbilical;
- g) impact forces due to rock dumping;
- h) 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 D (informative)

Umbilical Testing

D.1 Schedule of Tests Performed as Part of the Manufacturer's Quality Assurance Program

Table D.1 through Table D.10 reference the sections containing the relevant information.

Table D.1—LV Electric Cables/Electric Cable Elements

Test	Verification	Component FAT	Delivery Acceptance ^a	Umbilical FAT
Visual and dimensional characteristics	7.2.9.2	7.2.11.2	—	—
Conductor resistance	7.2.9.3	7.2.11.4	7.2.11.13 a)	11.3 a)
Insulation resistance	7.2.9.4	7.2.11.5	7.2.11.13 b)	11.3 b)
High-voltage DC	7.2.9.5	7.2.11.6	—	11.3 c)
High-voltage AC	7.2.9.6	—	—	—
Complete voltage breakdown	7.2.9.7	—	—	—
Inductance characteristics	7.2.9.9	7.2.11.7	—	11.3 d)
Capacitance characteristics	7.2.9.10	7.2.11.8	—	11.3 d)
Attenuation characteristics	7.2.9.11	7.2.11.9	—	11.3 d)
Characteristic impedence	7.2.9.12	7.2.11.10	—	11.3 d)
Cross-talk	—	7.2.11.11	—	11.3 e)
Spark test	—	7.2.11.3	—	—
Time-domain reflectometry	—	7.2.11.12	—	11.3 f)
^a These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.				

Table D.2—MV Electric Cables/Electric Cable Elements

Test	Verification	Component FAT	Delivery Acceptance ^a	Umbilical FAT
Visual and dimensional characteristics	7.2.10.2	7.2.12.2	—	—
Conductor resistance	7.2.10.3	7.2.12.4	7.2.12.10 a)	11.4 a)
Metallic screen integrity		7.2.12.9	—	11.4 e)
Insulation resistance	7.2.10.4	7.2.12.5	7.2.12.10 b)	11.4 b)
High-voltage AC	—	7.2.12.6	—	11.4 d)
Complete voltage breakdown	—	—	—	—
Partial discharge	7.2.10.4	7.2.12.5	—	11.4 c)
Capacitance characteristics	—	7.2.12.7	—	—
Spark test	—	7.2.12.3	—	—
Time-domain reflectometry	—	7.2.12.8	—	11.4 f)
Bending test	7.2.10.5	—	—	—
Tan δ measurement	7.2.10.6	—	—	—
Heating cycle test	7.2.10.7	—	—	—
Impulse test	7.2.10.8	—	—	—
Voltage test	7.2.10.9	—	—	—
Resistivity of semiconducting screens	7.2.10.10	—	—	—
Tensile strength characterization test of unspliced and spliced conductor	7.2.10.11	—	—	—
Hyperbaric testing of water-blocking method for specified water depth	7.2.10.12	—	—	—
Accelerated water treeing test ^b	7.2.10.13	—	—	—
Hyperbaric electrical testing	7.2.10.14	—	—	—
^a These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.				
^b This is considered a type test and needs only to be performed to qualify the extrusion equipment and material used for the insulation for all cables using that equipment and material.				

Table D.3—Optical-fiber 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	11.5
^a These tests are undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.				

Table D.4—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	7.3.8.3	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 D.5—Tubes

Test	Verification	Component FAT	Delivery Acceptance ^a	Umbilical FAT
Visual and dimensional	7.5.8.3	7.5.8.3	—	—
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 I	Annex I	—	—
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	7.5.7.2	—	—	—
NDE examination	7.5.8.12	7.5.8.12	—	—
Burst	7.5.8.13	—	—	—
Pressure	—	7.5.8.14	7.5.8.14	7.5.8.14
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 D.6—Umbilicals

Test	Verification/Qualification	Component FAT	Umbilical FAT
Visual and dimensional characteristics	—	11.2	11.2
Electrical continuity at the termination	—	—	11.10
Trial termination fit-up	—	—	11.6
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 o)	—	—
Elevated temperature test (for umbilicals with MV cables)	10.2.1 p)	—	—

D.2 Schedule of Tests Performed as Part of the Installer's Load-out and Installation Program

Tables D.7 through D.10 list the tests performed as part of the installer's load-out and installation program, together with the section reference in this document containing the relevant information.

Table D.7—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)	—	15.19 a) 1)	15.20 a) 1)
Insulation resistance	14.5.2.2	14.11 a) 2)	—	15.19 a) 2)	15.20 a) 2)
Continuity	—	—	15.9.2	—	—
Time-domain reflectometry ^b	14.5.2.3	14.11 a) 3)	—	15.19 a) 3)	15.20 a) 3)
^a These tests are required only for umbilicals stored for periods in excess of three months.					
^b TDR to be carried out only in the event of an unexplained CR or IR fault being encountered. Test to be in accordance with 7.2.11.12 for LV cables and 7.2.12.9 for MV cables.					

Table D.8—Optical Fibers

Test	Pre-load-out ^a	Post-load-out	Installation Monitoring	Post-pull-in	Post-hook-up
Optical TDR	14.5.3	14.11 b)	15.9.3	15.19 b)	15.20 b)
^a These tests are required only for umbilicals stored for periods in excess of three months.					

Table D.9—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)	—	15.19 c) 1)	15.20 c) 1)
Pressure integrity	—	—	15.9.4	—	—
Flow test	—	—	—	15.19 c) 3)	—
^a These tests are required only for umbilicals stored for periods in excess of three months.					

Table D.10—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)	—	15.19 c) 2)	15.20 c) 2)
Pressure integrity	—	—	15.9.4	—	—
Flow test	—	—	—	15.19 c) 3)	—
^a These tests are required only for umbilicals stored for periods in excess of three months.					

Annex E

(informative)

Fatigue Testing

The test regimes should be in accordance with the manufacturer's written specification, taking into account installation and service parameters. The testing should 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 should 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 should 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 should be representative of the predicted installation conditions. The sample should 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 should include changes of direction in the components.

An umbilical intended for dynamic service after installation should 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 should take into account such variables. The effect of such variables on the axial load within the umbilical and the degree of flexure is 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 the example provided in Table E.1.

The results of the analysis can show that a significant number of flex cycles occur at very low levels of angular deflection. At such levels of deflection, the cyclic stress levels in the electrical conductors and armor 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, at 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 should be determined by 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 setup 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:

- a) dynamic tension plus dynamic bending variations of the structural umbilical components as determined by the global analysis;
- b) steel tube pressurization at operating pressure;
- c) electrical continuity of each electrical cable;
- d) continuity of optic-fiber cable;
- e) 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 setup, 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.

The test load case matrix should include damage that represents all applicable sources, e.g. wave frequency loads, vessel slow drift frequency loads, and VIV frequency loads.

Several load cases may be combined into one load case on an equivalent damage ratio basis.

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 seconds	Duration days (unless otherwise noted)
A	250 (56.2)	1.45×10^6	± 2	4	66.7
B	260 (58.5)	5.1×10^5	± 3	4	23.5
C	280 (62.9)	4×10^5	± 4	5	23.0
D	300 (67.4)	2.5×10^5	± 5	6	17.3
E	320 (71.9)	1.7×10^5	± 6	8	15.6
F	350 (78.7)	2.15×10^5	± 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)

Hose and Tube Preferred Sizes

Tables F.1 and F.2 give the preferred hose and tube sizes.

Table F.1—Preferred Hose Size/Pressure Ratings

Nominal Bore		Design Pressure (DP)	
mm	(in)	MPa	(psi)
6.3	(¹ / ₄)	20.7	(3000)
9.5	(³ / ₈)	20.7	(3000)
12.7	(¹ / ₂)	20.7	(3000)
15.9	(⁵ / ₈)	20.7	(3000)
19.0	(³ / ₄)	20.7	(3000)
25.4	(1)	20.7	(3000)
31.8	(1 ¹ / ₄)	20.7	(3000)
38.1	(1 ¹ / ₂)	20.7	(3000)
6.3	(¹ / ₄)	34.5	(5000)
9.5	(³ / ₈)	34.5	(5000)
12.7	(¹ / ₂)	34.5	(5000)
15.9	(⁵ / ₈)	34.5	(5000)
19.0	(³ / ₄)	34.5	(5000)
25.4	(1)	34.5	(5000)
6.3	(¹ / ₄)	51.7	(7500)
9.5	(³ / ₈)	51.7	(7500)
12.7	(¹ / ₂)	51.7	(7500)
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 F.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 G

(normative)

Characterization Tests for Hoses and Umbilicals, Including Hoses

G.1 Hose

G.1.1 Volumetric Expansion Test

G.1.1.1 Performance

This test shall be performed in accordance with ISO 6801, or an equivalent method.

G.1.1.2 Measurement

This method requires measurements to be made on new and unaged hose.

G.1.1.3 Test Samples

Test samples shall not be less than 3 m (9.8 ft) in length between end fittings and shall not be tested within 24 hours of completion of manufacture of the hose.

G.1.1.4 Preconditioning

Prior to undertaking volumetric expansion measurements, precondition the hose by pressurizing the hose sample with water or other compatible incompressible fluid to the DP. Maintain the DP for a period of five days, during which the pressure shall be lowered to atmospheric pressure and returned to the DP once per day. After completing the five-day pressure cycle, test the sample for volumetric expansion three times within 48 hours using the procedure in G.1.1.5, and select the pressure ranges, starting at the highest pressure.

G.1.1.5 Procedure

Define the pressure range for the volumetric expansion measurement, from the DP down to nominally 10 % of the DP. The pressure steps shall be in decrements of 7.0 MPa (1015 psi) down to the nominally 10 % DP 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 \pm 5 minutes before measuring the volumetric expansion, pressurize the test sample to the DP \pm 5 % at a uniform rate of pressure rise, and ensure that the fluid level is set correctly in the burette.

On reaching the DP, open control valve (see Figure G.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 seconds \pm 5 seconds 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 seconds of reaching the defined incremental measurement level.

G.1.1.6 Results

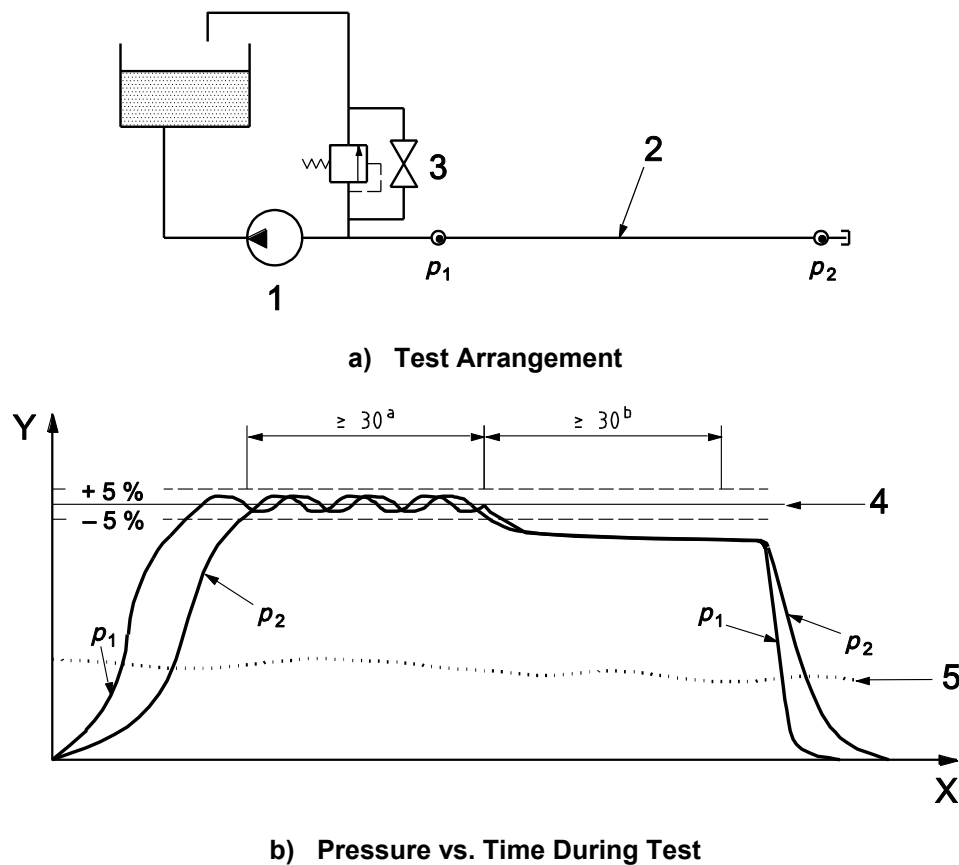
The measured results taken from the burette readings may be expressed as either TVE or AVE, either in terms of cubic centimeters per meter (cubic inches per foot) or as a percentage volume change.

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 behavior 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.



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 $\pm 5\%$; see 7.3.8.6.

^b Period during which the pressure is allowed to decay; see 7.3.8.6.

Figure G.1—Proof Pressure/Decay Test Arrangement

G.1.2 Dynamic Hose Response Test

G.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 setup is shown in Figure G.2.

G.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 two more times for each hydraulic control hose in the umbilical being subjected to this test.

After bleeding air from the hose, close the full-flow vent valve at the remote end of the umbilical. Pressurize the hose to the DP, 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 minutes \pm 10 seconds. Repressurize the hose to the DP 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 design pressure, for a period of 5 minutes \pm 10 seconds.

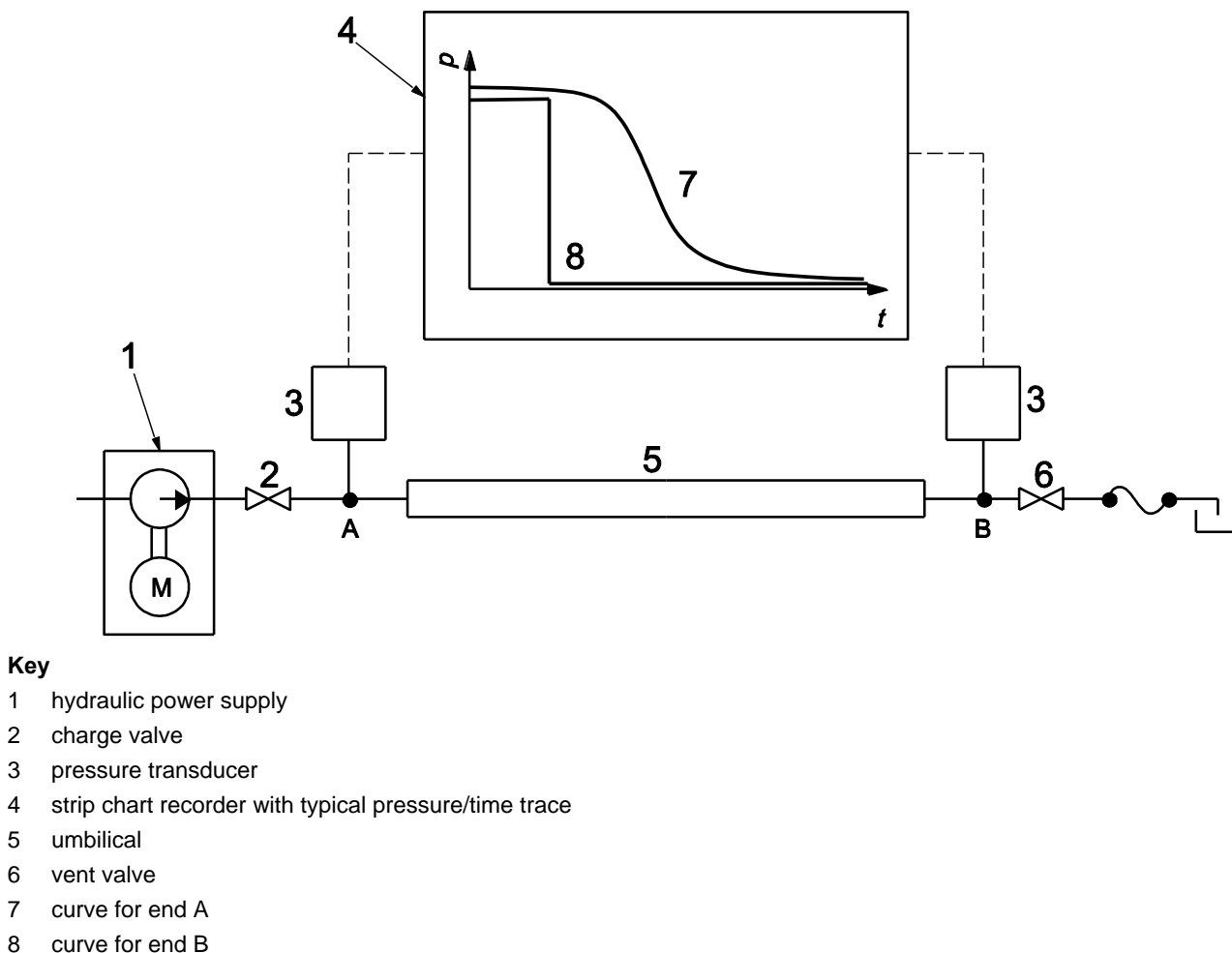


Figure G.2—Schematic Arrangement of Test Setup for Dynamic Response of Hoses

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.

G.2 Umbilical Bend Stiffness Test

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:

- hoses pressurized to the recommended installation value;
- all hoses pressurized to a common value as stated in the manufacturer's written specification.

For static umbilicals, condition a) should apply; for dynamic umbilicals, condition b) should apply.

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 setup; other test setups may be used (e.g. three-point bending).

- One end of the umbilical shall be anchored with all the components locked to produce a built-in end condition.
- Transverse load increments shall be applied to the other end, and the deflection shall be measured 30 seconds \pm 5 seconds after load application.
- No more than a further 30 seconds \pm 5 seconds shall elapse before applying the next load increment.

The load shall be decreased in a similar manner.

Bend stiffness shall be calculated and the section modulus obtained for the sample length. The following shall also be done.

- Repeat the bending cycle until a hysteretic behavior converges.
- Plot the load-displacement loops.
- Use the results to calibrate software tools.

NOTE The bending stiffness properties of the umbilical can change with tension in the umbilical. If precise verification of the bending stiffness at different tensions is required, alternate testing may be required.

Annex H (normative)

Buckling of Metallic Tubes

H.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 H.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:

$$\varepsilon_d \leq \eta_\varepsilon \times \varepsilon_c \quad (\text{H.1})$$

where

η_ε is the utilization factor; see Table H.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 6 in Section 7.5.2.2.

Table H.1—Utilization Factors

Condition	η_ε
Manufacture	0.70

Be aware that the utilization factor in Table H.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.

H.2 Collapse

The criterion for p_e , the external pressure, as expressed in Equation H.2, may be used to avoid collapse due to net external pressure:

$$p_e - p_{\min} \leq \eta_c \times p_c \quad (\text{H.2})$$

where

p_{\min} is the minimum internal pressure that is continuously sustained;

η_c is the utilization factor; see Table H.2;

p_c is the collapse capacity, equal to $\frac{p_p \times p_{el}}{\sqrt{p_p^2 + p_{el}^2}} \times g$;

where

p_{el} is the elastic collapse capacity, equal to $\frac{2 \times E}{1 - \nu^2} \times \left(\frac{t_2}{D}\right)^3$;

p_{pl} is the plastic collapse capacity, equal to $\sigma_{SMY} \times \frac{2 \times t_2}{D}$

where σ_{SMY} is the specified minimum yield stress;

$$g = \sqrt{\frac{1 + (p_p/p_{el})^2}{O^{-2} + (p_p/p_{el})^2}}; \text{ where } O = \sqrt{1 + (0,5 \times f_O \times D/t_2)^2} - 0,5 \times f_O \times D/t_2$$

where

D is the nominal outer diameter;

t_2 is the wall thickness from Table 6 in 7.5.2.2;

f_O is the ovality from manufacturing and installation, equal to $(D_{max} - D_{min})/D$; 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 H.2—Utilization Factors

Condition	η_c
Normal operation	0.62
Installation	0.75

Be aware that the utilization factors in Table H.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.

Annex I (informative)

Tube Material Matrix

I.1 General

Table I.1 shows the tube material matrix.

Table I.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: <ul style="list-style-type: none"> Yield strength Tensile strength Yield/tensile strength ratio Elongation Hardness 	Values as per the manufacturer's written specification and after client acceptance: <ul style="list-style-type: none"> Yield strength Tensile strength Yield/tensile strength ratio Elongation Hardness 	Values as per the manufacturer's written specification and after client acceptance: <ul style="list-style-type: none"> Yield strength Tensile strength Yield/tensile strength ratio Elongation Hardness 	Values as per the manufacturer's written specification and after client acceptance: <ul style="list-style-type: none"> Yield strength Tensile strength Yield/tensile strength ratio Elongation Hardness 	Values as per the manufacturer's written specification and after client acceptance: <ul style="list-style-type: none"> 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 I.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 intermetallic phases.	The ferrite content shall be within 35 % to 55 % mass fraction. The material shall be essentially free from grain-boundary carbides, nitrides and intermetallic 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.	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 the 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 the 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 I.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 center 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 center 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 center 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 Vickers 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 Vickers 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 Vickers 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.

Table I.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)
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
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 API 17. The minimum required burst pressure shall be two times the DP.	Tube supplier shall perform burst testing of tubes in accordance with this part of API 17. The minimum required burst pressure shall be two times the DP.	Tube supplier shall perform burst testing of tubes in accordance with this part of API 17. The minimum required burst pressure shall be two times the DP.	Tube supplier shall perform burst testing of tubes in accordance with this part of API 17. The minimum required burst pressure shall be two times the DP.	Tube supplier shall perform burst testing of tubes in accordance with this part of API 17. The minimum required burst pressure shall be two times the DP.

Table I.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	<p>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.</p> <p>PREN/PREW</p> <p>Test temperature shall be 50 °C and the exposure time shall be 24 hours. No visible pitting corrosion attack is acceptable at 20× magnification.</p> <p>Probing with a sharp instrument is required. The mass loss shall be less than 1.0 g/m².</p> <p>Should a pitting corrosion test fail, a propagation test may be performed in strict accordance with the manufacturer's written specification.</p> <p>ASTM G48-03, method B, is not relevant for tubes. Any crevice corrosion testing should be in accordance with the manufacturer's written specification.</p>	<p>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.</p> <p>PREN/PREW</p> <p>The exposure time shall be 24 hours. No visible pitting corrosion attack is acceptable at 20× magnification.</p> <p>Probing with a sharp instrument is required. The mass loss shall be less than 1.0 g/m².</p> <p>Should a pitting corrosion test fail, then a propagation test may be performed in strict accordance with the manufacturer's written specification.</p> <p>ASTM G48-03, method B, is not relevant for tubes. Any crevice corrosion testing should be in accordance with the manufacturer's written specification.</p> <p>Test temperature for base material: 50 °C (122 °F)</p> <p>Test temperature for orbital weld: 40 °C (104 °F)</p>	<p>Pitting corrosion testing shall be performed in accordance with ASTM G48-03, method A, chemical composition, in accordance with the relevant UNS codes.</p> <p>PREN/PREW</p> <p>The exposure time shall be 24 hours. No visible pitting corrosion attack is acceptable at 20× magnification.</p> <p>Probing with a sharp instrument is required. The mass loss shall be less than 1.0 g/m².</p> <p>Should a pitting corrosion test fail, a propagation test may be performed in strict accordance with the manufacturer's written specification.</p> <p>ASTM G48-03, method B, is not relevant for tubes.</p> <p>Any crevice corrosion testing should be in accordance with the manufacturer's written specification.</p> <p>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.</p> <p>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.</p> <p>Test temperature for strip or longitudinal seam weld: 50 °C (122 °F)</p> <p>Test temperature for orbital weld: 40 °C (104 °F)</p>	<p>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.</p>	<p>Alloy 316L requires some form external cathodic protection in a marine environment.</p>

Table I.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	<p>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.</p> <p>The acceptance criterion is a base-metal ferrite content of 35 % to 55 % mass fraction.</p> <p>The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates, and intermetallic phases.</p> <p>If intermetallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval.</p> <p>Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.</p>	<p>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.</p> <p>The acceptance criteria are:</p> <ul style="list-style-type: none"> a base-metal ferrite content within 35 % to 55 % mass fraction; a weld-metal ferrite content within 35 % to 60 % mass fraction. <p>The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates, and intermetallic phases.</p> <p>If intermetallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval.</p> <p>Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.</p>	<p>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.</p> <p>The acceptance criteria are:</p> <ul style="list-style-type: none"> a base-metal ferrite content within 35 % to 55 % mass fraction; a weld-metal ferrite content within 35 % to 60 % mass fraction. <p>The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates, and intermetallic phases.</p> <p>If intermetallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval.</p> <p>Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.</p>	<p>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.</p> <p>The acceptance criteria are:</p> <ul style="list-style-type: none"> a base-metal ferrite content within 35 % to 55 % mass fraction; a weld-metal ferrite content within 35 % to 60 % mass fraction. <p>The microstructure, as examined at a minimum 400X magnification on an etched specimen, shall be essentially free from grain boundary carbides, nitrides, precipitates, and intermetallic phases.</p> <p>If intermetallic phases are observed, testing may be performed to document adequate corrosion resistance and mechanical properties, subject to purchaser's approval.</p> <p>Metallographic examination should be carried out prior to start of production, since additional testing can be required pending the results from the metallography.</p>	N/A

Table I.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)
Nondestructive 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 I.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	<p>Multiple techniques are used to demonstrate that detrimental levels of intermetallic phase are not present.</p> <p>The method used for in-line detection of intermetallic 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.</p>	<p>Multiple techniques are used to demonstrate that detrimental levels of intermetallic phase are not present.</p> <p>The method used for in-line detection of intermetallic 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.</p>	<p>Multiple techniques are used to demonstrate that detrimental levels of intermetallic phase are not present.</p> <p>The method used for in-line detection of intermetallic 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.</p>	N/A	N/A
Ultrasonic examination	<p>Calibration shall be performed in accordance with ASTM A1016/A1016M and each tube shall be 100 % examined circumferentially and axially according to ASTM E213.</p> <p>Notch examination shall include both inside and outside of the tube.</p> <p>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 surfaces.</p>	<p>Calibration shall be performed in accordance with ASTM A1016/A1016M and each tube shall be 100 % examined circumferentially and axially according to ASTM E213.</p> <p>Notch examination shall include both inside and outside of the tube.</p> <p>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 surfaces.</p>	<p>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.</p> <p>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.</p> <p>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.</p>	<p>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.</p> <p>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.</p> <p>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.</p>	N/A

Table I.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	<p>X-ray examination shall be performed on all orbital welds (OW).</p> <p>The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively.</p> <p>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.</p> <p>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.</p>	<p>X-ray examination shall be performed on all orbital welds (OW).</p> <p>The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively.</p> <p>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.</p> <p>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.</p> <p>Repair of the longitudinal seam weld is not allowed.</p>	<p>X-ray examination shall be performed on all orbital welds (OW).</p> <p>The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively.</p> <p>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.</p> <p>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.</p> <p>Repair of the longitudinal seam weld is not allowed.</p>	<p>X-ray examination shall be performed on all orbital welds (OW).</p> <p>The image quality indicator (IQI) shall be either a wire or hole type in accordance with ASTM E747 or ASTM E1025, respectively.</p> <p>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.</p> <p>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.</p> <p>Repair of the longitudinal seam weld is not allowed.</p>
FAT	N/A	<p>A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel.</p> <p>The tubing shall be pressurized to a minimum of 1.5 times the DP and held for four hours minimum. Reels shall be tested indoors with dry paper beneath them.</p> <p>Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.</p>	<p>A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel.</p> <p>The tubing shall be pressurized to a minimum of 1.5 times the DP and held for four hours minimum. Reels shall be tested indoors with dry paper beneath them.</p> <p>Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.</p>	<p>A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel.</p> <p>The tubing shall be pressurized to a minimum of 1.5 times the DP and held for four hours minimum. Reels shall be tested indoors with dry paper beneath them.</p> <p>Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.</p>	<p>A final hydrostatic pressure test shall be performed after the tubing has been assembled on the shipping reel.</p> <p>The tubing shall be pressurized to a minimum of 1.5 times the DP and held for four hours minimum. Reels shall be tested indoors with dry paper beneath them.</p> <p>Upon satisfactory completion of the hydrostatic test, the tubing shall be purged of hydro test fluid or pigged until dry and then capped.</p>
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 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 manufacture as specified in ASTM A789/A789M.

Table I.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	<p>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.</p> <p>Any repaired area shall be subjected to the following testing:</p> <ul style="list-style-type: none"> ultrasonic wall thickness measurement; outer diameter measurement. <p>All tubes shall be checked for correct marking.</p> <p>A positive material identification (PMI) shall be performed on each tube.</p>	<p>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.</p> <p>Any repaired area shall be subjected to the following testing:</p> <ul style="list-style-type: none"> ultrasonic wall thickness measurement; outer diameter measurement. <p>All tubes shall be checked for correct marking.</p> <p>A positive material identification (PMI) shall be performed on each tube.</p> <p>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.</p>	<p>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.</p> <p>Any repaired area shall be subjected to the following testing:</p> <ul style="list-style-type: none"> ultrasonic wall thickness measurement; outer diameter measurement. <p>All tubes shall be checked for correct marking.</p> <p>A positive material identification (PMI) shall be performed on each tube.</p> <p>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.</p>	<p>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.</p> <p>Any repaired area shall be subjected to the following testing:</p> <ul style="list-style-type: none"> ultrasonic wall thickness measurement; outer diameter measurement. <p>All tubes shall be checked for correct marking.</p> <p>A positive material identification (PMI) shall be performed on each tube.</p> <p>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.</p>	<p>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.</p> <p>Any repaired area shall be subjected to the following testing:</p> <ul style="list-style-type: none"> ultrasonic wall thickness measurement; outer diameter measurement. <p>All tubes shall be checked for correct marking.</p> <p>A positive material identification (PMI) shall be performed on each tube.</p> <p>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.</p>
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 I.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 (cardboard, 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 (cardboard, 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 (cardboard, 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 (cardboard, 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 I.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	<p>Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, a strong emphasis shall be built into the process control.</p> <p>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 nonconformance report. The frequency of such verification shall be in accordance with the manufacturer's written specifications.</p> <p>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.</p> <p>Repeating the heat-treatment process is acceptable as long as the re-heat-treated tubes are considered as a separate lot.</p>	<p>Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, a strong emphasis shall be built into the process control.</p> <p>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 nonconformance report. The frequency of such verification shall be in accordance with the manufacturer's written specifications.</p> <p>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.</p> <p>Repeating the heat-treatment process is acceptable as long as the re-heat-treated tubes are considered as a separate lot.</p>	<p>Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, a strong emphasis shall be built into the process control.</p> <p>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 intermetallic phases.</p> <p>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.</p> <p>The strip-splice weld and the longitudinal seam weld shall be heat treated with a nonoxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.</p>	<p>Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, a strong emphasis shall be built into the process control.</p> <p>Heat treatment shall comply with ASTM A789/A789M unless otherwise agreed to between the supplier and purchaser.</p> <p>This is not a concern, because lean duplex is not expected to form detrimental levels of intermetallic phases under the heat-treatment time and temperature conditions encountered during manufacturing.</p> <p>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 intermetallic phase because it is not expected to form under the heat-treatment time and temperature conditions encountered during manufacturing.</p> <p>The strip-splice weld and the longitudinal seam weld shall be heat treated with a nonoxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.</p>	<p>Heat treatment is regarded as a critical process for ensuring tube quality because of its sensitivity and, as such, a strong emphasis shall be built into the process control.</p> <p>The strip-splice weld and the longitudinal seam weld shall be heat treated with a nonoxidizing atmosphere protecting both the inside and outside surfaces. The orbital weld is not heat treated.</p>
Certification	<p>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 API 17.</p>	<p>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 API 17.</p>	<p>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.</p>	<p>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.</p>	<p>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.</p>

Annex J (informative)

Umbilical Full-scale Tests

J.1 Umbilical Full Scale Tests

Table J.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 Section 10 are required unless waived by the purchaser if previous test results are applicable for the project.

Table J.1—Umbilical Full-scale Tests

Umbilical Full-Scale Test	Objectives and Considerations
Lay-up trial (manufacture of prototype length)	<p>Objectives:</p> <ul style="list-style-type: none">— Assess manufacturing feasibility.— Demonstrate feasibility of manufacturing and handling the candidate cross-section.— Confirm predicted properties (e.g. diameter, weight). <p>Considerations:</p> <ul style="list-style-type: none">— 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	<p>Objectives:</p> <ul style="list-style-type: none">— At loads up to the design tensile load, quantify the permanent set, residual twist, torque balance, rotation characteristics, and axial stiffness of the design.— 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. <p>Considerations:</p> <ul style="list-style-type: none">— Manner of termination to ensure the internal components are firmly gripped.— Number of load increments up to the maximum tensile load (minimum 10).— Method of recording load, extension, and rotation at each load step.— Hold duration at maximum tensile load (minimum one hour).— 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).— 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 J.1 (continued)

Umbilical Full-scale Test	Objectives and Considerations
Bend stiffness test	<p>Objectives: Confirm theoretical bending stiffness for the umbilical.</p> <p>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.</p>
End strength terminations (tension test with terminations)	<p>Objectives:</p> <ul style="list-style-type: none"> — Demonstrate that the strength of the end terminations is 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). <p>Considerations:</p> <ul style="list-style-type: none"> — Design tension may be different for each end; consider all possible load cases, installation, abandonment, recovery, operation in extreme conditions, 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 one hour). — Consider test value greater than calculated maximum design value, which includes SF.
Combined tension and bending test	<p>Objectives: Demonstrate that umbilical can meet specified installation or operational (whichever is the greater) tension and bending load combination.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — 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 one hour). — Evaluate relative movements of elements and deformation of elements as a result of interaction in the combined tension and bending test configuration. — Compare element ovalization with the results from the crush test.

Table J.1 (*continued*)

Umbilical Full-scale Test	Objectives and Considerations
Umbilical squeeze/crush test (installation tensioner simulation)	<p>Objectives:</p> <ul style="list-style-type: none"> — 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. <p>Considerations:</p> <ul style="list-style-type: none"> — For specific pads, confirm that proposed umbilical/tensioner combination meets project acceptance criteria specified in purchaser's contract. — For nonspecific 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. — Permanent component deformation, including ovality of tubes.
Internal/external friction factor assessment	<p>Objectives: Quantify friction factors between bundle and pads.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — 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). — Quantify friction factors between components in the cross-section. — Rate of application of load and hold periods. — Assess the creep behavior.
Umbilical impact test	<p>Objectives: Determine impact/load energy relationship with consequence.</p> <p>Considerations: Using load steps and an appropriately selected impact object, evaluate the energy required</p> <ul style="list-style-type: none"> — to initiate cosmetic damage, — to cause structural deformation to an element, and — to cause element failure under installation or operating conditions.

Table J.1 (*continued*)

Umbilical Full-scale Test	Objectives and Considerations
Dynamic fatigue test	<p>Objectives:</p> <ul style="list-style-type: none"> — 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. <p>Considerations:</p> <ul style="list-style-type: none"> — Replicate the maximum excursion predicted and 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	<p>Objectives: Quantify the flow rate longitudinally through the interstices of the cross-section.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — 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	<p>Objectives:</p> <ul style="list-style-type: none"> — 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. <p>Considerations:</p> <ul style="list-style-type: none"> — 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 <p>NOTE Empty, unpressurized tubes are the most conservative.</p> <ul style="list-style-type: none"> — Rate of increase of pressure. — Effect of cable deformation/insulation compression on cable properties.
Tensioner slip test	<p>Objectives: Determine the minimum squeeze load required to prevent umbilical slippage during installation.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — The test setup shall allow pulling the test samples until slippage occurs. — The test load case matrix and the number of test loads are to be determined by necessary installation analysis. — The test sample shall be sufficiently long to ensure that each of the loads from the load case matrix is applied to the different sections on the umbilical sample.

Table J.1 (*continued*)

Umbilical Full-scale Test	Objectives and Considerations
Host pull tube (bend-stiffener latch) interface tests	<p>Objectives: Confirm interface fit and quantify angular, radial, or other limitations.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — 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 of final connection mechanism shall be verified.
Buoyancy element slip test	<p>Objectives: Demonstrate that the design of the buoyancy element clamping device is adequate to prevent slippage of the buoyancy elements under installation and operation conditions.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — The buoyancy element clamp shall be tensioned in the longitudinal direction of the umbilical incrementally until the target test load is reached. — The umbilical surface should be wetted prior to installation of the clamp. Once the target test load is reached, the tension shall be held for 24 hours to ensure no slip.
Repair splice qualification (bundle)	<p>Objectives: Demonstrate feasibility of proposed repair hardware, repair method, and necessary tooling.</p> <p>Considerations:</p> <ul style="list-style-type: none"> — 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 the 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 tension and bending test on a sample with a repair splice.
Umbilical with medium-voltage cable elevated temperature test	<p>Objectives:</p> <ul style="list-style-type: none"> — Demonstrate that the umbilical components can meet the specified maximum design temperature specified by the project without any degradation in the component properties. <p>Considerations:</p> <ul style="list-style-type: none"> — The test should be representative of the installed condition, and the maximum temperature should be representative of operating and environmental conditions, e.g. solar radiation. — Use of thermocouples to monitor the temperature around different components. — Perform a visual inspection by dissecting the umbilical. — Correlate the test performance with thermal analysis results.

J.2 Example Procedure Detail: Umbilical Squeeze/Crush Test

J.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.

J.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 fibers, 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 the 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.

J.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 the purchaser and manufacturer.

J.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.

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