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Addendum 1

Delete the following from the cover:

Effective Date: January 15, 2018

In Section 1, Scope, on Page 1, delete the last sentence:

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

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Specification for Subsea Umbilicals

API SPECIFICATION 17E
FIFTH EDITION, JULY 2017

ADDENDUM 1, DECEMBER 2017



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Foreword

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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, $t < 6 \text{ mm}$ (0.2 in.);
- internal diameter, $ID < 50.8 \text{ mm}$ (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 ($U_m = 1.2\text{kV}$) up to 30kV ($U_m = 36\text{kV}$).

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*

IECA 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.

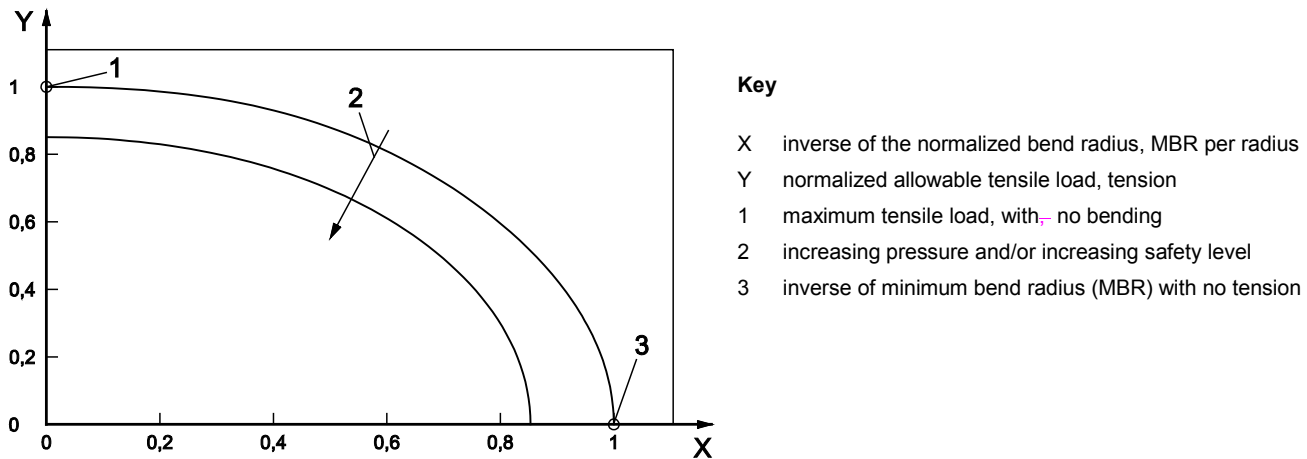


Figure 1—Capacity Curves

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:

- be capable of withstanding specified design loads and load combinations, and perform its function for the specified design life;
- be capable of storage and operation at the specified temperatures during the design life;
- 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;
- where applicable, have electric cables capable of transmitting power and signals with the required characteristics;
- where applicable, have optical fibers capable of transmitting signals at the required wavelengths within the attenuation specified;
- where applicable, have hoses and/or tubes capable of conveying fluids at the required flow rate, pressure, temperature, and cleanliness levels;
- be capable of venting, in a controlled manner, if permeation through components can occur;
- be capable of being installed, recovered, and reinstalled as defined in the manufacturer's written specification;
- 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, subsurface 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.



Documents

Document Sharing Hub

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	Probability of exceedance according to season and duration of the temporary period. If more information is not available, the following return period values may be applied for temporary conditions: — a 100-year return period if duration 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}	Annual exceedance probability of 10^{-2} to 10^{-4} If combined with accidental loads, the environmental load may be established so that the combined annual exceedance probability is 10^{-4} .
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 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 intermediate 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 umbilicals 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 MΩ.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.