Addendum 1

API Specification for Umbilicals

4 Functional Requirements

4.1 General Requirements

4.1.1 Umbilical

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

a) be capable of withstanding specified design loads and load combinations, and perform its function for the specified design life;
b) be capable of storage and operation at the specified temperatures during the design life:
c) be composed of materials compatible with the environment to which they are exposed, including permeating fluids, and in conformance with the corrosion control and compatibility requirements;
d) where applicable, have electric cables capable of transmitting power and signals with the required characteristics;
e) where applicable, have optical fibers capable of transmitting signals at the required wavelengths within the attenuation specified;
f) where applicable, have hoses and/or tubes capable of conveying fluids at the required flow rate, pressure, temperature, and cleanliness levels:
g) be capable of venting, in a controlled manner, if permeation through components can occur;
h) be capable of being installed, recovered, and reinstalled as defined in the manufacturer's written specification;
i) for dynamic umbilicals, the dynamic section of the umbilical shall be fabricated in one continuous length.

4.1.2 End Terminations and Ancillary Equipment

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

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

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

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

d) Cathodic protection shall meet the design life requirement.

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

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

4.2 Project-specific Requirements

The purchaser shall specify the functional requirements for the umbilical.

NOTE 1: Functional requirements neither specifically required nor specified by the purchaser, but that can affect the design, materials, manufacturing, testing, installation, and operation of the umbilical, shall be specified by the manufacturer. If the purchaser does not specify a requirement and its absence does not affect any of these activities, the manufacturer may assume there is no requirement.

NOTE 2: An example of a project functional specification can be found in Annex B.

5 Safety, Design, and Testing Philosophy

5.1 Application

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

5.2 Safety Objective

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

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

5.3 Systematic Review

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

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

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 subcontractor activities when applicable.

5.4.2 Quality Assurance

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

5.5 Design Philosophy

5.5.1 Design Principles

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

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

B) The umbilical system shall be designed such that an unintended event does not escalate into an accident of significantly greater extent than the original event.
C) The umbilical system shall permit simple and reliable installation, retrieval, and reinstallation, and be robust with respect to use.
D) The umbilical system shall provide adequate access for replacement and repair.
E) Design of structural details and selection of materials shall address the effects of corrosion, aging, erosion, and wear.
F) A conservative design approach shall be applied for the umbilical mechanical components. Redundancy may be considered for essential components.

5.5.2 Design Basis

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

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

5.6 Testing

5.6.1 General

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

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

5.6.2 Qualification Testing

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

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

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

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

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

Analysis may be used to compare umbilical and component designs, and to judge the relevance of data from previous testing and operation experience. If such analysis is performed, it shall be carried out according to the requirements of this document (see Section 6).

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

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

5.6.3 Verification Testing

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

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

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

5.6.4. Factory Acceptance Testing

Factory acceptance testing shall be performed to ensure that the umbilical or components meet the design values/criteria specified by the purchaser and stated in the design basis, i.e. to ensure that the sample subjected to verification testing is representative for the manufactured components.

NOTE Factory acceptance testing includes testing performed on the actual delivery component or umbilical, e.g. tests that are performed to document that a welded tube string can withstand the test pressure over a defined time period, or to verify that an electrical/optical signal element has the characteristics it is designed to have. These tests are normally performed several times per product.

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

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

6 Design Requirements

6.1 General

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

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

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

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

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

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

See Annex E for guidance on fatigue testing.

6.2 Loads

6.2.1 Load Classification

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

6.2.2 Functional Loads

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

A) loads due to weight and buoyancy of the umbilical, its contents and attachments, both temporary and permanent;
B) marine growth based on information for the actual geographical location;
C) pressure within hoses and tubes;
D) thermal loads resulting from radiant heat, heat generated from the operation of MV power conductors, hot injected gas/fluids, or from adjacent hot riser(s);
E) external hydrostatic pressure;
F) testing pressures, including installation, commissioning, and storage pressures;
G) external soil or rock reaction forces for trenched, buried, or rock-dumped umbilicals;
H) static reaction and deformation loads from supports and protection structures;
I) temporary installation or recovery loads, including applied tension and crushing loads, impact loads, and guidance-induced loads;
J) displacements due to pressure- and tension-induced rotation;
K) interaction effects of clamping the umbilical;
L) loads due to rigid or flexible pipe crossings, or spans;
M) loads due to positioning tolerances during installation;
N) loads from inspection and maintenance tools.

6.2.3 Environmental Loads

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

A) waves;
B) current;
C) wave-frequency host motions;
D) low-frequency host motions due to wave drift and wind-loading and station-keeping system characteristics;
E) vortex-induced host motions due to current loading;
F) host offset from nominal position due to environmental loading;

G) ice;
H) earthquake;
I) wind;
J) subsea landslides;
K) UV radiation

6.2.4 Accidental Loads

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

A) dropped objects;
B) trawl-board impact;
C) anchor-line failure;
D) fire and explosion;
E) compartment damage or unintended flooding of support vessel or other buoyancy device (e g. subsea arch structure);
F) loss or displacement of buoyancy modules in lazy-wave umbilical configuration;
G) failure of thrusters;
H) dynamic-positioning failure
I) net external pressure (due to flooding, crushing, incorrect installation rate, etc);
J) net internal pressure;
K) failure of turret drive system.

6.2.5 Load Combinations and Conditions

6.2.5.1 General

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

Variation of the loads with respect to time shall be addressed.

6.2.5.2 Extreme Load Combinations

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

A) Normal operation: This shall apply to the permanent operational state of the umbilical, considering functional and environmental loads. Design conditions with a 10’2 annual exceedance probability (i.e. 100-year return period) shall be applied.
B) Abnormal operation: This shall apply to the permanent operational state of the umbilical, considering functional, environmental, and accidental loads. Combined design conditions with an annual exceedance probability between 10‘2 and 10'4 shall be evaluated.
C) Temporary conditions: This shall apply to temporary conditions, such as installation, retrieval, pressure testing, and other intermediate conditions prior to permanent operation, e.g. temporary in-field configurations prior to platform tie-in of umbilicals in dynamic service or burial of static umbilicals. The applicable return period for the design conditions depends on the seasonal timing and duration of the temporary period. The return periods shall be defined such that the probability of exceedance in the temporary state is no greater than that of the permanent normal operational state.

Accidental loads, in terms of frequency of occurrence and magnitude, should be determined based on risk analyses and relevant accumulated experiences. Account shall be taken of other loads that can reasonably be present at the time of the accidental event.

Further, accidental loads shall be determined with due account of the factors of influence.

NOTE 1 Such factors may be personnel qualifications, operational procedures, the arrangement of the installation, equipment, safety systems, and control procedures.

Combined design conditions with an annual exceedance probability higher than 10-2 should be considered to be normal operation.

NOTE 2 Load combinations with an annual exceedance probability lower than 10^* 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 > 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 inplace 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 tieins, 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 analyzes 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. Fatique-load analyses of umbilicals in dynamic service Analyses of installation scenarios to establish limiting criteria for the operations
On-bottom Stability analyses	Analyses to assessthe displacementof 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 Assessmentof 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	Analysesto establish the lay limits of installation operations and to assess and comparethe variablesfor all planned and contingency operations	Assessmentof allowable environmental criteria forfirst-endinitiation, 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 Analysesof 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 irregularwave, 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.

DNVRP-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 requirementfor qualification testing shall be assessed in accordance with 5.6.

In most cases, the focus of this assessmentis 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 numberof 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.

lf 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.

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 y - 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 l- 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 groupedinto 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 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 andjustified 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 accountin 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 this 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 verity 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 performancev chemical compatibility or reduced corrosion resistance which shall be taken into consideration in the umbilical design.

The following shall be taken into account in the analysis:

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

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

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

D) Expected range of operating frequencies.

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

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

6.6 Installation Analysis

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

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

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

6.7 Fatigue Life

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

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

NOTE 2 Qualification or verification testing may be considered necessary to confirm that the manufacturer's design methodology, analysis methodologies, and software tools are mature and accurate for the prediction of fatigue damage and fatigue life.

7. Component Design, Manufacture, and Test

7.1 General

7.1.1 Design Verification

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

NOTE 1 For new component designs that are similar to previously verified designs and whose performance can be predicted with a high level of confidence, design verification tests may be included with some or all of the component FATs.

NOTE 2 If the component design is similar to a previously validated design and the umbilical is being installed under similar environmental and service conditions, design verification may be substituted by previous historical design verification data.

The performance of the end terminations, midline connectors, and ancillary equipment shall be verified by testing, if applicable.

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

7.1.2 Quality Plan

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

A) plan(s) and process flow description/diagram;
B) project-specific quality plan;
C) manufacturing process;
D) manufacturer(s) of functional components and any supplier quality plans;
E) handling, loading, and shipping procedures.

7.1.3 Materials Selection

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

A) installed environment;
B) installed duty;
C) ability to be used in the manufacturing process;
D) in-service repair;
E) degradation related to the seawater environment and service fluids.

NOTE EEMUA Publication 194 includes guidance on materials selection for umbilicals and subsea equipment.

7.2 Electric Cables

7.2.1 General

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

The design of the electric cables shall recognize that the cables may be terminated in some form of waterblocking 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 Uo, U, and (7m.

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 ä 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 mm2 (0.0005 in2). It shall be incorporated in such a way that the drain wire remains in contact with the metallic part of the screen.

7.2.5.9 MV Cable Screening

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

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

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

The screen shall be electrically continuous throughout the cable length, and should be applied in such a manner that its electrical continuity shall not be broken throughout its design life.

7.2.5.10 Sheathing

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

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

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

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

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

7.2.5.11 Armor/ Reinforcement

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

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

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

7.2.5.12 Cable Identification

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

A) the manufacturer;
B) a unique component reference, e.g. “Cable 3”;
C) the batch number;
D) conductor size;
E) voltage rating;
F) description, e.g. single, pair, quad;
G) for MV cables, the individual phases within a triad shall be uniquely identified.

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

7.2.6 Performance Requirements

7.2.6.1 LV Cable Performance

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

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

A) DC conductor resistance;
B) insulation resistance (DC): minimum acceptable value is 1000 MQ.km @ 1000 V (DC).
    a. 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 I EC 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

a. 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.
b. 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.
c. 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 UQ, 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 x Uo + 2kV. 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 x (/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 Ö 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 5 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:
    a. tensile strength characterization test of unspliced and spliced (if splicing is required) conductor;
    b. testing of water-blocking method for specified water depth (where this feature is included);
    c. accelerated water-treeing test in accordance with ICEA S-97-682;
    d. 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 õ 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 £2 m
B) insulation screen: 500 £2 m

7.2.10.11 Tensile Strength Characterization Test of Conductor

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

7.2.10.12 Testing of Water-blocking Method

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

7.2.10.13 Accelerated Water-treeing Test

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

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

7.2.10.14 Hyperbaric Electrical Testing at Specified Water Depth

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

7.2.11 LV Cable Acceptance Testing

7.2.11.1 General

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

7.2.11.2 Visual and Dimensional

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

7.2.11.3 Spark Testing

All cores shall be spark-tested during insulation extrusion.

Other cable sheathing layers should be subjected to spark testing, provided the extrusion is applied directly over a screen or metallic armor layer. There shall be no indication of faults during the extrusion process in order to pass this test.

During the process of insulation and sheath extrusion, the minimum voltage levels shall be in accordance with IEC 602230 for the insulation and sheath thicknesses.

7.2.11.4 DC Conductor Resistance

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

A) after insulation extrusion;
B) after lay-up of the cores;
C) after completion of the electric cable.

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

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

7.2.11.5 Insulation Resistance

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

NOTE This may be different from the value used for qualification testing.

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

7.2.11.6 High-voltage DC

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

NOTE This may be different from the value used for qualification testing.

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

7.2.11.7 Inductance

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

A) on a sample of minimum length 10 m (32.8 ft) removed from the completed length; or
B) on the completed length, provided the overall length does not introduce spurious results.

7.2.11.8 Capacitance

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

A) on a sample of minimum length 10 m (32.8 ft) removed from the completed length; or
B) on the completed length, provided the overall length does not introduce spurious results.

7.2.11.9 Attenuation

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

A) on a sample of minimum length 10 m (32.8 ft) removed from the completed length; or
B) on the completed length, provided the overall length does not introduce spurious results.

7.2.11.10 Characteristic Impedance

On completion of cable manufacture, the characteristic impedance shall be established in accordance with the procedure specified in 7.2.9.12 as follows:

A) on a sample of minimum length 10 m (32.8 ft) removed from the completed length; or
B) on the completed length, provided the overall length does not introduce spurious results.

7.2.11.11 Cross-talk

For cables containing independent conductor pairs that require minimized cross-talk, the cross-talk between conductor pairs at the specified testing conditions shall be measured on the complete cable length for the appropriate mode.

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

7.2.11.12 Time-domain Reflectometry

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

7.2.11.13 Delivery Testing

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

A) DC conductor resistance as specified in 7.2.9.3;
B) insulation resistance as specified in 7.2.9.4.

7.2.12 MV Cable Acceptance Testing

7.2.12.1 General

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

7.2.12.2 Visual and Dimensional

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

7.2.12.3 Spark Testing

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

Other cable sheathing layers should be subjected to spark testing, provided the extrusion is applied directly over a screen or metallic armor layer. There shall be no indication of faults during the extrusion process in order to pass this test.

During the process of insulation and sheath extrusion, the minimum voltage levels shall be in accordance with IEC 62230 for the insulation and sheath thicknesses.

7.2.12.4 DC Conductor Resistance

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

A) after insulation extrusion;
B) after lay-up of the cores;
C) after completion of the electric cable.

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

7.2.12.5 Partial Discharge Test

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

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

The discharge magnitude shall not exceed 10 pC.

7.2.12.6 High Voltage

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

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

No breakdown of the insulation shall occur.

7.2.12.7 Capacitance

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

A) on a sample of minimum length 10 m (32.8 ft) removed from the completed length; or
B) on the completed length, provided the overall length does not introduce spurious results.

7.2.12.8 Time-domain Reflectometry

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

7.2.12.9 Metallic Screen Integrity

The metallic screen layer shall be checked, and:

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

7.2.12.10 Delivery Testing

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

A) DC conductor resistance as specified in 7.2.12.4;
B) Insulation resistance as specified in 7.2.11.5.

7.3 Hoses

7.3.1 General

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

7.3.2 Hose Sizing

All hoses shall be referenced by nominal bore and DP.

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

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

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

Table 3 – Nominal Bore and Wall Thickness Tolerances

Nominal Bore		Tolerance	Liner Wall Thickness, *t*	
mm	(in)	%	mm	(in)
6.0 to 10.0	(0.236 to 0.394)	+5.0 -3.0	± 0.2	(0.008)
10.1 to 20.0	(0.395 to 0.787)	+3.0 -2.0	± 0.2	(0.008)
20.1 to 38.1	(0.788 to 1.5)	+2.0 -1.5	± 0.25	(0.010)

Table 4 – Concentricity

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

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

7.3.3 Hose Construction

7.3.3.1 General

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

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

7.3.3.2 Liner

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

NOTE Multilayer liners may be acceptable if application requirements cannot be satisfied by a single4ayer construction. For instance, in situations where there are high external pressures, an internal support may be incorporated.

For high collapse-resistant (HCR) hoses, the liner may incorporate an internal structure, such as an interlocking carcass, to provide resistance to external hydrostatic pressure. The interlocked carcass shall be of suitable material, compatible with both external environment and inner fluid.

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

7.3.3.4 Reinforcement

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

7.3.3.5 Sheath

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

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

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

7.3.3.6 Identification

At a minimum, the following information shall be marked, along the complete length of a hose, on the external sheath at regular intervals not exceeding 1 m {3.28 ft):

A) manufacturer;
B) batch number;
C) nominal bore size;
D) DP;
E) manufacturer's part number; unique component reference, e.g. “Line 6.”

7.3.3.7 Termination Interface

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

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

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

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

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

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

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

7.3.4 Performance Requirements

7.3.4.1 Design Pressure Ratios

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

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

7.3.4.2 Collapse Pressure

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

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

7.3.4.3 Change in Length

The hose shall be designed such that the change in length when the hose is pressurized from atmospheric pressure to its DP shall be within the range -1.5 % to + 2 %.

7.3.5 Structural Analysis

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

7.3.6 Manufacturing

7.3.6.1 Liner Extrusion

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

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

A) extruder barrel/head temperatures;
B) melt pressure/temperature;
C) screw speed/power requirements;
D) haul-off speed.

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

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

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

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

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

7.3.6.2 Reinforcement Application

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

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

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

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

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

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

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

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

Storage reel surfaces shall be smooth, such that the fiber is not damaged.

7.3.6.3 Sheath Extrusion

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

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

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

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

7.3.7 Verification/Qualification Testing

7.3.7.1General

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

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

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

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

7.3.7.2 Test Fluid

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

7.3.7.3 Visual and Dimensional

One unaged representative sample of 150 mm (5.91 in.) minimum length shall be taken from each end of a manufactured hose length. During the dimensional tests, the hose shall be visually examined and shall be free from damage, irregularities, and visual non-conformances in each part of the construction. Measurements of the following parameters of each sample shall be made in accordance with the manufacturer's written procedure:

A) internal diameter;
B) diameter over reinforcement;
C) external diameter;
D) hose concentricity;
E) liner wall thickness.

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

7.3.7.4 Change in Length

One unaged representative sample shall be taken from each end of a manufactured hose length. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15.75 in). The test shall be performed on each sample in accordance with the change-in-length test for hydraulic hoses specified in ISO 1402 at a test pressure equal to the DP.

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

7.3.7.5 Leakage

One unaged representative sample shall be taken from each end of a manufactured hose length and assembled with the intended material and design of end fitting incorporated at each end of each sample. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15.75 in). The test shall be performed on each sample in accordance with the leakage test for hydraulic hoses specified in ISO 1402. There shall be no evidence of leakage during or on completion of the test.

7.3.7.6 Burst

One unaged representative sample shall be taken from each end of a manufactured hose length and assembled with the intended material and design of end fitting incorporated at each end of each sample. Two further samples shall be prepared with a minimum of one splice in the reinforcement of each sample made in accordance with the manufacturer's written specification. These particular samples shall be clearly marked, showing the position of each splice. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15.75 in). Each sample shall be tested using the burst-pressure test for hydraulic hoses specified in ISO 1402 at the standard laboratory/ambient temperature. Test results for samples with splices and samples without splices shall be recorded. The burst pressure shall not be less than the value specified in 7.3.4.1.

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

7.3.7.7 Impulse

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

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

All hose assemblies shall be subjected to a proof-pressure test as specified in ISO 1402 before commencing the impulse test. The test shall be conducted in accordance with the impulse test procedure specified in ISO 6803 at the reduced test-fluid temperature of 55 °C ± 3 °C (131 °F ± 5 °F). Compatibility of the test fluid with the hose liner shall be confirmed prior to commencement of the test. The test pressure shall be 1.33 x DP, and the hose shall withstand a minimum of 200,000 cycles without any signs of leakage or failure.

NOTE For hoses greater than 25.4 mm (1 in.) nominal bore, design pressures higher than those specified in Table F.1, hoses constructed with an internal carcass to provide support against external hydrostatic pressure, alternative installed test configurations, pressure waveforms, and/or number of cycles forming the acceptance/rejection criteria may be acceptable, as defined in the manufacturer's written specification.

7.3.7.8 Cold Bend

One unaged representative sample shall be taken from the end of a manufactured hose length. The sample length, measured between the hose end fittings, shall not be less than 400 mm (15.75 in). The test shall be carried out in accordance with the cold flexibility test in accordance with ISO 10619-2:2011, method B, where the test temperature is - 40 °C ± 3 °C (- 40 °F ± 5 °F). The sample shall fail the test if any signs of leakage, distortion, or cracking are apparent.

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

7.3.7.9 Collapse

A sample of hose, with a length of not less than 500 mm (19.69 in.) between end fittings, shall be installed in a pressure vessel and bent to its minimum bend radius. The hose shall be filled with water until the water reaches a burette on the end of the hose. The vessel shall be filled with water and the pressure gradually increased at a rate in accordance with the manufacturer’s written specification.

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

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

7.3.7.10 Volumetric Expansion

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

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

7.3.7.11 End-fitting Rotation

Two unaged representative hose samples of length not less than 600 mm (23.62 in.) shall have swivel female service-design fittings attached at one end only.

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

Hydrostatic pressure cycling between zero and 1.5 x DP shall be applied 10 times consecutively, at a frequency of less than 1.5 cycles per minute. The time for the test pressure rise and decay shall be a minimum of 10 seconds. On completion of 10 cycles, the pressure shall be held constant at 1.5 x DP for a minimum of 10 minutes. The sample shall be inspected for signs of leakage and distortion. Any such signs shall result in failure of the test.

7.3.7.12 Compatibility Testing

7.3.7.12.1 General

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

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

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

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

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

7.3.7.12.2 Immersion Tests

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

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

7.3.7.12.3 Pressure Cycling

Pressure cycling tests shall be performed on a minimum of six representative hose samples—terminated with the same abutment design features as the service end fittings—each approximately 1 m (3.28 ft) long; the six representative hose samples may be joined in a series for convenience. Prior to testing, the hose assemblies shall be subject to a change-in-length test as described in 7.3.7.4, followed by a proof test in accordance with ISO 1402. The hose string shall be immersed in town-mains water, held at a temperature of 40 °C ± 1 °C (104 °F ± 1.8 °F) for a period of 12 months. In the event that scheduling does not permit a 12-month program, a higher temperature for a shorter duration and a lower number of test samples may be acceptable. In this event, the duration and temperature shall be as stated in the manufacturer's written specification. If elevated temperatures are used, care shall be taken that the failure mechanism is representative, and that the material temperature limits are not exceeded.

The water shall be renewed monthly.

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

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

The hose/fluid combination shall pass this compatibility test if:

A) none of the hoses fails during the period of pressure cycling; and
B) the manufacturer's written specification predicts a minimum design life greater than the specified service life.

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

7.3.7.13 Permeability Testing

7.3.7.13.1 General

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

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

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

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

7.3.7.13.2 Liquids

The permeability of the liner to liquids shall be measured on a sample at least 1 m (3.28 ft) long using the test apparatus in accordance with ISO 8308. The nitrogen-charge pressure shall be checked daily and adjusted, if necessary, and at all other times the "main" and "venting" valves shall be kept tightly closed. The loss of fluid shall be measured daily over a period of at least 30 days, or until the level of fluid in the burette has fallen below the minimum mark if this occurs sooner. A graph of fluid loss against elapsed time shall be plotted. The average gradient of this graph shall be used to determine the characteristic permeation rate for the particular fluid/material combination.

7.3.7.13.3 Gases

The permeability of the liner to gases shall be measured on a sample 1 m (3.28 ft) long in accordance with ISO 4080.

7.3.8 Component Factory Acceptance Tests

7.3.8.1 Visual and Dimensional Inspection

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

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

A) for the liner: *d, D*, concentricity,wall thickness;
B) for the reinforcement: *D*, pitch (for each layer);
C) for the sheath: *D*, concentricity;
D) for the completed hose: *d, D*, concentricity.

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

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

7.3.8.2 Test Fluid

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

For integrity tests that are performed on each completed hose length, the test fluid shall be one of the following, suitably filtered to allow the final system cleanliness, as defined in the manufacturer's written specification:

A) specified system control fluid;
B) proprietary storage fluid;
C) town-mains or potable water; the chloride content of town-mains or potable water shall be equal to or less than 20 mg/l (20 ppm) so as not to introduce corrosion for hoses that incorporate stainless steel materials;
D) deionized water.

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

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

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

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

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

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

7.3.8.3 Liner Burst Test

After extrusion, alm (3.28 ft) length of liner shall be removed from each end of each extruded length and subjected to a burst test. The burst pressure shall be not less than

80 % of the calculated burst pressure, based on the minimum wall thickness, maximum bore diameter, and tensile stress at 20 % liner material elongation, using standard thin-wall cylinder theory. The liner shall fail in a ductile manner in order to pass this test.

7.3.8.4 Change in Length

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

7.3.8.5 Burst Test

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

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

7.3.8.6 Proof Pressure/decay Test

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

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

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

7.3.8.7 Delivery to Umbilical Manufacturer

Should completed hoses be transported from the hose manufacturer's facility to the umbilical manufacturer's facility, a proof pressure/decay test as specified in 7.3 8.6, at a test pressure of 1.5 x DP, shall be performed on all hoses following delivery and prior to lay-up.

7.4 Optical-fiber Cable

7.4.1 General

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

7.4.2 Fiber Type

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

7.4.3 Fiber Construction

7.4.3.1 Core

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

7.4.3.2 Cladding

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

7.4.3.3 Coating

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

7.4.4 Cable Construction

7.4.4.1 General

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

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

7.4.4.2 Fiber Package

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

The tube package, together with external armoring that may be provided in accordance with 7.4 4.4, shall be designed to provide mechanical protection for the fibers against tensile and crushing loads.

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

7.4.4.3 Sheathing

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

7.4.4.4 Armor/Reinforcement

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

7.4.4.5 Outer sheath

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

7.4.4.6 Cable identification

Each individual cable shall have a unique identification and shall be marked along the complete length at regular intervals not exceeding 1 m (3.28 ft), with:

A) the manufacturer;
B) the batch number;
C) the fiber type;
D) the number of fibers;
E) the manufacturer’s part number;
F) a unique component reference, e.g. “Line 6.”

7.4.5 Termination Interface

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

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

NOTE This document is not applicable to the design of optical-fiber terminations for subsea use.

7.4.6 Performance Requirements

7.4.6.1 Optical Attenuation

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

7.4.6.1 Fiber Strain

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

7.4.7 Jointing

7.4.7.1 Cable Jointing

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

7.4.7.2 Fiber Splicing

Jointing of the fibers shall be allowed, with the use of high-strength, qualified fusion-splicing techniques. The acceptance level of splice-loss attenuation shall be as defined in the manufacturer's written specification. Splices shall be individually subjected to tensile proof testing to the load level defined in the manufacturer's written specification [typically from 700 MPa to 1750 MPa (100 ksi to 250 ksi)].

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

7.4.8 Structural Analysis

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

7.4.9 Manufacturing

7.4.9.1 Fiber Manufacture

Fibers shall be produced from high-grade silica glass meeting the manufacturer's written specification, and in accordance with the requirements of IEC 60793-1-1, I EC 60793-2, ITU-T-G.650.1, ITU-T G650.2, ITU-T G.652, ITU-T G.654, and ITU-T G.655.

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

7.4.9.2 Fiber-package Construction

The individual fibers shall be assembled into the fiber package in accordance with the manufacturer’s written specification.

7.4.9.3 Sheathing

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

7.4.9.4 Armoring/reinforcement

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

7.4.10 Verification/qualification Testing

7.4.10.1 General

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

7.4.10.2 Visual and Dimensional

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

7.4.10.3 Transmission and Optical Characteristics

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

7.4.10.4 Mechanical Characteristics

Mechanical characteristics of the optical-fiber cables shall be verified in accordance with IEC 60794-1-21 or in accordance with ITU-T G.976.

7.4.10.5 Environmental Resistance

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

7.4.10.6 External Pressure Test

A sample of the optical-fiber cable having a length not less than 10 m (32.8 ft) shall be subject to an external hydrostatic pressure test for a period of 14 days at a minimum pressure equivalent to the maximum installation depth for the umbilical. The specimen's optical fibers shall be joined in series and periodically monitored in accordance with the manufacturer's written specification. Any changes in attenuation measured shall not cause degradation in system performance over the design life of the system.

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

7.4.10.7 Fiber Splicing

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

7.4.11 Acceptance Testing

7.4.11.1 General

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

7.4.11.2 Visual and Dimensional

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

7.4.11.2 Optical Time-domain Reflectometry/attenuation

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

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

7.4.12 Delivery Testing

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

7.5 Metallic Tubes

7.5.1 General

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

7.5.2 Tube Size

7.5.2.1 General

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

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

NOTE Preferred tube sizes are tabulated in Annex F.

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

7.5.2.2 Wall Thickness

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

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

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

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

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

Table 6 – Wall Thickness for Stress Calculations

Condition	Pressure Containment	Combined Loading	Fatigue
Operation	$t_1 = t_{nom} - t_{fab} - t_{corr}$	$t_2 = t_{nom} - t_{nom} - t_{corr}$	$t_3 = t_{nom} - 0.5 \cdot t_{corr}$
Pressure test and installation	$t_1 = t_{nom} - t_{fab}$	$t_2 = t_{nom}$	$t_3 = t_{nom}$
where t_{nom} is the nominal wall thickness; t_{tab} is the maximum fabrication negative tolerance; t_{corr} is the general corrosion allowance (external and internal corrosion, if applicable)			

NOTE 3 Corrosion allowance is relevant only for materials susceptible to general corrosion, i.e. unprotected carbon steel.

See 7.5.8.3 for maximum wall-thickness tolerances.

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

For fatigue calculations, see 6.2.5.3.

7.5.2.3 Diameter

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

7.5.2.4 Material SMYS

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

7.5.2.4 Load Case Variables

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

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