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

Part 5: **Subsea umbilicals**

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

Partie 5: Faisceaux de câbles immergés

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Contents

Page

Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this part of ISO 13628 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

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

— *Part 1: General requirements and recommendations*

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

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

— *Part 4: Subsea wellhead and tree equipment*

— *Part 5: Subsea umbilicals*

— *Part 6: Subsea production control systems*

— *Part 7: Completion/workover riser systems*

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

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

Annex D forms a normative part of this part of ISO 13628. Annexes A, B, C and E are for information only.

Introduction

This part of ISO 13628 is based on API Spec 17E, second edition, September 1998, and API RP 17I, first edition August 1996.

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

In this part of ISO 13628, where practical, US Customary units are included in parentheses for information.

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

Part 5:
Subsea umbilicals

1 Scope

This part of ISO 13628 specifies requirements and gives recommendations for the design, material selection, manufacture, design verification, testing, installation and operation of subsea control systems, chemical injection, gas lift, utility and service umbilicals and associated ancillary equipment for the petroleum and natural gas industries.

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

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

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

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 13628. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 13628 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

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

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

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

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

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

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

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

IEC 60228, *Conductors of insulated cables*

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

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

IEC 60793-1-1, *Optical fibres — Part 1: Generic specification — General*

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

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

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

ASTM A 370, *Standard test methods and definitions for mechanical testing of steel products*

ASTM A 450/A 450M, *Standard specification for general requirements for carbon, ferritic alloy and austenitic alloy steel tubes*

ASTM E 562, *Standard test method for determining volume fraction by systematic manual point count*

ASTM G 48, *Standard test methods for pitting and crevice corrosion resistance of stainless steels and related alloys by the use of ferritic chloride solution*

BS 5099, *Specification for spark testing of electric cables*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this part of ISO 13628, the following terms and definitions apply:

3.1.1
ancillary equipment
accessory to the umbilical system which does not form part of the main functional purpose

EXAMPLES Weak link, buoyancy collar and I-tube or J-tube seals.

3.1.2
bend limiter
device for limiting the bend radius of the umbilical by mechanical means

NOTE It typically comprises a series of interlocking metallic or moulded rings, applied over the umbilical.

3.1.3
bend stiffener
device for limiting the bend radius of the umbilical by providing a localized increase in bending stiffness

NOTE The stiffener is usually a moulded device, sometimes reinforced, depending on the required duty, applied over the umbilical.

3.1.4
bird-caging
phenomenon whereby armour wires locally rearrange with an increase and/or decrease in pitch circle diameter as a result of accumulated axial and radial stresses in the armour layer(s)

3.1.5
bundle
laid-up functional components and associated fillers in the umbilical prior to sheathing

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

3.1.6
carousel
storage container which can be rotated by a drive about a vertical axis

NOTE It incorporates an inner core structure and an outer peripheral structure, both of which support the umbilical. The umbilical is stored at nominally zero tension. Carousels which do not have a structure on their outer periphery to support the umbilical are often known as turntables.

3.1.7
caterpillar
cable engine in which the umbilical is held between belts which transfer motive power to the umbilical

3.1.8
characterization data
data relating to a component or an umbilical giving an indication of performance but not giving specific acceptance/rejection criteria

3.1.9
chinese finger
type of gripper or stopper used to hold the umbilical via its outer diameter, comprising a number of spirally interwoven wires attached to a built-in anchorage arrangement

3.1.10
core
generic term used to describe an individual electrically insulated conductor

3.1.11
crab lay
installation deployment activity whereby the installation vessel moves sideways along, or at the end of, the installation route

3.1.12
design life
service life multiplied by an appropriate safety factor

3.1.13
design working pressure
DWP
maximum working pressure at which a hose or tube is rated for continuous operation

3.1.14
design working load
maximum working load multiplied by an appropriate safety factor

3.1.15
end termination
mechanical fitting attached to the end of an umbilical which provides a means of transferring installation and operating loads, fluid and electrical services to a mating assembly mounted on the subsea facility or surface facility

3.1.16
factory acceptance test
FAT
series of tests carried out on the complete umbilical system after manufacture is complete, to verify the integrity of the umbilical

3.1.17
functional components
components included within an umbilical which are required to fulfil the operational service needs

EXAMPLES Hoses, tubes, electric/optical fibre cables.

3.1.18
functional specification
document that specifies the totality of needs expressed by features, characteristics, process conditions, boundaries and exclusions defining the performance of a product or service including quality assurance requirements

3.1.19
host facility
fixed or floating facility to which the umbilical is mechanically and functionally connected and which provides the functions and services to be transmitted through the umbilical

EXAMPLES Platform, buoy, floating production system.

3.1.20
hydrogen getter
medium, within an optical fibre system, that chemically neutralizes hydrogen

3.1.21
lay-up
cabling
operation of assembling electrical cores or optical fibres into a cable*,* or hoses, tubes, electric cables, optical fibre cables into a bundle, or sub-bundle

3.1.22
loadout
transfer of an umbilical or umbilical system from a storage facility onto an installation/shipping vessel either by transfer spooling or by lifting the product stored on its installation/shipping reel

3.1.23
manufacturer's written specification
specification for the umbilical, the umbilical components and their manufacture, generated by the manufacturer in compliance with requirements specified by the purchaser and this part of ISO 13628

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

3.1.24
maximum working load
maximum working tensile load that the umbilical can continuously withstand during handling and/or in the installed configuration without suffering damage or loss of performance

NOTE As the bending radius of the umbilical decreases, the maximum working load decreases.

3.1.25
messenger wire
device installed or pre-fitted into an I-tube or J-tube for transferring the primary pulling device, usually a rope, into the tube to provide means of pulling an umbilical through the tube

3.1.26
minimum bend radius
radius to which a functional component may be bent during processing, reeling and unreeling, storage and installation, service and recovery without damage

NOTE 1 Typical functional components which may be bent include electrical/optical fibre cable, hose, tube, umbilical, etc.

NOTE 2 Minimum bend radius is measured from the centre of the bend to the functional component outer diameter on the inside of its bend, which may vary with the load applied to the component or umbilical.

3.1.27
minimum breaking load
minimum tensile load that the umbilical can sustain before mechanical failure occurs when the load is applied with the umbilical in a straight condition

3.1.28
moonpool
open access between a vessel deck and the sea, through which equipment and/or product is deployed

3.1.29
multi-coupler
multiway connector arrangement comprising two stabplate sub-assemblies, one of which is made of a number of hydraulic and/or electric and/or optical coupler halves, each carrying a separate service, which mate simultaneously with corresponding coupler halves on the other sub-assembly when the two sub-assemblies are brought together

3.1.30
pull-in head
device used for terminating the end of an umbilical so that it can be loaded/offloaded from a vessel and pulled along the seabed and/or through an I-tube or J-tube

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

3.1.31
reel
device for storing umbilicals or components comprising two flanges, separated by a barrel, with the barrel axis normally being horizontal

3.1.32
service life
specified time during which the umbilical system shall be capable of meeting the functional requirements

3.1.33
S-N data
data obtained by plotting cyclic stress level versus number of cycles to failure

3.1.34
splice, verb
join together component lengths or sub-components to achieve the required production length

3.1.35
subsea termination interface
mechanism which forms the transition between the umbilical and the subsea termination or subsea umbilical distribution unit

NOTE The interface comprises typically an umbilical armour termination, bend stiffener, hose and/or tube end fittings. If the umbilical contains electric cables, then electrical penetrator(s) and/or electrical connectors may also be incorporated.

3.1.36
subsea umbilical distribution unit
mechanism for mechanically, electrically, optically and/or hydraulically connecting an umbilical independently to more than one subsea system

NOTE In this context, hydraulic fluids includes production system service fluids and produced fluid, control fluid and gas lift lines.

3.1.37
subsea umbilical termination
mechanism for mechanically, electrically, optically and/or hydraulically connecting an umbilical or jumper bundle to a subsea system

NOTE In this context, hydraulic fluids include production system service fluids and produced fluid, control fluid, well service fluid and gas lift lines.

3.1.38
umbilical, noun
group of electric cables, optical fibre cables, hoses, tubes, either on their own or in combination with each other, cabled together for flexibility and oversheathed and/or armoured for mechanical strength

3.1.39
umbilical joint
means of joining together two lengths of umbilical to effect a repair or to achieve the required production length

3.1.40
umbilical system
umbilical, complete with end terminations and other ancillary equipment, installed between a fixed platform, a floating production facility or a land-based station, and a fixed platform, a floating production system or a subsea system, providing control, data communication and transportation of production system service fluids and/or utility supplies

3.1.41
unaged representative sample
sample of umbilical, or its internal components, which has not previously been subjected to loadings, stresses and/or elevated temperature

EXAMPLES Electric cables, hoses, tubes and optical fibres.

3.1.42
utility umbilical
umbilical for the provision of electric/hydraulic power, process fluids and data communications installed between two fixed platforms, between a fixed platform and a floating facility, or between a fixed platform/floating facility and a land-based station

3.1.43
virgin material
virgin stock
new and unused material as supplied by the material manufacturer

NOTE Virgin material or virgin stock does not comprise or contain regranulated, recycled, reprocessed, reused or other similar material.

3.1.44
weak link
device which is used to ensure that the umbilical parts or severs at a specified load and location

3.2 Abbreviated terms

For the purposes of this part of ISO 13628, the following abbreviations apply:

AC alternating current

AVE apparent volumetric expansion

DC direct current

DWP design working pressure

FAT factory acceptance test

FIR full indicated reading

d inside diameter

KP kilometre point

LAT lowest astronomical tide

NDE non-destructive examination

D outside diameter

OTDR optical time-domain reflectometer

QA quality assurance

ROV remotely operated vehicle

σ_{y} specified minimum yield stress

TAN titrated acid number

TVE true volumetric expansion

UV ultra-violet

t wall thickness

4 Functional requirements

4.1 General requirements

4.1.1 Umbilical

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

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

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

c) materials: compatible with the environment to which they are exposed and in conformance with the corrosion control and compatibility requirements;

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

e) optical fibres: capable of transmitting signals at the required wavelengths within the attenuation requirements;

f) hoses and/or tubes: capable of transmitting fluids at the required flowrate, pressure, temperature and cleanliness levels;

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

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

4.1.2 End terminations and ancillary equipment

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

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

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

b) The end termination shall provide a structural interface between the umbilical and bend limiter/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) Corrosion 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.

4.2 Project-specific requirements

The purchaser shall specify the functional requirements for the umbilical.

Functional requirements not specifically required or specified by the purchaser but which may affect the design, materials, manufacturing, testing, installation and operation of the umbilical shall be specified by the manufacturer.

NOTE 1 Annex A provides a basis for such specifications.

NOTE 2 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.

5 Quality assurance

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

6 Design requirements

6.1 General

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

6.2 Design methodology

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

a) description of the theoretical basis, including calculation procedures and methods for evaluating the umbilical design parameters and the criteria to be satisfied in order to meet the functional requirements specified in clause 4;

b) documentation of the design life assessment methodology, subject to the requirements of 6.3;

c) verification of the theoretical basis via prototype tests on component samples and on samples of the complete umbilical as specified in 7.6, 7.8.7, 7.9.7 and 10.2. The verification shall include the capacity of all umbilical structural layers. Simplified conservative analysis methods for checking of non-critical layers, such as anti-wear layers, shall be acceptable if the method does not influence the reliability of the calculation of stresses in the other layers;

d) documented basis for stress concentration factors to account for the geometry of metallic structural components, including stress concentrations at and within the end-termination interface, clamped accessories, contact with rigid surfaces, manufacturing tolerances, and load-induced gaps;

e) manufacturing and design tolerances, manufacturing-induced stresses, welds and other effects which influence structural capacity.

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

If the umbilical design is outside the envelope of previously validated designs, then the manufacturer shall perform prototype tests to verify the design methodology for this new design. The prototype tests shall validate fitness-for-purpose for those design parameters which are outside the previously validated envelope.

6.3 Analysis

6.3.1 General

The manufacturer shall, as part of the design evaluations, consider the results of any installation, dynamic service and structural analysis that may have been carried out in relation to the umbilical design.

The output of the analyses shall be used to demonstrate that the umbilical is suitable for installation and will remain fit for service during its design life.

The analysis results shall be verified either during the design verification testing or during factory acceptance 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.

6.3.2 Definition of load classes

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

a) **functional loads** are all loads acting on the umbilical during manufacture, installation and operation, including those loads such as the following which act on the umbilical in water (with the exception of wind, wave or current loads):

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

   2) pressure within hoses and tubes;

3) thermal expansion and contraction loads;

4) external pressure;

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

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

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

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

9) residual installation loads in the umbilical structure during service;

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

11) interaction effects of laying-up or clamping the umbilical;

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

13) loads due to positioning tolerances during installation;

14) loads from inspection and maintenance tools.

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

c) **accidental loads** are those loads caused directly or indirectly by unplanned activities, including, but not limited to, the following:

1) dropped objects;

2) trawl board impact;

3) anchor line failure;

4) fire and explosion;

5) compartment damage or unintended flooding;

6) failure of thrusters;

7) dynamic positioning failure of the installation vessel;

8) external over-pressure;

9) internal over-pressure;

10) failure of turret drive system.

6.3.3 Load combinations and conditions

The umbilical design shall be shown to meet the requirements under all the design load combinations which act on the umbilical. Variation of the loads with respect to time, load effects from the umbilical system and its supports, including effects from the environment and soil conditions, shall be analysed.

The design load conditions that shall be analysed are factory-acceptance testing, installation and operation.

Design checks shall be carried out for any temporary conditions specified by the purchaser and shall be subject to the same design criteria as the design load conditions.

The design load cases to be analysed shall be derived from the loading conditions for the following load combinations:

a) functional;

b) functional and environmental;

c) functional, environmental and accidental.

The load combinations considered should attempt to accurately portray the relevant loading conditions which will be applied to the umbilical. For example, during deployment it is normal practice to pressurize to a lower level than working pressure, purely for monitoring purposes, and thus the combined load case for this condition may be significantly different to that encountered under the working condition(s). Similarly, for dynamic applications, the operation of the wellhead control system may be suspended in severe sea states, thereby obviating the load case of normal working pressure combined with high axial and superimposed bending loads. In practice it is unlikely that all load combinations could be evaluated. The design analysis should therefore be a selective process if the critical and controlling load cases form the basis of the evaluation. Non-controlling and non-critical cases are not normally considered.

6.3.4 Installation analysis

This analysis shall be used to establish the loadings imposed on the umbilical during installation including those imposed due to internal monitoring pressure, vessel motion, installation equipment, clamping loads, trenching operations, rock dumping, crushing, seabed stability and pull-in operations.

The analysis shall be used to establish the following parameters which shall be considered during the design of the umbilical:

a) allowable limits in the offset between the touch-down point of the umbilical on the seabed and the vessel as a function of sea-state and current;

b) the variation of tension and curvature along the umbilical as a function of sea-state and current;

c) tension and curvature time domain plots for a number of points along the umbilical, including the points established as having the maximum values of tension and minimum radii of curvature;

d) allowable vessel motions to avoid overstressing the umbilical;

e) residual tension from trenching;

f) the maximum period of time, as a function of sea-state, that the laying vessel can maintain position prior to failure occurring within the umbilical;

g) impact forces due to rock dumping;

h) lateral deformations due to crushing loads during storage and passage through cable haulers in combination with any internal pressure monitoring and lay tension loads.

If the installation involves an I-tube or J-tube pull, the maximum pull-in force on the umbilical, taking into account the friction both on the seabed and within the I-tube or J-tube, shall also be determined.

The umbilical design loads, minimum bend radii and allowable crushing load shall be within the limits established by the installation analysis.

6.3.5 Dynamic service analysis

This analysis shall be used to establish the umbilical loadings arising from self weight, currents, wave motion effects at the surface, vessel/buoy motions, umbilical configuration, etc.

The analysis shall be used to establish the following information:

a) the variation of tension and curvature along the installed umbilical as a function of sea-state and current;

b) tension and curvature time series plots for a number of points along the umbilical, including the points established as having the maximum values of tension and minimum radii of curvature.

When considering the fatigue life performance, due consideration shall be made for the probabilistic nature of fatigue life. Particular attention should be paid to vortex-induced vibrations in umbilicals that are in dynamic service, as well as sections of umbilical that extend from the bottom of I-tubes to the seafloor. A suitable safety margin shall be maintained between calculated fatigue life and the required service life.

As bend stiffeners and ancillary equipment may affect the umbilical loading, they should be designed to keep the umbilical within its allowable operational limits.

NOTE A typical safety factor is 10, although this figure depends on the level of analysis, and any necessary assumptions that need to be made.

6.3.6 Structural analysis

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

Details relating to structural analyses of umbilical components are provided within the individual component design subclauses.

The analysis shall demonstrate and justify that the metallic and non-metallic materials used within the umbilical system are designed to satisfy the application requirements of the material throughout the umbilical design life. If possible, this shall be performed using recognized standards and applicable factors of safety.

The design process shall consider the following:

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

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

c) seabed stability, including the need for additional ballasting and impact on other installation activities;

d) fatigue of armour wires, bend stiffeners, polymers and pressure-retaining components;

e) minimum breaking loads;

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

g) cumulative strain of copper conductors, armour wires, metallic tubes and fibres throughout the manufacture, handling and installation processes;

h) strain on optical fibres.

7 Component design, manufacture and test

7.1 General

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

For new component designs which 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 acceptance tests. For unusual designs, or designs significantly different from previously verified designs, design verification testing shall be undertaken as a separate programme.

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

Verification and acceptance tests to be performed should also be considered for the end terminations and midline connectors and ancillary equipment, if applicable.

NOTE Verification and acceptance tests to be performed during and on completion of component manufacture specified in this clause are summarized in annex B.

7.2 Electric cable

7.2.1 General

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

7.2.2 Operating voltage

7.2.2.1 Power cables

Power cable voltage ratings shall be selected from the range 0 V up to the standard rated voltages $U_0/(U \cdot U_m) = 3{,}6/(6 \times 7{,}2)$ kV rms, where U_0, U and U_m are as defined in IEC 60502-1 and IEC 60502-2.

7.2.2.2 Signal cables

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

7.2.3 Construction

7.2.3.1 General

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

Electric cores and cables should be manufactured as continuous lengths.

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

If necessary, armouring or other forms of protection should be provided.

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 which may 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 may arise in the laid-up components and/or deepwater service.

7.2.3.2 Configuration and type of conductor

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

If stranded, each conductor shall comprise a minimum of seven strands. The minimum nominal cross-sectional area shall be 2,5 mm^2 (0,004 in^2). The nominal cross-sectional area for the conductor shall meet the functional requirements of clause 4.

7.2.3.3 Power cables

Power conductors shall be insulated, twisted and/or sheathed and may be screened and oversheathed in accordance with the manufacturer’s written specification.

The chosen insulation material shall be of virgin stock applied as a continuous seamless circular single/multiple extrusion, and shall meet the requirements of IEC 60502-1 and IEC 60502-2. The minimum allowable insulation thickness shall meet the requirements of recognized and applicable national or International Standards for submarine service which shall be cited in the manufacturer's written specification.

7.2.3.4 Signal cables

The signal conductors shall be insulated, twisted and/or sheathed, and may be screened and oversheathed in accordance with the manufacturer's written specification. The signal cables shall be designed to meet the electrical signal transmission characteristics of the communications system adopted.

The chosen insulation material shall be of virgin stock applied as a continuous seamless circular single/multiple extrusion, and shall meet the requirements of IEC 60502-1 and IEC 60502-2. The minimum allowable insulation thickness shall meet the requirements of recognized and applicable national or International Standards for submarine service which shall be cited in the manufacturer's written specification.

7.2.3.5 Conductor coding

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

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

7.2.3.6 Lay-up

Twisting of individual cores shall be undertaken using helical cabling equipment.

For an intermediate lay-up operation, the cabled cores shall 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.

7.2.3.7 Fillers

To achieve a circular consolidated arrangement, fillers shall be included in the interstices of the laid-up cores and the bundled components bound together using a binder tape, or the laid-up cores shall be consolidated by means of an extruded polymer applied directly over the cores so as to directly fill the interstices. The filler and binder tape materials shall be compatible with other materials in the cable, in particular the electrical insulation. The materials shall be as stated in the manufacturer's written specification.

7.2.3.8 Screening

If required, the cable shall be screened with plain or tinned annealed copper tape, or a two-component tape comprising a thin film of copper bonded to a polymer-based substrate. The thickness and number of layers and minimum cross-sectional area 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.

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.

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

7.2.3.9 Sheath

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

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

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

7.2.3.10 Identification

The cables shall be uniquely identified in accordance with the manufacturer's written specification. As a minimum the marking shall include:

a) manufacturer;

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

c) batch number;

d) voltage rating.

Embossed printing is not permitted.

7.2.3.11 Termination interface

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

NOTE This part of ISO 13628 does not provide detailed specifications of electrical terminations for use subsea.

7.3 Performance requirements — Electric cable

7.3.1 Conductor resistance

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

7.3.2 Insulation resistance

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

7.3.3 Screening layer resistivity (non-metallic layers)

For power cable incorporating semiconducting screening layers, the resistivities shall not exceed the following values:

a) Conductor screen: 1 000 $\Omega \cdot$ m;

b) Core screen: 500 $\Omega \cdot$ m.

7.3.4 Performance characteristics

7.3.4.1 Signal

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

a) attenuation;

b) characteristic impedance;

c) inductance;

d) capacitance.

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

7.3.4.2 Power

The power cable design shall consider:

a) voltage rating;

b) current rating;

c) number of phases;

d) maximum ambient temperature;

e) maximum voltage drop.

7.4 Structural analysis — Electric cable

Structural analysis, taking account of data generated from the umbilical structural analysis specified in 6.3.6, shall be undertaken to verify the acceptability of the electric cable design for tensile, compressive and fatigue loadings upon the conductors.

7.5 Manufacture — Electric cable

7.5.1 Conductor stranding

The stranding process shall ensure that individual strands and the stranded conductor shall not be subject to compressive and tensile loadings which can introduce kinks or reduction in conductor or strand cross-sectional area.

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

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

7.5.2 Insulation extrusion

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

a) extruder barrel/head temperatures;

b) melt pressure/temperature;

c) screw speed/power requirements;

d) haul-off speed.

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

The insulation thickness and the outside diameter shall be measured continuously, at a minimum of two positions 90° apart, and recorded continuously.

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

7.5.3 Lay-up

Only cores in individual electric cables and composite electric cables which have been laid up in a continuous helix shall be used in umbilicals manufactured in accordance with this part of ISO 13628. Other lay-up processes are acceptable but shall be qualified for the application.

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

If necessary, filler material shall be incorporated to form a compact and reasonably circular bundle. These fillers may be included in the interstices of the laid-up cores or, alternatively, the interstices may be filled as part of a subsequent sheathing operation.

During lay-up, the twisted cores shall be subject to frequent 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 which 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.

7.5.4 Sheath extrusion

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

The insulation thickness and the outside diameter shall be measured continuously, at a minimum of two positions 90° apart, and recorded continuously.

7.6 Verification tests

7.6.1 Visual and dimensional checks

Electrical cores shall be 100 % visually examined 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.

7.6.2 Conductor resistance test

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

7.6.3 Resistivity of screening layers

The resistivity of the semiconducting screening layers in the completed power core shall not exceed the values specified in 7.3.3.

7.6.4 Insulation resistance

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

The individual insulated conductors shall be immersed in town mains 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 depth, whichever is greater, or higher in accordance with the hydrostatic pressure at maximum service depth, for a minimum period of 22 h and then insulation-resistance tested while still under pressure. Insulation resistance shall be measured. The value of insulation resistance shall not be less than the value defined in 7.3.2.

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

7.6.5 High voltage DC test

A high voltage 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.

The individual insulated conductors shall be immersed in town mains water. Insulation resistance shall be measured. The specimens shall then be subjected to a hydrostatic pressure of 3,5 MPa (500 psi), or higher in accordance with the hydrostatic pressure at maximum service depth, for a minimum period of 22 h. The DC test voltage for signal conductors shall be 3 kV, and for power conductors shall be 5 kV or three times U_0 whichever is greater. Each insulated conductor shall withstand the DC voltage between conductor and water at each of the pressure levels, for a period of not less than 5 min. 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.

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

This test may be combined with the insulation resistance test specified in 7.6.4, using the same samples, provided the insulation resistance test is performed first.

7.6.6 High voltage AC test

On completion of the high voltage DC test specified in 7.6.5, a high voltage AC test shall be performed on the insulated conductors subject to the same hydrostatic pressure.

The test shall be performed with an alternating voltage of sine waveform having a frequency in the range 40 Hz to 62 Hz, unless otherwise stated in the manufacturer's written specification. The value of the applied test voltage shall be as shown in Table 1. The voltage shall be applied between conductor and water. It shall be increased at the rate defined in 7.6.9, and maintained at the full value for 5 min without breakdown of the insulation.

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

Table 1 — AC test voltages

Voltage designation of cable		**Test voltage** (rms) V
Signal cables	$\leqslant U_0/(U \cdot U_m) = 0{,}6/(1{,}0 \times 1{,}2)$ kV	1 500
Power cables $\leqslant U = 600$ V	$\leqslant 6$ mm^2 (0,009 3 in^2)	1 500
	$>$ Above 6 mm^2 (0,009 3 in^2)	3 000
Power cables $> U = 600$ V	$\leqslant U_0/(U \cdot U_m) = 3{,}6/(6 \times 7{,}2)$ kV	7 500
See IEC 60502-1 and IEC 60502-2 for definition of U_0, U and U_m.		

7.6.7 Complete voltage 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 7.6.5, with two samples being tested at ambient hydrostatic pressure, and two being tested at the higher pressure used in the test defined in 7.6.5. 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 $3 \times U_0$ the insulated conductor shall be considered suitable.

7.6.8 Partial discharge test

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

7.6.9 Rate of application of test voltages

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

7.6.10 Inductance characteristics

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be measured for inductance. The inductance of each conductor pair in the cable shall be measured at fixed frequencies as specified in the manufacturer's written specification. The measured values shall comply with the requirements specified in 7.3.4, which shall include limits for deviation between actual and specified values.

7.6.11 Capacitance characteristics

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be measured for capacitance. The capacitance of each conductor pair in the cable shall be measured at fixed frequencies as stated in the manufacturer's written specification. The capacitance of each power unit shall be measured at the transmission frequency with respect to ground, unless stated otherwise in the manufacturer's written specification. The measured values shall comply with the requirements specified in 7.3.4. The specification shall include limits for deviation between actual and specified values.

7.6.12 Attenuation characteristics

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

A sample of completed electric cable, of 10 m (32,8 ft) minimum length, shall be evaluated for attenuation. The attenuation of each conductor pair shall be measured or derived at the frequencies specified in the manufacturer's written specification and a curve of attenuation versus frequency shall be produced. The measured values shall be in accordance with the requirements specified in 7.3.4.

7.6.13 Characteristic impedance

A sample of completed electric cable of 10 m (32,8 ft) minimum length, shall be measured for characteristic impedance. The characteristic impedance of each pair shall be measured or derived at the frequencies specified in the manufacturer’s written specification and a curve of impedance versus frequency shall be produced. The results shall be in accordance with the requirements specified in 7.3.4 which shall include limits for deviation between actual and specified values.

7.7 Component acceptance tests — Electric cable

7.7.1 Visual and dimensional inspection

During the manufacturing processes, each conductor and core shall be 100 % visually examined and shall be free from damage, kinks, faults or contamination. Raw materials shall also be screened for contamination. Core lay-up, taping, sheathing, fill and sheathing, screening, etc. shall be visually examined. Manufacturing parameters shall be periodically monitored in accordance with, and shall comply with, the manufacturer's written specification. Examination of conductors shall comply with the requirements of IEC 60228.

7.7.2 Spark test

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

NOTE Cores incorporating semiconducting layers are not capable of being spark-tested.

7.7.3 DC conductor resistance test

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

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.

7.7.4 Insulation resistance test

This test shall be performed on the complete conductor lengths in accordance with the procedure and acceptance value specified in 7.6.4 after insulation extrusion. The test shall also be repeated without the requirement for immersion in town mains water under pressure after lay-up, and on completion of manufacture of the electric cable.

7.7.5 High voltage DC test

This test shall be performed on the completed conductor length in accordance with the procedures and acceptance values specified in 7.6.5 after insulation extrusion. The test shall also be repeated without the requirement for immersion in town mains water under pressure after lay-up, and on completion of manufacture of the electric cable.

7.7.6 Inductance characteristics

On completion of cable manufacture, the inductance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.6.10 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.

7.7.7 Capacitance characteristics

On completion of cable manufacture, the capacitance characteristics shall be measured in accordance with the procedure and acceptance values specified in 7.6.11 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.

7.7.8 Attenuation characteristics

On completion of cable manufacture, the attenuation characteristics shall be measured or derived in accordance with the procedure and acceptance values specified in 7.6.12 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.

7.7.9 Characteristic impedance

On completion of cable manufacture, the characteristic impedance shall be measured in accordance with the procedure specified in 7.6.13 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.

7.7.10 Cross-talk

For cables containing independent conductor pairs, if cross-talk has to be minimized, the cross-talk between conductor pairs at the rated voltage, current and the rated frequency range 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.

7.7.11 Time-domain reflectometry

A time-domain reflectometry trace shall be obtained for each conductor from both ends. The width of the pulse shall be sufficient to allow the complete conductor length to be scanned. 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.

7.7.12 Delivery to umbilical manufacturer

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 7.7.3;

b) insulation resistance as specified in 7.7.4 ;

c) high voltage DC test as specified in 7.7.5, for high voltage screened power cables.

7.8 Optical fibre cable

7.8.1 General

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

7.8.2 Fibre type and coding

The fibre type shall be of either single-mode or multimode design. The design shall be as given in the manufacturer’s written specification. Individual fibre identification shall be by means of fibre colouring.

7.8.3 Cable construction

The fibres shall be contained within a package which shall prevent water and minimize hydrogen contact with each fibre. The carrier package for mechanical protection and its contents shall be designed to block water ingress in the event that the optical fibre cable in the umbilical is severed.

Additional protection against hydrogen shall be incorporated in the form of a hydrogen getter (3.1.20).

The cable shall be designed to provide mechanical protection for the fibres against tensile and crushing loads.

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

7.8.4 Construction

7.8.5 Termination interface

The design of the optical fibre cables shall recognize that the cables will be terminated in some form of waterblocking arrangement, which shall function throughout the design life.

The long-term stability at the termination interface shall not be impeded by the materials of construction or the design.

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

7.8.6 Performance requirements

7.8.6.1 Optical attenuation

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

7.8.6.2 Fibre strain

The umbilical and optical fibre cables shall be designed so that potentially damaging strain levels are not imposed on the optical fibres.

7.8.6.3 Cable jointing

7.8.6.3.1 Cable

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

7.8.6.3.2 Fibre jointing

Jointing of the fibres shall be allowed, with the use of high strength qualified fusion splicing techniques. The acceptance level of splice loss attenuation shall be as defined in the manufacturer’s written specification. Splices shall be individually subject to tensile testing, to the load level defined in the manufacturer’s written specification.

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

7.8.7 Verification tests

7.8.7.1 Transmission and optical characteristics

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

7.8.7.2 Mechanical characteristics

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

7.8.7.3 Environmental resistance

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

7.8.7.4 External pressure test

A sample of the optical fibre cable of minimum length not less than 1 m (3,28 ft) shall be subject to an external hydrostatic pressure test for a period of 14 d at a pressure equivalent to the maximum installation depth for the umbilical. The specimen's optical fibres shall be joined in series and periodically monitored in accordance with the manufacturer's written specification. Any changes in attenuation measured shall not cause degradation in system performance over the design life of the system.

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

7.8.7.5 Fibre splicing

Fibre splicing shall be verified in accordance with the manufacturer's written specification.

7.8.8 Component acceptance tests

7.8.8.1 Visual and dimensional inspection

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

7.8.8.2 Optical time-domain reflectometry (ODTR)

Each fibre within the cable shall be subject to an OTDR test from each end, at wavelengths specified within the manufacturer's written specification.

Graphs produced shall 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.

7.8.9 Delivery to umbilical manufacturer

If the completed cable is transported from the cable manufacturer's facility to the umbilical manufacturer's facility, an OTDR test as specified in 7.8.8.2 shall be performed on all fibres following delivery and prior to lay-up. Attenuation values shall meet the requirements of the manufacturer's written specification.

7.9 Hoses

7.9.1 General

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

7.9.2 Hose sizing

All hoses shall be referenced by nominal bore and DWP.

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

Tolerances on nominal bore shall not exceed the values given in Table 2, and the inside and outside diameters of the hose shall be concentric within the limits in Table 3.

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

Table 2 — Nominal bore and wall thickness tolerances

Nominal bore		**Tol.**	**Liner wall thickness**	
		%	t	
mm	(in)		mm	(in)
6,0 to 10,0	(0,233 to 0,394)	+ 5,0 − 3,0	± 0,2	(0,007 9)
10,1 to 20,0	(0,395 to 0,787)	+ 3,0 − 2,0	± 0,2	(0,007 9)
20,1 to 38,1	(0,788 to 1,5)	+ 2,0 − 1,5	± 0,25	(0,009 8)

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

Table 3 — Concentricity

Nominal bore		**Concentricity, FIR**	
mm	(in)	mm	(in)
Up to 25,4	(1,0)	1,0	(0,040)
Over 25,4	(1,0)	1,5	(0,060)

7.9.3 Hose construction

7.9.3.1 General

The hose shall comprise 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.

7.9.3.2 Hose liner

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

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

For collapse-resistant hoses, the liner may incorporate an internal structure such as an interlocking carcass to provide resistance to external hydrostatic pressure.

The 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, such that fluid cleanliness cannot be maintained.

7.9.3.3 Hose reinforcement

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

7.9.3.4 Hose sheath

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

The sheath shall provide for the venting of permeated fluids if the particular fluid/hose liner combination may give rise to permeation. The sheath material shall be compatible with the intersticial 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.

7.9.3.5 Identification

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

a) manufacturer;

b) batch number;

c) nominal bore size;

d) DWP;

e) manufacturer's part number;

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

7.9.3.6 Termination interface

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

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

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

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

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

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

7.9.4 Performance requirements

7.9.4.1 Design pressure ratios

Table 4 indicates the required ratio of proof and burst pressures to the DWP for thermoplastic hoses, in accordance with ISO 7751.

Table 4 — Ratios of test pressure to DWP

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

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

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

For higher DWP ratings and/or larger bore sizes than those specified in annex C, lower burst pressure ratios may be acceptable which shall be in accordance with the manufacturer's written specification. These hoses for higher working pressures shall be design-verified in accordance with 7.9.7.

7.9.4.2 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 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.

7.9.4.3 Change in length

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

7.9.5 Structural analysis

Structural analysis, taking account of data generated from the umbilical structural analysis specified in 6.3.6, shall be undertaken to confirm the acceptability of the hose design for the loadings it will experience during testing and service.

7.9.6 Hose manufacture

7.9.6.1 Liner extrusion

Transfer of raw material into the extruder shall employ vacuum draw-off from a sealed 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 which may build up on the extruder tooling shall be continuously monitored. If such deposits impact or are transferred onto the liner surface (external or internal), the effect of these shall be examined. The liner shall be rejected if it is outside the manufacturer’s written specification.

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

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

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

7.9.6.2 Reinforcement application

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

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

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

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

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

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

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

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

7.9.6.3 Sheath extrusion

Extrusion of the hose sheath shall follow the same process requirements as for 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 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 which may permeate the liner (typically methane and methanol), the sheath shall be adequately vented to prevent pressure build-up between the liner and sheath. The requirement for venting shall be identified and the venting method shall be in accordance with the manufacturer's written specification.

7.9.7 Verification tests

7.9.7.1 General

The tests specified below 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 will be joined by a coupling, for tests specified in 7.9.7.5 to 7.9.7.7 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 only be a requirement to perform a burst test as specified in 7.9.7.6 to verify the coupling for service. In addition, the test procedure specified in 7.9.7.11 shall be performed if threaded couplings are to be incorporated.

If a material is specified that is of higher strength than a design already verified, there shall be no requirement to undertake impulse testing. Verification shall be restricted to leakage and burst testing as specified in 7.9.7.5 and 7.9.7.6.

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

7.9.7.2 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.

7.9.7.3 Visual and dimensional checks

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 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 all the above parameters. The values and tolerances shall not exceed those specified in 7.9.2.

7.9.7.4 Change-in-length test

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

The measured change-in-length shall be within the range specified in 7.9.4.3.

7.9.7.5 Leakage test

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.

7.9.7.6 Burst test

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 according to 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 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 7.9.4.1.

This test may be combined with the change-in-length test specified in 7.9.7.4 after having first performed the change-in-length test.

7.9.7.7 Impulse test

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 according to the manufacturer's written specification. The splices shall be located nominally in the centre of the test sample and their location clearly identified.

End fittings shall be attached to each sample using the same procedure that will be used to attach the fittings that will be employed in service. At least four end fittings shall be of the same design and material of construction as those that will be employed in service. The sample length shall be calculated using the formula specified in ISO 6803.

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 × DWP, and the hose shall withstand a minimum of 200 000 cycles without any signs of leakage or failure.

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

7.9.7.8 Cold bend test

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 specified in ISO 4672:1997, Method B, where the test temperature is – 40 °C ± 3 °C (– 40 °F ± 5 °F). The sample shall fail the test if any signs of leakage, distortion or cracking are apparent.

7.9.7.9 Collapse test

A sample of hose, with a length not less than 500 mm (19,69 in) between end fittings, shall be installed into 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 7.9.4.2.

7.9.7.10 Volumetric expansion test

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

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

7.9.7.11 End fitting anti-rotation test

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

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

7.9.7.12 Fluid compatibility tests

7.9.7.12.1 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 and material combinations. The fluid/material combinations and the applicable test procedure shall be as stated in the manufacturer's written specification.

Immersion testing which utilises plaques or dumbbells may only be used 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 programme 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 may not be required.

7.9.7.12.2 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 as described in ISO 527.

7.9.7.12.3 Pressure cycling tests

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, which 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 7.9.7.4, followed by a proof test as described in 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 twelve months. In the event that timescales do not permit a twelve-month programme, a higher temperature for a shorter duration and a lower number of test samples may be acceptable. In this event the duration and temperature shall be as stated in the manufacturer's written specification. If elevated temperatures are used, then care shall be taken that the failure mechanism is representative, and that the material temperature limits are not exceeded.

The water shall be renewed monthly.

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

At specified time intervals, samples of hose shall be removed from one of the test assemblies and the remaining hose re-terminated and re-introduced into the test programme. 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 the minimum design life is greater than the specified service life.

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

7.9.7.13 Permeability tests

7.9.7.13.1 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 below may be acceptable.

NOTE 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.

7.9.7.13.2 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 described in ISO 8308. The nitrogen-charge pressure shall be checked daily and adjusted if necessary, and at all other times the “main” and “venting” valves shall be kept tightly closed. The loss of fluid shall be measured daily over a period of at least 30 d, or until the level of fluid in the burette has fallen below the minimum mark if this occurs sooner. A graph of fluid loss against elapsed time shall be plotted. The average gradient of this graph shall be used to determine the characteristic permeation rate for the particular fluid/material combination.

7.9.7.13.3 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.

7.9.8 Component acceptance tests

7.9.8.1 Visual and dimensional inspection

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

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

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

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

c) sheath: D, concentricity;

d) completed hose: d, D, concentricity.

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

7.9.8.2 Test fluid

For sample testing, the test fluid shall be in accordance with the manufacturer's written specification. For integrity tests to be performed on each completed hose length, the test fluid shall be one of the following:

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

b) town mains water, and a quantity of monoethylene glycol to prevent freezing, suitably filtered as specified in 7.9.8.2 a), if there is potential for chemical reaction between the control fluid and the intended well-service fluid, or if specified in the manufacturer's written specification. If there is a risk of biological growth in the test fluid, a suitable biocide shall be added;

c) town mains water, suitably filtered as specified in 7.9.8.2 a), if the fluid in the hoses will not be subject to freezing.

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

For fluids a) and b), the test fluid shall remain in the hoses throughout umbilical manufacture, load-out, shipping and installation. For fluid c), the water shall be replaced with the specified installation/service fluids as part of the final flushing/cleaning operation.

The test fluid(s) in both the shipping containers and the hoses shall be stored so as to prevent freezing occurring. The test fluid(s) shall be clean, and the introduction of contamination during fluid transfer and pressure/flowrate testing shall be avoided. Completed hose lengths shall be sealed at each end at all times when testing is not in progress.

At all times, the temperature of the test fluid shall be maintained within the allowable range which is specified in the manufacturer's written specifications.

NOTE The use of two different test fluids may necessitate duplicate test equipment during umbilical manufacture, load-out and installation.

7.9.8.3 Liner burst test

After extrusion, a 1 m (3,28 ft) length of liner shall be removed from each end of each extruded length, and subjected to a burst test. The burst pressure shall be not less than 80 % of the calculated burst pressure based upon 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.

7.9.8.4 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 7.9.7.4.

7.9.8.5 Burst test

On completion of 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 7.9.7.6, with the exception that it is not a requirement for reinforcement splices or production couplings/end fittings to be included in any of the test samples.

This test may be combined with the change-in-length test in 7.9.8.4.

7.9.8.6 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 4. The test pressure shall be measured at both ends of the hose, and shall be maintained within ± 5 % over a minimum period of 30 min. At the end of this period, if the pressure has been maintained, the pressure source shall be isolated and the pressure-decay characteristic monitored over a minimum period of 60 min.

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

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

7.9.8.7 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 7.9.8.6, at a test pressure of 1,5 × DWP, shall be performed on all hoses following delivery and prior to lay-up.

7.10 Metallic tubes

7.10.1 General

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

7.10.2 Tube sizing

7.10.2.1 Nominal bore and DWP

All tubes shall be referenced by nominal bore and DWP.

Tolerances for nominal bore, wall thickness and ovality shall be in accordance with the values specified in the manufacturer's written specification.

NOTE Preferred bore sizes are tabulated in annex C.

7.10.2.2 Tube wall thickness

7.10.2.2.1 Wall thickness calculations

Wall thickness calculations shall include:

a) external and internal corrosion allowance;

b) minimum wall thickness;

c) maximum bore,

d) maximum allowable internal and external tube defects;

e) minimum yield strength of the material.

7.10.2.2.2 Calculation of stresses

Typical load cases, see 6.3.2, shall be considered, both in isolation and in combination with each other, and the effects on the tubes analysed. Three stress components shall be considered as detailed below.

a) Circumferential stresses

1) hoop stress distribution due to internal pressure under working, test and installation conditions;

2) shear stresses generated due to any torsional loading applied during installation and working conditions.

b) Radial stresses

Radial stress distribution due to internal and external pressure during working and test pressure conditions.

c) Axial stresses

1) axial stress generated due to direct tensile loads applied during manufacture, installation or operating conditions;

2) bending stress generated during testing, installation or operating conditions;

3) end cap stress when pressurizing the tube.

In order that the umbilical manufacturer can determine the load cases and combinations of load cases, it is imperative that the purchaser define the spectrum of envisaged operating conditions. Normal and shear stresses shall be combined, in accordance with von Mises' criterion, in order to establish an equivalent stress σ_e (due to all load cases). This stress shall then be equated to the SMYS of the material, modified by the appropriate factors specified in Table 5, from which the required wall thickness shall be calculated.

Hoop stress, σ_h, shall be calculated in accordance with the following formulae:

$$\sigma_{hav} = \frac{p \cdot d}{2t_{nom}} \qquad (D/t_{nom} > 20) \tag{1}$$

$$\sigma_{hb} = p\,\frac{(D^2 + d^2)}{(D^2 - d^2)} \qquad (D/t_{nom} \leqslant 20) \tag{2}$$

where

σ_{hav} is the average hoop stress in the tube wall, in newtons per square millimetre (N/mm^2);

σ_{hb} is the maximum hoop stress at the tube bore, in newtons per square millimetre (N/mm^2);

p is the internal pressure in tube, in megapascals;

D is the nominal outside diameter, in millimetres;

d is the nominal inside diameter, in millimetres;

t_{nom} is the wall thickness $= \frac{(D-d)}{2}$, in millimetres.

The radial stress:

$$\sigma_{rb} = -p \tag{3}$$

where

σ_{rb} is the maximum radial stress at the tube bore, in newtons per square millimetre (N/mm^2)

The following wall thicknesses shall be used for stress calculations:

For pressure containment calculations:

$t = t_{nom} - \Delta t_{fab}$

For operations:

$t = t_{nom} - \Delta t_{fab} - \Delta t_{corr}$

For handling and installation:

$t = t_{nom}$

For flexibility calculations:

$t = t_{nom}$

where

t_{nom} is the nominal wall thickness, in millimetres;

Δt_{fab} is the fabrication tolerance on wall thickness, in millimetres;

Δt_{corr} is the corrosion allowance (if applicable), in millimetres.

Consideration shall be given to the presence of external hydrostatic pressure acting on the outside diameter of the tube. The opposing effect of internal versus external hydrostatic pressures shall also be accounted for throughout the length of the umbilical. The load sharing between the various components in the umbilical and the end effects shall be considered. The effect of temperature limits upon the mechanical properties of the material shall also be considered during the flexibility analysis. For externally clad or internally lined tubes, the strength contribution of the cladding or lining may be ignored.

7.10.2.3 Strength criteria

7.10.2.3.1 General

Tubes shall be designed for the following mechanical failure modes and deformations:

a) yielding;

b) buckling;

c) fatigue;

d) ovality.

7.10.2.3.2 Stresses due to load combinations for static umbilicals

The maximum equivalent stress σ_e shall not exceed:

$$\sigma_e \leqslant F_e \cdot \sigma_y \tag{4}$$

where

σ_e is the maximum equivalent stress, in newtons per square millimetre (N/mm^2);

F_e is the equivalent stress design factor, obtained from Table 5;

σ_y is the specified minimum yield stress.

Table 5 — Equivalent stress design factors

Design condition	Type of load	F_e
Normal operation [a]	Functional	0,67
	Functional and environmental	0,87
Abnormal operation [a]	Functional, environmental and accidental	1,0
Installation [b]	Functional and environmental	1,0
Pressure test	Functional and environmental	0,96

[a] Normal and abnormal apply to environmental and accidental loads only. Normal is defined as an annual exceedence of 10^{-2} whilst abnormal is 10^{-4}.

[b] Due to size limitations of deployment equipment, some degree of plastic bending may occur during installation. The design factor for installation refers to equivalent stress levels resulting from catenary loads, compressive loads and torsional loads imposed during installation. Consideration should be given to the effects of residual stress resulting from any plastic bending.

7.10.2.4 Allowable strain

7.10.2.4.1 General

Strain criteria shall be considered as part of the design if the following apply:

a) the maximum calculated accumulated plastic strain, in the reeling, handling and installation is less than the maximum strain qualified for the base material and welds;

b) the configuration of the umbilical is controlled by imposed deformations or displacements;

c) the possible umbilical displacements are limited by geometrical constraints before exceeding the permissible strain.

7.10.2.4.2 Strain ageing

The effects of strain ageing, if any, shall be taken into account as part of the design process.

7.10.2.4.3 Strain hardening

For any material which exhibits significant strain-hardening effects, i.e. changes in σ_y greater than 10 %, tube specimens shall be subjected to low-cycle plastic fatigue testing. To qualify the material, samples shall be plastically deformed, preferably to the maximum deformation experienced during the manufacturing and installation phases, and then straightened. The process shall be repeated for a number of cycles representative of those involved in the manufacture, load-out and installation phases. After deformation, the tube shall be subjected to a standard tensile test and the mechanical properties obtained shall be analysed and compared with those of the base material to demonstrate that the strain-hardened material shall still be within its ductile limits. Samples of continuous and butt-welded tube shall be tested and compared. Results shall meet the requirements stated in the manufacturer's written specification.

7.10.2.5 Buckling

For handling an umbilical in special applications (e.g. deep water), the following buckling modes shall be considered:

a) local buckling of the tube due to external pressure, axial tension or compression, bending and torsion, or a combination of these loads;

b) propagation buckling.

7.10.2.6 Fatigue life determination

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

a) demonstrate that initiation of cracking will not occur,

b) define requirements for inspection for fatigue, if internal inspection will be possible in the installed condition.

Fatigue analyses shall include a prediction of load cycles during construction, installation, recovery, reinstallation, operation and translation of load cycles into nominal stress or strain cycles.

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

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

7.10.3 Construction

7.10.3.1 General

There are a number of possibilities for the material type and method of construction of the tubes. Depending on the base material, the tube may incorporate corrosion-protection mechanisms.

7.10.3.2 Material

The choice of the base tube material shall be made in consideration of the following:

a) installed environment;

b) installed duty;

c) weldability and weld reliability;

d) corrosion in respect of the seawater environment and service fluids;

e) processability;

f) in-service repair.

The manufacturer shall either undertake corrosion testing on the specified service fluids, or provide documentary evidence of previous tests which demonstrate compatibility of the service fluid with the base tube material for the specified design life.

7.10.3.3 Form of tubing

Tube for incorporation in an umbilical shall be of seam-welded or seamless construction.

NOTE As a result of manufacturing constraints, tube of seamless construction can require a large number of welds to achieve the final production lengths.

7.10.3.4 Corrosion/erosion protection

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

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

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

a) thermoplastic oversheath;

b) dissimilar metallic oversheath providing cathodic protection;

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

d) built-in corrosion allowance.

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

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

b) built-in corrosion allowance;

c) built-in erosion allowance.

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

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

7.10.3.5 Tube marking

All tubes supplied by the tubing manufacturer shall be numbered and have identification, as a minimum, in accordance with ASTM A 450. The marking shall also indicate the material dimension ($D \cdot t_{\text{nom}}$), supplier, heat, batch and tube number and whether the tubing is seamless or welded.

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

7.10.3.6 Termination interface

The end fitting design and material shall be suitable for the tube design and the tube material of construction. Tube DWP and corrosion resistance shall not be impaired by the fitting design.

All joints and fittings shall be compatible with the specified service fluids and seawater at the pressure equivalent to maximum design values.

7.10.4 Performance requirements

7.10.4.1 Design pressure ratios

The tubes shall be designed to withstand a minimum test pressure ratio of 1,25 × DWP.

7.10.4.2 Minimum bend radius

The minimum bend radius to which the tube can be bent without down-rating or affecting its performance shall be as stated in the manufacturer's written specification.

7.10.4.3 Corrosion

Design-life corrosion resistance shall be demonstrated. The maximum temperature that can be experienced by a tube assembly throughout the design life shall also be addressed as part of the corrosion evaluation. The material shall have a critical pitting temperature and critical crevice temperature, if applicable, which exceed the maximum service temperature.

7.10.4.4 Structural analysis

Structural analysis, taking into account data generated from the umbilical structural analysis specified in 6.3.6, shall be undertaken to confirm the acceptability of each tube design for loadings it will experience during testing and service.

7.10.5 Tube manufacture

7.10.5.1 Manufacturing process

7.10.5.1.1 General

For seam-welded and seamless tube, the manufacture shall be carefully controlled and monitored. The manufacturing process shall ensure that raw material, partly finished and finished tubes do not come into contact with contaminants.

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

7.10.5.1.2 Changes to essential variables

The following changes in the manufacturing processes shall require requalification of the manufacturing process:

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

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

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

7.10.5.1.3 Metal-making

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

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

Slabs/ingots of finished metal shall be inspected to meet the surface finish requirements before plate, strip or tube forming is commenced.

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

7.10.5.1.4 Plate and strip manufacture

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

Repair of plate and strip by welding is not permitted.

7.10.5.2 Tube manufacture

Manufacture of the tube shall be performed using the specified precursor materials, following the sequence of activities and remaining within the essential variables specified in the tube manufacturer's written specification. Tubes shall be manufactured to specified lengths and joints shall not be allowed unless specified.

The manufacturing practice and the instrumentation used to ensure proper control of the manufacturing process variables and their tolerances shall be as defined in the tube manufacturer's written specification.

During manufacture, the tube shall be subject to visual inspections for the detection of defects such as contamination, scratches, gouges and colour changes in accordance with the tube manufacturer's written specification.

7.10.5.3 Degreasing

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

7.10.5.4 Corrosion protection

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

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

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

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

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

b) coating thickness/tolerances and adhesion levels;

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

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

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

f) application, thickness and consistency of sealer material, if applied, and the effect of these properties upon the corrosion mechanism for the corrosion protection to remain effective;

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

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

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

7.10.5.5 Internal cleaning

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

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

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

c) flowrates to achieve cleanliness levels without overstressing the tube.

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

7.10.5.6 Tube welding

7.10.5.6.1 General

Tube jointing shall be undertaken in accordance with qualified jointing procedures by qualified personnel. All factory-produced welded joints shall be subject to radiographical examination to a recognized national or International Standard to check for alignment, full penetration, fusion and weld integrity.

Detailed weld qualification procedures, together with non-destructive examination procedures, shall be provided. Such procedures shall cover both automated factory-produced welds and manually produced welds for offshore repair jointing where automated welding may not be practical.

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

7.10.5.6.2 Annealing

If the manufacturing process requires annealing operations to achieve the required mechanical properties, such operations shall be undertaken in accordance with the qualified procedures defined in the tube manufacturer's written specification. After the annealing process, the tube surfaces shall be cleaned and all traces of agents, (chemical pickling, brushing, grinding or shot-blasting) shall be removed from the surface prior to shipment.

7.10.5.6.3 Tube preparation

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

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

b) tube end preparation, including:

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

   2) removal of internal and external burrs;

   3) prevention of swarf ingress into the tube;

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

d) tube- and weld-head alignment for welding of the tube ends in accordance with the approved welding procedure;

e) gas purging, if required.

7.10.5.6.4 Automated or manual production welding

All tube-to-tube girth welds shall be performed using qualified welding procedures for both automated and manual processes. All welds shall consist of a single-pass, fully fused run, with a uniform root and surface profile, unless the tube wall thickness requires a multiple-pass welding sequence. In automated processes, the automated head shall be regularly checked for correct operation and sequencing.

7.10.5.6.5 Weld preparation

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

a) radial alignment of the weld gap within specified tolerances;

b) secure and accurate location of the welding system;

c) control of ambient environment;

d) control of welding equipment parameters.

7.10.5.6.6 Weld process qualification

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

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

NOTE Examples of suitable experience and training are given in ISO 9606 and ISO 9956.

7.10.5.6.7 Weld repairs

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

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

7.10.5.7 Tube repairs

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

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

7.10.6 Verification tests

7.10.6.1 General

As a minimum, the tests specified below shall be performed to verify each tube design and provide characterization data.

7.10.6.2 Visual and dimensional checks

Each tube shall be 100 % visually inspected and shall be free of internal and external surface defects. This shall include examination of the tube material(s) for contamination, verification of dimensions and construction. The following parameters shall be measured in accordance with the manufacturer's written specification:

a) internal diameter;

b) external diameter;

c) diameter of any intermediate layers;

d) ovality;

e) concentricity;

f) tube wall thickness.

The manufacturer's written specification shall include dimensional specifications for the tube, stating the values and manufacturing tolerances for all the above parameters.

7.10.6.3 Tensile tests

Tensile tests shall be carried out in accordance with ASTM A 450. Results shall comply with the material specification.

7.10.6.4 Flattening tests

Flattening tests shall be carried out in accordance with ASTM A 450. Results shall comply with the material specification.

7.10.6.5 Hardness tests

Hardness tests shall be carried out in accordance with ASTM A 370. Results shall comply with the material specification.

7.10.6.6 Flaring tests

Flaring tests shall be carried out in accordance with ASTM A 450. Results shall be in accordance with ASTM A 450.

7.10.6.7 Chemical analysis

Complete chemical analysis shall be undertaken. In the case of high alloy materials, this shall include a ferrite content verification in accordance with ASTM E 562. The tube component elements and ferrite content shall be within the limits specified in the manufacturer's written specification.

7.10.6.8 Corrosion test

The tubes, including welds if applicable, shall be corrosion-tested in accordance with ASTM G 48, Method A. The specimen geometry, specimen preparation, test temperature, temperature monitoring, pH envelope and test acceptance criteria shall be in accordance with the manufacturer's written specification.

7.10.6.9 Weld qualification

All welding operations shall be qualified in accordance with a suitable standard. Such standards include, but are not limited to:

a) ISO 9956;

b) ISO 14732;

c) ASME B 31.3;

d) ASME, Section IX .

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

— heat input parameters;

— gas composition;

— weld comsumables.

7.10.6.10 Non-destructive examination (NDE)

All tubes shall be subject to NDE in accordance with ASTM A 450 or better, subject to the maximum allowable size of defect that can be tolerated by the service conditions. All NDE procedures and operators shall be qualified in accordance with a suitable standard. Such standards include, but are not limited to:

a) ISO 9712;

b) ASME B 31.3;

c) ASME, Section V .

All welds shall be subject to NDE using the method and acceptance criteria detailed in the qualified welding procedure. Welds not in accordance with the procedure acceptance criteria shall be deemed unacceptable.

7.10.6.11 Burst tests

One representative sample shall be taken from each end of a manufactured tube length and assembled with the intended material and design of end fitting incorporated at each end of each sample. If the sample does not contain suitable butt welds, two further samples containing at least one butt weld shall be prepared. The welds shall be performed in accordance with the qualified procedure to be utilized in the manufacture of the umbilical tube lengths. The sample length shall not be less than 400 mm (15,75 in) between end fittings.

The minimum burst pressure, determined in accordance with the manufacturer's written specification, shall not be less than the value calculated using minimum values of the material mechanical properties.

7.10.7 Acceptance tests

7.10.7.1 Visual and dimensional tests

During the manufacturing processes, the tube, partly completed tube string and base material shall remain free from damage, faults or contamination.

Manufacturing parameters shall be periodically monitored and shall comply with the manufacturer’s written specification. Dimensional inspection of the following shall be carried out in accordance with the manufacturer’s written specification:

a) outside diameter, D;

b) nominal thickness, t_{nom};

c) inside diameter, d;

d) concentricity.

Tubes outside their manufacturing tolerances shall be rejected. All welds shall be subject to visual and dimensional inspection as defined in the applicable weld qualification procedure.

7.10.7.2 Non-destructive examination (NDE)

Appropriate NDE methods and techniques shall be used to monitor tubes along each complete length for defects in the tube wall in seamless tubes and longitudinal weld integrity in seamed tube.

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

7.10.7.3 Test fluid

For sample testing, the test fluid shall be in accordance with the manufacturer’s written specification. For integrity tests which are to be performed on each completed tube length, the test fluid shall be one of the following:

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

b) town mains water plus a minimum of 25 % monoethylene glycol, suitably filtered as specified in 7.10.7.3 a), if there is potential for chemical reaction between the control fluid and the intended well-service fluid, or if specified in the manufacturer’s written specification;

c) towns mains water plus biocide, suitably filtered as specified in 7.10.7.3 a), if there is the potential for microbiological growth within the filled tube, or if specified in the manufacturer’s written specification.

The final choice of pressure-test fluid(s) to be incorporated in the tubes shall take account of the relevant system and environmental factors and shall be agreed with the purchaser.

For fluids a) and b), the test fluid shall remain in the tubes throughout umbilical manufacture, load-out, shipping and installation. For fluid c), the water shall be replaced with the specified installation/service fluid as part of the final flushing/cleaning operation.

If tubes will undergo intermediate welding operations during the laying-up operation, the fluid shall be removed prior to welding.

Storage of the test fluid(s) in both the shipping containers and the tubes shall be such as to prevent freezing. The test fluid(s) shall be clean and the introduction of contamination during fluid transfer and pressure/flowrate testing shall be avoided. Completed tube lengths shall be sealed at each end at all times when testing is not in progress.

The chloride content of town mains water shall be at a level such as not to introduce corrosion for tubes fabricated in stainless steel.

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

7.10.7.4 Burst test

7.10.7.4.1 Single-heat-number manufacture

Representative samples of tube shall be selected in accordance with the manufacturer’s written specification from the production batch. The sample length shall not be less than 400 mm (15,75 in) between end fittings attached for test purposes. The burst pressure, determined in accordance with the manufacturer's written specification, shall not be less than the value calculated using minimum values of the material mechanical properties.

7.10.7.4.2 Multiple-heat-number manufacture

Representative samples of tube shall be selected in accordance with the manufacturer's written specification from each heat number. The sample length shall not be less than 400 mm (15,75 in) between end fittings attached for test purposes. The burst pressure, determined in accordance with the manufacturer's written specification, shall not be less than the value calculated using minimum values of the material mechanical properties.

7.10.7.5 Pressure test

Tubes, when completed, shall be subjected to a pressure test to $1,25 \times$ DWP, in accordance with the manufacturer’s written specification.

8 Terminations and ancillary equipment design

8.1 General

The subsea end of an electric cable, optical fibre cable, thermoplastic hose or metallic tube may be terminated in one half of a connector assembly which can be mated underwater. Alternatively, the umbilical components may be terminated directly into a subsea control pod or junction box. The surface end of the umbilical shall, if applicable, have the armour-strength member terminated and suspended by a flange connected to the top of a riser I- or J-tube, with the electric and optical fibre cables, hoses and tubes accessible for connection to platform equipment.

The design of umbilical terminations and ancillary equipment is invariably specific to a particular umbilical system and, as such, detailed specification data are outside the scope of this part of ISO 13628. The following information is provided for guidance only.

a) In reviewing the design requirements for terminations and ancillary equipment, such reviews should consider the effects of component test parameters on the active elements within the terminations and ancillary equipment.

b) End terminations should be designed, if applicable, to take account of free-flooding umbilical designs.

c) For termination equipment of metallic construction, corrosion protection, if required, should be provided by either independent cathodic protection, or a facility for electrical bonding to a cathodic protection system. In the selection of termination materials, consideration should be given to their corrosion-resistance properties. Calcification of exposed metal surfaces which could result from cathodic protection should be considered.

d) If necessary, bend limiters/stiffeners should be incorporated to prevent damaging forces being applied to the umbilical during load-out, deployment and service.

8.2 Terminations

8.2.1 Armour terminations

Armoured umbilicals shall be terminated with end terminations with a minimum loading capability equal to or exceeding the maximum working load of the umbilical.

8.2.2 Cable terminations

For electric/optical fibre cable terminations to be permanently installed subsea (e.g. penetrators, connectors, etc.), the design shall take into account the requirement for effective water-blocking at the cable entry, pin-to-pin conductive connectors and pigtails if applicable. If bonded and/or non-pressure-balanced designs are to be employed, the design shall address the reliability of the bonding, including the possibility for cathodic delamination, and/or sealing mechanism in a seawater environment throughout the design life.

If connectors can be exposed to extended immersion in a seawater environment without connection to mating halves, suitable blanking arrangements shall be incorporated. Such blanking arrangements shall both provide mechanical protection and prevent electrolytic action between adjacent pins in the event electrical power is applied to the connected electrical cores.

The terminations shall be tested in accordance with the manufacturer's written specification.

8.2.3 Pull-in head

A pull-in head shall be used to pull the umbilical along the seabed or through the I- or J-tube. The pull-in head shall be designed to withstand installation loads without damage to the umbilical or its functional components.

The pull-in head shall be designed, if possible, to allow uninterrupted travel over rollers/sheaves and through I- or J-tube risers without damage or snagging. The manufacturer shall specify the size relationship between the I- or J-tube internal and pull-in head diameters.

The pull-in head shall be designed to house the hose, tube, electrical and optical fibre cable terminations.

Electric and optical fibre cables shall be sealed to prevent seawater ingress.

8.2.4 Topside hang-off

A topside hang-off shall be used to secure the umbilical to the top of the I- or J-tube riser or other securing locations. The hang-off equipment shall be designed to withstand static or dynamic loads associated with vessel motions and installation forces, and to transfer the breaking load without damaging the umbilical or umbilical components.

The hang-off design shall take into account that, once installed, inspection access at the top of the I- or J-tube may not be practical, and the potential for long-term corrosion or creep at the load-bearing components shall be addressed.

8.2.5 Subsea termination interface

A subsea termination interface shall be used to provide the transition between the umbilical and its subsea termination or subsea umbilical distribution unit.

The design of the bend limiter/stiffener shall take account of the size, mass and centre of gravity of the subsea termination and their effect on the umbilical during load-out, deployment and subsea pull-in.

8.2.6 Subsea umbilical termination

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

NOTE Suitable handling facilities may be included, if required, for use during load-out and installation.

If the design incorporates isolation valves and/or electrical/optical shorting/test points requiring access, the design shall be such that these can be readily accessed and operated. The method of access and operation shall be as specified in the manufacturer's written specification.

8.2.7 Subsea umbilical distribution unit

The subsea umbilical distribution unit shall mechanically and functionally connect the umbilical to several subsea systems in a similar manner to the subsea umbilical termination. If a significant number of systems are to be connected, the size, mass, centre of gravity, deployment and pull-in shall be considered in respect of bend strain relief for the umbilical.

8.3 Ancillary equipment

8.3.1 Joint box

A joint box shall be used to join umbilical sub-lengths to achieve overall length requirements or to repair a damaged umbilical. Each umbilical end to be joined shall have an armour termination, if applicable. These shall be joined using a connecting sleeve or barrel which shall allow for the transmittal of the load from one sub-length to the other. The means of connecting the sleeve or barrel should allow removal for access during the design life of the umbilical.

The joint box shall be of a streamlined design, with a bend stiffener at each end if required, and shall be of compact size to facilitate reeling, storage and installation requirements.

The joining of the electric cables, optical fibres, hoses and tubes within the joint box shall be according to the manufacturer's written specification.

Joint boxes should not be incorporated in any section of an umbilical that will operate in a dynamic mode.

8.3.2 Weak link

A weak link is an optional component designed to protect the umbilical, and equipment connected to the umbilical, from excessive line loads. The required load at which the weak link shall be activated shall be defined in the manufacturer's written specification. The weak link shall be designed to have a design life equal to or greater than the umbilical.

For weak-link designs which are integral to the umbilical, in order to facilitate installation and retrieval of the umbilical, the weak link shall have an override mechanism which shall be easily removable and replaceable when the weak link is installed on the seabed. With the override mechanism in place, the weak link shall be capable of withstanding the maximum umbilical tensile working load without either being activated or suffering mechanical failure.

If the weak link is activated, the functional lines shall be cleanly severed. Damage to the services shall be minimized by ensuring that the internal umbilical components are not excessively loaded during activation. The design shall facilitate repair of the umbilical after activation.

An alternative weak-link design may be employed in the form of a shearing guillotine which acts on jumper hoses or cables installed between the subsea umbilical termination/distribution unit and a subsea system. The jumpers severed shall be replaceable subsea.

Other approaches to the design of weak links (such as multi-coupler arrangements) may be acceptable and shall be defined in the manufacturer's written specification. If a weak link is required, the manufacturer's written specification shall state the type of weak-link design to be used.

If the weak link is activated, its operation shall not prevent the safe shutdown of the wellhead and christmas tree equipment under any circumstances. The hydraulic pressure in the parted hydraulic lines shall be capable of reducing to ambient pressure in the umbilical section connected to the wellhead/christmas tree equipment.

8.3.3 Buoyancy attachments

Depending on the installed configuration, a dynamic umbilical can necessitate buoyancy attachments in the form of collars, tanks, etc. to achieve the necessary configuration and dynamic motions. The method of attachment shall not to induce stress cracking in the umbilical sheath, nor allow excessive stress relaxation within the compressive zone of the attachment if clamped, nor allow excessive strain of the umbilical and its components.

9 Umbilical design

9.1 Temperature range

The umbilical and its constituent components and materials shall be capable of operating within the normal temperature range of – 15 °C to 40 °C (5 °F to 104 °F). For some cold weather applications, it may be possible for the umbilical to experience temperatures lower than the specified minimum (during storage, load-out and installation and for the topside length during service). Additionally, for some installed conditions (I- or J-tube risers in warm climates, close proximity to production risers in an enclosed environment, etc.) and storage, it may be possible for the umbilical to be exposed to a temperature higher than the specified maximum. It shall, however, be capable of operating continuously at the specified service temperature for the specified design life. The maximum and minimum temperatures shall be specified in the manufacturer's written specification, based on the functional requirements of clause 4.

NOTE Continuous or frequent exposure to elevated temperatures may affect the design life of the umbilical.

9.2 Maximum working load

The maximum working load for the umbilical shall not be less that the value stated in the manufacturer's written specification.

9.3 Minimum breaking load

The minimum breaking load, with the umbilical straight, shall be in accordance with the manufacturer's written specification.

In all cases the specified load level shall be such that, under all possible installation and service conditions, an adequate margin of safety is demonstrated to exist by analysis.

9.4 Minimum bend radius

The minimum radii to which the umbilical can be bent for storage and service without affecting its performance shall be as stated in the manufacturer's written specification. The minimum bend radii of the electrical cables, hoses, tubes and optical fibre cables shall also be as stated in the manufacturer's written specification.

9.5 Dynamic service life

The umbilical shall be designed to be fatigue-resistant for the specified design life, with an adequate safety factor derived from analysis, when operating in a dynamic mode and subject to the loads, number of flexures and motions such that it meets the requirements of clause 4.

NOTE A safety factor of 10 has been found suitable, depending on the level of analysis and the methodology.

9.6 Seabed stability

The umbilical shall be designed to be sufficiently stable, when laid on the seabed, for the seabed condition and seabed current values, to meet the requirements of clause 4.

9.7 Service environment

The umbilical and its constituent components shall be designed for immersion in seawater for the specified design life. Consideration shall also be given to

a) storage prior to installation,

b) exposure to service fluids,

c) the seabed and the topsides environment in terms of radiation, ozone, temperature and chemicals,

d) imposed dynamic conditions within the free-hanging regions,

e) protection against dropped objects.

9.8 Cross-sectional arrangement

The umbilical shall be designed to meet the functional requirements of clause 4, the design requirements of clause 6 and the mechanical properties of the manufacturer's written specification. Consideration shall be given to the following.

a) The cross-section shall be as compact as possible.

b) The cross-section should be as symmetrical as possible. This may be achieved by the use of additional components or fillers.

NOTE The requirements of a) and b) are not always coincident.

c) In the case of umbilicals containing electric cables, the cables should be placed towards the centre of the umbilical bundle. Alternative cross-sectional arrangements with electric cables or electric cable sub-bundles around the outside of the bundle are permissible. In this case, the design of the electric cables and sub-bundles shall take into account the additional tensile and compressive loadings which may be imposed on the electrical conductors so that the design life is not compromised.

d) If steel tubes form part of an umbilical which also includes thermoplastic hoses and/or cables, consideration shall be given to the crushing forces exerted by steel tubes during manufacture, reeling, installation and service.

e) If fillers are used in the interstices of the umbilical, the filler material should be selected with consideration of the crushing forces on the bundle due to umbilical manufacture, installation and service.

f) For deepwater installations, the cross-sectional arrangement shall take account of the requirement for the umbilical to free-flood at a rate such that the external forces imposed during installation do not damage the components.

9.9 Lay-up

Individual functional components (electric cables, optical fibre cables, hoses, tubes, fillers, etc.) shall be laid up to form the umbilical bundle or sub-bundle.

If required, the bundle lay-up procedure shall be carried out with hoses pressurized. The pressure level used shall be in accordance with the manufacturer's written specification which shall be sufficient to prevent distortion of the hoses. All subsequent manufacturing operations shall be carried out with the hoses pressurized to the same nominal pressure.

9.10 Sub-bundles

Sub-bundles, which may comprise electric cables, optical fibre cables, hoses, tubes or combinations of components, shall be designed and dimensionally sized to provide a circular configuration. The sub-bundle should be designed to be as symmetrical as possible about its central axis.

To maintain stability after laying up the sub-components, a binder tape shall be applied at a constant helical angle.

For geometrical and/or mechanical requirements (e.g. interfacing with an electrical penetrator), the bundled and taped subcomponents may be oversheathed in a thermoplastic material which shall be as stated in the manufacturer's written specification.

Any sheath shall be readily removable to ensure the surface of components are free from damage and marks, etc. that may compromise boot-type overseals.

9.11 Inner sheath

When an umbilical is to be armoured, an inner sheath shall be applied over the taped bundle to provide mechanical protection, increase bundle stability and provide a bedding for the armour wires. The sheath construction shall be

a) for static applications: either a continuously extruded thermoplastic material or a layer of helically applied synthetic fibre roving. The material shall provide sufficient resistance to abrasion and stress cracking during load-out and installation,

b) for dynamic applications: a continuously extruded thermoplastic material.

The inner sheath shall be free of contaminants, faults and other defects. The sheath shall be of sufficient thickness to ensure proper distribution of radial compression between the armour wire and the bundle. The thickness of the sheath, and the tolerance for thickness and concentricity, shall be in accordance with the manufacturer’s written specification.

The sheath extrusion process shall be in accordance with the manufacturer's written specification. It shall be selected by the manufacturer to suit the subsequent armouring process (if applicable) and to ensure that the bundle components can move freely and independently of each other during bending and flexing.

9.12 Armouring

Umbilicals which contain electrical conductors and/or optical fibres but do not include load-bearing tubes shall be armoured or shall include a suitable strain member. For umbilicals which are to be torque-balanced and/or require acceptance of high tensile loading, the armouring shall consist of two or more contra-helically applied layers of steel armour wires. (If required, other suitable materials which provide the specified performance may be used.)

The armour wires shall be applied under uniform tension and designed to limit rotation as umbilical tension varies from zero to the maximum working axial load. For dynamic umbilicals, the armouring may also serve to provide ballast to achieve the necessary stability during dynamic operation. For multi-layer armour and/or ballast packages, additional layers shall be applied in the opposite direction to the adjacent layer(s). The size and lay lengths of the armour wires shall be specified by the manufacturer to provide the necessary tensile strength, axial elongation, bending stiffness and weight for the design life of the umbilical.

NOTE EN 10257-2 provides specifications for suitable steel wires.

For an umbilical containing steel tubes, the laid-up tubes may have sufficient inherent tensile capacity to provide strain relief in the event electrical conductors are incorporated within the umbilical. In this particular instance, the tube wall thickness shall be suitably sized to accommodate the stresses resulting from pressurization and tensile loading during service and/or installation.

In the event of onerous installation and/or service conditions, the inclusion of an armour layer for mechanical protection of the components, or ballasting of the umbilical, shall be considered as part of the design performance analysis.

If required, thermoplastic filler rods may be used in place of armour wires to minimize the tensile strength and/or mass of the umbilical. The fillers shall be distributed uniformly with the steel wires.

9.13 Outer sheath

An outer sheath shall be applied as

a) a continuously extruded thermoplastic sheath or

b) a covering of helically applied textile rovings.

For dynamic applications, a continuously extruded thermoplastic sheath shall be employed in accordance with the requirements of 9.11.

To provide visual indication of twist during installation, a high-visibility line of contrasting colour shall be applied along the umbilical length.

9.14 Length marking

The umbilical shall be sequentially marked in lengths of 100 m (328 ft) increments, with the exception of the first and last 100 m (328 ft), which shall be sequentially marked in 10 m (32,8 ft) increments. The marks shall be durable throughout storage, load-out and installation of the umbilical and legible to divers or underwater video cameras providing all-round (360°) visibility and with a minimum character height of 25,4 mm (1,0 in).

10 Umbilical manufacture and test

10.1 Umbilical manufacture

10.1.1 Lay-up

The lay-up operations shall be carried out in a clean, dedicated controlled area which shall be subject to a regular cleaning schedule.

If relatively stiff components are to be laid up, consideration shall be given to the following:

a) minimizing contact forces between the components and the laying-up machine, and appropriate routing design, to prevent damage to the components;

b) maintaining bend radii at all times equal to, or greater than, the radius required to produce the maximum allowable bending strain, as specified in the manufacturer's written specification;

c) preforming the components to facilitate manufacture of the umbilical bundle or sub-bundle;

d) minimizing built-in torsion in individual components during the bundling process.

For both planetary and oscillatory cabling, the components, sub-bundles and fillers shall not be subject to excessive compressive and tensile loadings. If the weight of a component or sub-bundle could induce damaging loads, the pay-off reels shall be powered.

In order to minimize damage to the external surface of the components, contact forces between the components and the bundling machine shall not exceed the values defined in the manufacturer's written specification. To further minimize surface damage, consideration shall be given to rollers placed wherever such contact forces are relatively high.

Continuous inspection procedures shall be undertaken to ensure that the components are not gouged, scratched or otherwise damaged during bundle assembly.

Whilst stored on processing reels or passing through the bundling machine, component bending radii shall be maintained at all times equal to or greater than the radius required to produce the maximum allowable bending strain. Such minimum bending radii shall be defined in the manufacturer's written specification.

The bundled components or intermediate bundled components shall be stored on a suitably sized reel and/or carousel in a dry dedicated and controlled area. The spooling tension and/or number of layers shall be such as not to induce damaging deformation to the bundle structure or individual components.

10.1.2 Inner sheath

The bundle (or sub-bundle) shall be kept dry prior to and during passage through the extruder.

During extrusion, the following process parameters shall be measured and recorded in accordance with the manufacturer's written specification:

a) extruder barrel/head temperatures;

b) melt pressure/temperature;

c) screw speed/power requirement;

d) haul-off speed;

e) outside diameter.

If the inner sheath comprises rovings, these shall be applied under uniform tension. The tension applied to the roving yarns shall be checked for each bobbin at the commencement of each production run and thereafter in accordance with the manufacturer's written specification. Splices within the roving shall be produced and validated in accordance with the manufacturer's written specification.

During sheath application, the product shall be subject to frequent visual inspection to ensure uninterrupted and uniform coverage and no extraneous material is included under the sheath. Care shall be taken to ensure that the bundle (or sub-bundle) is not stretched and the binder tape is not disturbed during this process.

Repairs to a sheath are allowable and shall be performed in accordance with the manufacturer's written specification.

10.1.3 Armouring

The operation shall be carried out in a clean dedicated, controlled area which shall be subject to a regular cleaning routine.

Breaking strength, yield strength and load-extension measurements shall be performed on samples from each batch of armour wire to confirm that the material properties are within the specified limits.

Armour wires shall be wound uniformly onto armour bobbins and subsequently processed in a manner which does not damage or reduce the effectiveness of the galvanising layer (if present) or contaminate it with extraneous matter.

During armour application, the bundle and its components shall not be subject to excessive compressive loadings which result in deformation or damage. Separator tapes applied between armour layers, if used, shall be applied at uniform tension. The tension applied to the armour wires shall be checked for each bobbin at the commencement of each production run and thereafter in accordance with the manufacturer's written specification.

During armour application, the product shall be subject to frequent visual inspection to ensure uninterrupted and uniform coverage and no extraneous material is included under the armour. Care shall be taken to ensure that the sheathed bundle is not stretched and the sheath is not disturbed during this process.

If armour wire welds are included in an armouring layer, they shall be staggered and shall be made in accordance with the manufacturer's written specification.

10.1.4 Outer sheath

Application of the outer sheath shall follow the same process requirements as for the inner sheath.

The longitudinal stripe shall be visually inspected in accordance with the manufacturer's written specification for continuity and evidence of twist in the umbilical.

10.2 Verification tests

10.2.1 General

Verification tests shall be undertaken to validate the performance of the umbilical. This process can be undertaken using a separate length manufactured prior to main production, or, if the risk is small, using sample(s) from the production length.

If the umbilical contains electrical cores, the following electrical tests shall be performed as an integral part of the mechanical tests:

a) continuous monitoring of the conductor path with each conductor in the umbilical connected in series. The measured DC conductor resistance value shall not exceed the value defined in 7.7.3 at the beginning and end of the test;

b) insulation resistance shall be measured during and after completion of the mechanical testing. The measured value shall comply with the requirements of 7.7.4.

If the umbilical contains optical fibres, light-signal monitoring shall be performed as an integral part of the mechanical test.

If tests require the umbilical to be tensile-loaded, the mechanical means of anchoring shall employ the same design principles as for the service umbilical system.

NOTE 1 Umbilical verification tests to be performed and specified in 10.2 are summarized in annex B.

NOTE 2 For deepwater applications, it may be necessary to carry out free-flooding tests, and external hydrostatic tests to confirm the load-bearing integrity of the internal components.

10.2.2 Tensile test

A representative length of the completed umbilical, which takes account of end effects and pitch lengths of the umbilical components, shall be subjected to a two-stage tensile loading programme.

The first stage shall involve three load cycles to establish the permanent set and residual twist of the umbilical design, up to the maximum design working load. Stage two shall involve a further loading to establish the load at which the components within the umbilical cease to function, and the ultimate tensile strength of the umbilical.

Both ends of the sample shall be terminated in such a manner that for armoured umbilicals the armour wires are gripped, and for unarmoured umbilicals the internal components are firmly gripped. When loaded into the test rig, the specimen shall have freedom to rotate under the action of the tensile load. During tensile testing umbilicals containing hoses/tubes shall be pressurized to their specified installation pressure (for static umbilicals), or to the value defined in the manufacturer's written specification (for dynamic umbilicals). Electrical testing, if applicable, shall be performed in accordance with the requirements of 10.2.1. Optical fibres shall be monitored for optical continuity.

The tensile load shall be applied in a minimum of 10 increments up to the maximum design working load and at each load level, the load, extension and rotation shall be recorded. On reaching the maximum working load, the load shall be reduced and the same procedure utilised during load-down. The procedure shall be repeated for the second and third cycles.

Following completion of the three load cycles, and with the pressure removed, the load shall be increased until mechanical failure occurs, or minimum breaking load is reached, whichever is the sooner. Any prior functional failure of the umbilical shall be noted. At the conclusion of the testing, the umbilical specimen shall be stripped down and visually examined in the event of premature failure of functional components.

10.2.3 Bend stiffness test

A representative sample of the completed umbilical shall be subjected to a bend stiffness test procedure in accordance with the test procedure detailed in annex D.

NOTE This is normally a characterization test without acceptance/rejection criteria, unless specified otherwise in the manufacturer’s written specification.

10.2.4 Crush test

A sample of completed umbilical shall be subjected to lateral loading to allow determination of its resistance to deformation.

In the case of umbilicals containing fluid conduits, the resistance to lateral loading shall be obtained for the following conditions:

a) hoses/tubes unpressurized;

b) hoses/tubes pressurized to the recommended installation value;

c) all hoses/tubes pressurized to a common value as stated in the manufacturer's written specification.

For static umbilicals, conditions a) and/or b) shall apply; for dynamic umbilicals a) and/or b) and/or c) shall apply.

Tubes may be unpressurized.

The lateral deformation tests specified in a), b) and c) above shall be performed on separate representative umbilical samples which have not been subjected to previous testing.

If umbilicals contain electrical cores, electrical testing shall be in accordance with the requirements of 10.2.1, or in accordance with the manufacturer's written specification. Optical fibres, if present, shall be monitored for optical continuity.

The test sample shall be loaded between two parallel plates each a minimum of 250 mm (9,84 in) in length and located diametrically opposite each other in a compressive loading device. With the hoses pressurized to their specified pressure, the plates shall be moved towards each other at a rate not exceeding 5 mm/min (0,196 9 in/min).

The reduction in umbilical diameter between the load plates shall be continuously recorded as a function of the applied load. On reaching the maximum applied load specified in the manufacturer's written specification or 10 % deformation, whichever occurs first, the loading plates shall be moved apart at a rate not exceeding 5 mm/min (0,196 9 in/min). When the load has reduced to zero, the sample shall be sectioned and examined, and the effects of the applied load on the umbilical and the functional components shall be determined and documented.

A launching simulation test for both static and dynamic umbilicals should be considered, and, if necessary carried out by a static test using a bend rig. Other areas that need consideration include load-out and service for dynamic umbilicals.

NOTE The test loading system may be more representative of the installation system than a pair of plates.

10.2.5 Fatigue tests

Mechanical testing shall be undertaken to determine the fatigue resistance of an umbilical. Test regimes shall be chosen to demonstrate that a particular design or design feature is suitable to withstand the repeated flexures sustained by an umbilical during manufacture, transfer spooling, load-out, I- or J-tube pull-in, burial and, for a dynamic installation, operational service throughout the service life.

The test regimes shall be in accordance with the manufacturer's written specification, taking into account installation/service parameters, and the results of design activities and analyses.

NOTE Because of the wide range of fatigue conditions to which an umbilical can be exposed, it is not possible to generalize and specify test methods and parameters to cover all eventualities. Instead, the testing is application-specific. Guidance notes on fatigue testing are provided in annex E.

For static umbilicals, hoses and tubes shall be pressurized to their recommended installation pressure. Hoses and tubes in dynamic umbilicals shall be pressurized to their maximum in-service working pressure, unless analysis shows that varying the pressure in some time- (or cycle-)dependent manner is more representative. However, if an umbilical contains hoses or tubes with a multiplicity of working pressures, for expediency a common pressure may be adopted. Electrical cores shall be continuously monitored for DC continuity. Optical fibres shall be continuously monitored for optical continuity. Conductor DC resistance, core insulation resistance and optical attenuation shall be measured at the beginning and the end of the fatigue test programme, and at periodic intervals as defined in the manufacturer's written specification.

If a component incorporates a splice, the effect of the splice shall be subject to fatigue test evaluation.

11 Umbilical factory acceptance tests (FATs)

11.1 General

The tests detailed in this clause are the minimum requirements for each manufactured length. If the acceptance criteria for a test are not met, the cause of the failure shall be investigated and a report compiled.

Factory acceptance tests shall be undertaken either prior to, or after, fitment of end terminations.

NOTE 1 Some types of termination may preclude the possibility of carrying out some test types after they are fitted or, alternatively, modified/reduced test parameters may be necessary. For instance, some types of electrical connectors may not be capable of withstanding a high voltage test.

Additional FATs may be required to confirm the integrity and performance compliance of components or umbilical, resulting from additional design or design verification requirements, or assembly of sub-bundles. If required, these tests, including acceptance/rejection criteria if applicable, shall be specified in the manufacturer's written specification.

NOTE 2 Umbilical FATs to be performed are specified in clause 11 and summarized in annex B.

11.2 Visual and dimensional inspection

During the manufacturing processes, the components, partially completed and completed umbilical shall be free from damage, faults or contamination. Raw materials should also be inspected for contamination. Manufacturing parameters shall be periodically monitored according to, and shall comply with, the manufacturer's written specification.

11.3 Electric cable

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

a) DC conductor resistance as specified in 7.7.3;

b) insulation resistance as specified in 7.7.4;

c) high voltage DC as specified in 7.7.5;

d) transmission-line characteristics as specified in 7.7.6, 7.7.7, 7.7.8 and 7.7.9;

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

e) cross-talk as specified in 7.7.10;

f) time-domain reflectometry as specified in 7.7.11.

11.4 Optical fibre cables

On completion of umbilical manufacture, the optical fibre cables shall be subject to an optical time-domain reflectometry test as specified in 7.8.8.2.

11.5 Hoses

On completion of umbilical manufacture, the hoses shall be subject to the following FATs:

a) **proof pressure/decay test** as specified in 7.9.8.6 at a test pressure of 1,5 × DWP;

b) **flow test**;

The manufacturer's written specification shall state the nominal flowrate that each hose shall be required to pass. The manufacturer shall calculate expected pressure drops for the specified fluid at nominal flowrate, and the test shall require that the nominal flowrate is passed through the hose. A constant high pressure supply shall be connected to one end of each manufactured hose length and the other end shall be vented to atmosphere. The test fluid shall be passed through the hose until the pressure reading at the hose inlet is constant within 5 %, and the flowrate is constant within 5 %. The flowrate, pressure drop across the hose and fluid temperature at inlet and outlet shall be recorded. The actual pressure drop and the calculated pressure drop shall be compared and the difference between the two shall not exceed the tolerance value stated in the manufacturer's written specification.

NOTE Reasonable correlation may be expected in turbulent flow, but poor correlation is to be expected under laminar flow conditions. For short umbilicals (typical length less than 200 m), poor correlation is to be expected.

c) **dynamic response;**

This is an optional test performed in accordance with the procedure described in annex D. The results from this test shall be used to characterize a hose within an umbilical and do not constitute acceptance/ rejection criteria.

d) **fluid cleanliness;**

Upon satisfactory completion of all other acceptance tests, each hose length specified in the manufacturer's written specification shall be flushed with the specified test fluid. The highest possible flowrate shall be used which does not result in the hose being subject to a pressure greater than the DWP at the hose inlet. The fluid temperature shall be monitored at inlet and outlet continuously to ensure that the hose temperature rating is not exceeded. Each hose length shall be flushed for a complete volume change and thereafter until the cleanliness level is reached. At the end of this period, three consecutive fluid samples per hose shall be taken at intervals of at least 10 min, using the procedure specified in ISO 4406. The cleanliness levels shall meet or exceed the value(s) specified in the manufacturer's written specification.

NOTE 2 For convenience, short hose lengths may be connected together to facilitate the flushing requirements. For hose pressures in excess of 69,0 MPa (10 000 psi), an inlet pressure lower than the hose DWP may result due to limitations in flushing equipment capacity.

NOTE 3 The flow test and the fluid cleanliness tests may be combined.

11.6 Tubes

On completion of umbilical manufacture, the tubes shall be subject to the following FATs:

a) proof pressure test in accordance with the procedure of 11.5 a) at a test pressure of 1,25 × DWP;

b) flow test in accordance with the procedure of 11.5 b);

c) fluid cleanliness in accordance with the procedure of 11.5 d).

12 Storage

12.1 General

Upon satisfactory completion of all umbilical FATs, the umbilical shall be stored on either a carousel, a reel or a turntable, or coiled into a storage tank until load-out is undertaken. The umbilical shall not be stored in direct sunlight if the resultant internal temperatures are shown to affect component performance.

If an umbilical is to be stored for an extended duration, typically in excess of six months, and/or periods of temperature extremes, consideration should be given to the effect on the fluid within the hoses and tubes. If necessary, the fluid shall be replaced by a more appropriate fluid. The requirement to change fluid and fluid type shall be defined in the manufacturer's written specification, which shall also detail frequency of inspection and testing to confirm product integrity.

If an umbilical is stored on a reel, the reel flange diameter shall be greater than the diameter of the outermost layer by at least one umbilical diameter. The diameter of the reel shall take into account end termination dimensions and bend stiffener/bend limiter limitations. Spooling of an umbilical onto its storage reel (which may also be the shipping and/or installation reel) shall be undertaken with sufficient back-tension to minimize the risk of loose turns developing when the product is removed from the reel.

In recognition that the umbilical may be subjected to tests during, or at the end of, the storage period, both ends shall be readily accessible.

Whether stored on a reel or carousel, the number of layers shall be such as not to impart damaging forces to the underlying layers. Reels and carousels shall be located on flat stable ground in a safe area away from machinery and/or processes which produce corrosive and/or damaging products, and away from constantly used work areas. If appropriate, suitable barriers shall be erected to minimize the risk of damage as a result of collision with passing vehicles.

12.2 Protection of umbilical services

12.2.1 Electrical services

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

12.2.2 Optical fibre cables

Optical fibre cables shall be capped and sealed to prevent water ingress.

12.2.3 Hydraulic services

In the case of umbilicals containing hoses or tubes, each hose/tube shall be filled with fluid, and the ends assembled with suitable pressure-retaining fittings. In the event of a storage period greater than six months, the hoses/tubes shall be pressurized to a gauge pressure of 7 MPa (1 015 psi) unless otherwise specified in the manufacturer's written specification, and the manufacturer shall log the pressure in each hose/tube string in accordance with the manufacturer's written specification until load-out. Any pressure variations logged which cannot be accounted for by temperature variation shall be further investigated.

This requirement does not apply to spare lengths.

12.3 Spare length

A spare length may be manufactured as a separate item or it may be part of the main umbilical as an overlength. The precautions described in 12.2 shall be applied to the spare length, but without the necessity to pressurize hoses/tubes. The spare length shall be clearly and indelibly marked with identification references in accordance with the manufacturer's written specification.

12.4 Repair kits

Repair kits for jointing umbilical lengths shall be stored under cover in suitable containers to prevent damage and deterioration of quality and to provide protection for offshore shipping. The containers shall be clearly labelled. The labelling shall include the expiry date of any parts of the kit (e.g. resins, solvents) that have limited shelf lives.

12.5 Handling for integration tests

It may be necessary to carry out integration testing of umbilicals. In the case of short, relatively light umbilicals this may be undertaken away from the manufacturer's premises. Care shall be taken to ensure that any umbilical transportation or handling is undertaken without infringing any of the handling or storage parameters or causing damage to the umbilical.

The manufacturer shall prepare a procedure for the transportation and handling which shall state who is responsible for the handling of the umbilical at each stage. All transportation and handling shall be carried out in accordance with this procedure.

13 Pre-installation activity

13.1 Umbilical information

The manufacturer shall provide, as a minimum, the following umbilical installation interface information:

a) outer finish details, including friction coefficients both dry and lubricated with water;

b) design working loads;

c) ultimate tensile strength;

d) axial stiffness;

e) bending stiffness;

f) weight in air (when hoses/tubes filled with the installation fluid);

g) weight in water (when hoses/tubes filled with the installation and service fluids);

h) length (and tolerance on/accuracy of length);

i) length-marking details applied, and their direction;

j) nominal diameter and tolerance;

k) minimum bend radius under installation conditions;

l) load-torque characteristics (torque-balance);

m) maximum crushing load per unit length;

n) allowable combination of axial steady state and fatigue loads, and number of cycles, to which the umbilical may be subjected during deployment;

o) repair joint dimensions and fitting procedure;

p) pressure to be applied to the hoses and tubes during load-out and installation;

q) hose/tube sizes, termination details for hose connections and DWPs;

r) power/signal/optical characteristics;

s) details of storage prior to load-out;

t) confirmation of longitudinal line for twist monitoring;

u) umbilical termination test connection details.

13.2 Route information

The following seabed and environmental information is required along the entire route, including areas identified for placement of any excess umbilical length:

a) seabed topography along the proposed route corridor of required/agreed width;

b) seabed water depth profile along the route centreline;

c) seabed conditions (e.g. rock outcrops, boulders, sediments, debris, obstructions);

d) seabed geotechnical parameters relevant to umbilical stability on the seabed and any planned burial;

e) adjacent pipelines, cables and other seabed structures (existing and planned), or those to be traversed;

f) current and tidal information relevant to umbilical deployment as well as seabed stability.

13.3 Terminations and ancillary equipment information

The installer shall be provided with at least the following information on the proposed system of termination of the umbilical:

a) dimensions;

b) weight in air;

c) weight in water;

d) details of functional interfaces with subsea structure;

e) lifting arrangements designed into the termination, weak-links, junction boxes, production/repair joints and ancillary items if applicable;

f) temporary and permanent hang-off arrangements on the platform;

g) I- or J-tube messenger wire/rope (if fitted).

13.4 Host facility information

The purchaser shall provide the relevant details of the platform(s). These include, as a minimum:

a) plan/elevation/envelope of jacket and topsides;

b) I- or J-tube dimensions, geometry and locations on the platform for pad-eyes, shackles and winches;

c) I- or J-tube bellmouth sealing details and bend limiter/stiffener interface details, if applicable;

d) pipeline and riser positions;

e) other activities scheduled for the work site during the installation operations;

f) detail drawings relating to the top of I- or J-tube and surrounding area, including roofing over I- or J-tube;

g) zone and/or area classification rating.

The purchaser shall inform the installer of the permit-to-work system and the nature and location of any known obstructions.

Suitable sites on the platform shall be provided, as necessary, for the installer to mount appropriate vessel-positioning system stations, installation aids and pull-in winches. Details of services available on the host facility (if any) shall also be provided.

13.5 Subsea structure information

The purchaser shall provide details of the subsea structure and equipment, so that the subsea pull-in of the umbilical termination can be planned, if relevant.

13.6 Host facility visit

The installer should visit the fixed and/or floating offshore facilities to examine the I- or J-tube(s) and hang-off positions in order to decide where to position the pull-in winch, temporary rigging, testing and monitoring equipment. The requirements on equipment regarding safety zoning and other applicable requirements shall also be established. If ROV operations are scheduled from the offshore facility, the feasibility of these shall also be assessed.

14 Load-out

14.1 General

Responsibility for handling the umbilical at every stage shall be clearly defined, and the exact point in the operation at which responsibility is transferred from one party to another shall be agreed before operations commence.

NOTE 1 The following clauses are written with the assumption that at the load-out site all operations are coordinated and controlled by the installer.

NOTE 2 Occasionally, for example if the umbilical has been used for integration tests, load-out may not be from the umbilical manufacturer's facility.

14.2 Technical audit of load-out facilities

The installer should visit the load-out site and inspect the onshore facilities intended to be used, and assess the acceptability of the equipment and location for the operation.

The matters to be considered in the course of the visit shall include, as a minimum:

a) installation vessel;

   1) constraints on the draught of the vessel and other dimensions;

   2) mooring and manoeuvrability requirements;

   3) craneage operations between the quayside and the vessel.

b) umbilical storage facilities;

   1) storage system;

   2) access to facility;

   3) arrangement of terminations and ancillary equipment;

   4) limitations on handling from storage due to umbilical parameters (mass, minimum bend radius, crush load limitations) and terminations/ancillary equipment;

   5) protection during storage.

c) onshore umbilical handling systems;

   1) type of system;

   2) method of control and communications;

   3) manning requirements (including necessity for 24 h working);

4) rated pay-out speed;

5) interface with storage facility;

6) interface with vessel umbilical handling system;

7) requirement to provide additional equipment (e.g. portable cable engine, roller path, etc);

8) limitations on handling due to umbilical parameters (mass, minimum bend radius, crush load limitations) and terminations /ancillary equipment;

9) craneage and lifting facilities for handling terminations and ancillary equipment.

The availability of on-site manpower and support functions, together with safety requirements, shall be reviewed.

The lifting equipment certification shall be examined.

14.3 Load-out procedure

A load-out procedure shall be developed by the installer describing the proposed operation and identifying all the onshore equipment to be used. The manufacturer shall provide supporting information for the onshore load-out for inclusion within the installer's procedure. The end of the umbilical system which needs to be loaded first shall be stated, as shall the order of umbilical loading in cases of more than one umbilical being loaded. The procedure shall include details of the method and equipment to be used in handling terminations, joints, weak links, ancillary equipment, etc.

14.4 Pre-load-out meetings

Meetings shall be held between the installer and the manufacturer to establish the basis for the load-out operation and to confirm the point of hand-over of responsibility for the umbilical. Critical aspects shall be reviewed and emphasized, including, but not limited to, the following:

a) chain of command for the operation, and point of hand-over of responsibility;

b) responsibilities and staffing for the load-out;

c) interfaces between the installer and the manufacturer;

d) communications procedures;

e) review of the load-out procedure and contingency;

f) timetable for load-out, including timetable for necessary access permits;

g) handling of terminations/ancillary equipment and any intermediate joints;

h) assistance from the manufacturer for pre- and post-load-out tests;

i) provision of all necessary information to the Vessel Master for the calculation of vessel stability;

j) safety procedures and the generation of a safety plan.

14.5 Pre-load-out tests

14.5.1 General

Pre-load-out tests shall be carried out if the umbilical system has been transported from the manufacturer's works to another site, or has been stored for more than three months.

The tests shall be carried out prior to the load-out operation, but with a sufficient time interval such that rectification could be carried out if necessary.

NOTE Annex B provides information on the required test programme.

14.5.2 Electric cables

14.5.2.1 DC conductor resistance test

The temperature-corrected DC conductor resistance shall be measured as specified in 11.3 and shall be within ± 2 % of the values obtained during the umbilical FATs.

14.5.2.2 Insulation resistance test

The insulation resistance between individual conductors and between conductors and screen and/or earth shall be measured as specified in 11.3 and compared with those obtained during the FAT. Any changes shall be evaluated.

14.5.3 Optical fibre cables

An OTDR trace shall be obtained for each fibre and, if possible, from both ends as specified in 11.4.

The OTDR traces obtained shall be compared with those obtained during the FAT and any changes shall be evaluated.

14.5.4 Hoses/tubes

14.5.4.1 Hydraulic control hoses/tubes

The test fluid shall be as specified in 7.9.8.2 or 7.10.7.3.

14.5.4.2 Hose proof pressure/decay test

A proof pressure/decay test as specified in 11.5 a), but to 1,1 × DWP, shall be carried out on each hose line in the umbilical.

The test pressure and fluid temperature shall be measured at both ends of the hose, if possible.

14.5.4.3 Tube proof pressure/decay test

A proof pressure test as specified in 11.6 a), but to 1,1 × DWP, shall be carried out on each tube that is in the umbilical.

14.6 Load-out operation

Following berthing of the installation vessel, the load-out supervisor shall arrange for

a) a briefing for all personnel involved in the operation to explain the procedures to be adopted, including communications procedures and the timetable for the load-out. Particular emphasis shall be placed on the safety plan for the operation,

b) examination of calibration and functional testing records of the onshore and vessel-based equipment to be used, and confirmation that these are all current.

Upon satisfactory completion of the preliminary activities, the load-out shall be allowed to commence.

14.7 Stopping and starting the load-out

All operations shall be coordinated by the load-out supervisor and shall aim to prevent the possibility of injury to personnel, or damage to assets and/or the umbilical. If in the view of an operator involved in the operation there is a problem, or a potential problem, they shall have the authority to cause the load-out to be halted in a controlled manner. Once the operation has been stopped, authorization for recommencement of load-out shall only be given by the load-out supervisor, and shall only be given after the problem has been resolved, or the potential problem averted.

14.8 Handling of the umbilical

14.8.1 General

The handling of the umbilical during the load-out shall be carried out and monitored in a manner such that the umbilical, terminations and ancillary equipment are not subjected to any damage.

14.8.2 Twist

The umbilical shall be visually monitored at all times throughout the operation to observe the presence of twist. The presence of significant twist shall be investigated.

14.8.3 Bending

The bend radius of the umbilical during the load-out shall at all times be greater than the minimum bend radius as specified by the manufacturer's written specification.

14.8.4 Lifting the umbilical

If it is necessary to lift the umbilical, bend shoes or webbing strops shall be used. At no time shall wire ropes directly attached to the umbilical be used for this purpose. If strops are used, care shall be taken to avoid infringing the minimum bend radius requirement or inducing buckling, by using multiple strops.

The use of chinese fingers is permitted, if appropriate.

14.8.5 Transfer across spans

If the umbilical is transferred without support, the tension shall be such that the resulting catenary does not infringe the minimum bend radius. At each end of the span, the umbilical shall be supported by suitably radiused bend shoes, sheaves, chutes or bell mouths.

The catenaries shall be carefully monitored, and the load-out speeds altered accordingly, to ensure that the catenary tensions and profiles remain within the limits specified in the load-out procedure.

If the storage facility is not directly alongside the point at which the vessel is berthed, a gantry may be used for transporting the umbilical to the vessel. Alternatively, roller paths or caterpillars may be used.

14.8.6 Terminations

Terminations shall be handled using the built-in lifting devices such as eye bolts or lifting lugs. Handling of large terminations shall be given special consideration. When carrying out lifting operations on terminations, care shall be taken that there is no inadvertent removal of the surface protective coating on the item due to scratching, chafing or similar effects. The conduct of the operation shall be planned so as to ensure that the load-out handling of the termination does not introduce unacceptable levels of tension, twist or bending into the umbilical at the termination.

The subsea termination shall be fastened on-board the vessel in a position that allows access for testing of the umbilical and in the orientation required (with respect to the vertical) to ensure subsequent satisfactory pull-in and connection to the subsea structure.

14.8.7 Weak link

Prior to commencement of the load-out, the weak link(s), if fitted, shall be checked to verify that their override system (if applicable) is in place and that there is no possibility of inadvertent actuation during load-out or subsequent deployment.

14.9 Load-out monitoring

14.9.1 General

For load-out involving transfer spooling of the umbilical from the land-based storage facility onto the installation/shipping vessel storage facility, the umbilical system shall be subject to monitoring. The procedures in 14.9.2 to 14.9.6 shall be undertaken.

14.9.2 Electric cables

The DC conductor continuity shall be continuously monitored during the load-out operation. The system used shall be capable of recording brief breaks in continuity. Should there be any loss of continuity, the operation shall be halted and a DC conductor resistance test on individual cables shall be carried out in accordance with the requirements specified in 7.7.3.

14.9.3 Optical fibre cables

The attenuation of the fibres shall be continuously monitored during the load-out operation using an OTDR. Should there be any change in attenuation or any apparent discontinuity in the fibre, the operation shall be halted and an investigation shall be carried out.

14.9.4 Hoses/tubes

Each hose/tube shall be pressurized to a gauge pressure of 7,0 MPa (1 015 psi) unless otherwise specified in the manufacturer's written specification. On reaching the specified pressure to within ± 5 % and of the same value at each end of each fluid line, the pressure source shall be isolated and the pressure versus time characteristics monitored during the load-out operation.

Throughout the load-out period, the ambient temperature shall be continuously monitored. There shall be no evidence of leakage or failure prior to, during, or on completion of the load-out operation.

14.9.5 Visual examination

The umbilical shall be examined during the load-out operation for signs of distortion, kinking, surface damage, raised diameters, bird-caging of armour wires, or other defects. The examination shall be carried out over 100 % of the umbilical length.

14.9.6 Umbilical length

The installer shall ensure that the length loaded out onto the vessel is as specified, and that length markings as required for the subsequent lay operations are marked on the umbilical.

14.10 Load-out on a reel or carousel

In cases where the umbilical is not transferred from an onshore carousel/reel to a vessel carousel/reel, i.e. the storage system is the installation vessel storage system, there is no requirement for load-out monitoring. However, a full series of post-load-out tests shall be carried out. If the operation involves an earlier transfer from storage system to storage system, the monitoring of that operation shall be identical to the load-out monitoring.

14.11 Post-load-out tests

The following tests shall be carried out immediately after the load-out operation:

a) electric cables (see 14.5.2);

   1) DC conductor resistance;

   2) insulation resistance;

   3) high voltage DC test for cables in excess of 1 kV (see 11.3);

b) optical fibres (see 14.5.3);

   1) OTDR;

c) hydraulic (see 14.5.4);

   1) hose pressure/decay test;

   2) tube pressure test.

Each insulated conductor shall be tested at high-voltage DC. The DC withstand voltage shall be measured between each conductor and all other conductors and armouring for a period of not less than 5 min. At the end of this period, the leakage current shall be measured and shall not exceed the value stated in the manufacturer's written specification.

15 Installation operations

15.1 General

The information provided in this clause is of a general nature, since the installation operation, in terms of route, type of lay and protection used, can be carried out in many different ways.

15.2 Requirements for installation vessel and equipment

The installation vessel and its installation equipment shall be in good condition and working order, and be verified according to relevant regulations and safety plans prior to the vessel mobilization.

Items of lifting equipment shall have suitable certification.

Vessel equipment requirements shall include but not be limited to suitable:

a) communication facilities,

b) navigation and positioning systems (surface and subsea), including applicable recording, processing, displaying, plotting and storage,

c) lay chutes, of a size that will avoid infringement of the minimum bend radius of the umbilical,

d) conveyor systems to move the umbilical without the presence of uncontrolled spans or the possibility of the umbilical coming into contact with surfaces other than those of the handling and storage systems,

e) cable engines,

f) powered/unpowered sheaves,

g) trenching/burial equipment,

h) ROV spread,

i) diving spread,

j) tension-measuring equipment to continuously monitor and record the tension to which the umbilical is subjected. Alarms shall be included within the system,

k) length-measuring system,

l) departure angle measuring equipment to continuously monitor the angle at which the umbilical leaves the vessel. Alarms shall be included within the system,

m) umbilical functional testing equipment,

n) installation aids,

o) device to cut the umbilical, and holding clamps, in case of emergency.

It shall be ensured that the umbilical, with its associated terminations, can be handled, moved across the deck of the vessel and overboarded in a safe manner without the possibility of damage and hold-ups due to sharp edges, rough surfaces and obstructions.

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

15.3 Pre-installation survey

15.3.1 General

Before commencing the umbilical installation, the installer shall carry out a pre-installation survey along the proposed route and width of corridor, unless the purchaser has arranged for others to undertake it.

The pre-installation survey shall be carried out using positioning and navigation equipment equivalent to that which will be used during the installation operations.

The survey shall identify any seabed obstructions and debris that may be hazardous to the umbilical or may impede its installation. The installer shall propose suitable methods of seabed preparation for those areas where such preparation is considered necessary, and shall carry out that preparation.

15.3.2 Requirements of survey

Consideration shall be given during the pre-installation survey to the following activities:

a) surveillance of the planned route using a side-scan sonar or an ROV in order to confirm the data from earlier activities and to survey the right-of-way for the umbilical installation vessel;

b) confirmation of the position of any adjacent pipelines, cables, umbilicals or other structures;

c) establishing the position and identity of any pieces of debris which lie along the proposed route and in a defined corridor on either side of it. Removal of debris, if necessary and feasible, should be undertaken subsequently;

d) survey of possible route deviations which may be necessary to avoid debris or to comply with contingency plans or to use up excess umbilical length prior to termination lay-down;

e) survey of the host facility areas, including the I- or J-tubes, and the area of termination lay-down;

f) confirmation that any pre-installed messenger wires and fittings are in good condition and usable;

g) confirmation that all subsea preparations for any pipeline crossings are satisfactory;

h) deployment of temporary installation aids if necessary (e.g. at turn points on the route) and mud mattresses at subsea termination positions;

i) deployment of transponders or beacons at critical positions (e.g. pipeline crossings) on the route and at the target area for lay-down of the umbilical subsea termination;

j) bathymetric sub-bottom profiler and side-scan sonar surveys of the route;

k) longitudinal profile, seabed conditions and water depth along the route length, and subsequent correction to LAT by making allowance for the predicted tide during the survey;

l) conduct of a magnetometer survey along the route. If there are any anomalies between this survey and the results of the sonar survey, they should be further investigated.

15.3.3 Reporting

The output from the survey shall include the following:

a) a report on the proposed route, including full details of any hazards identified, seabed preparations required and debris to be cleared. This shall highlight any discrepancies between information supplied to the installer and the survey findings;

b) a set of survey video tapes, which include the camera position on the display;

c) a route map, indicating water depth, possible route deviations and the positions of any hazards or debris.

15.4 I- or J-tube pull-in operations

15.4.1 General

In the course of installing umbilicals, it is usually necessary to carry out at least one I- or J-tube pull-in operation. In the case of host facility-host facility links, two such operations are necessary.

15.4.2 Preparatory work

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

a) review of installation calculations, to establish limit loads during the pull-in operation;

b) gauging (pigging) of the I- or J-tube to check that it is clear of obstructions and fouling;

c) installing the messenger wire into the I- or J-tube (if one is not already in place);

d) establishment of pull-in equipment and personnel on the host facility. This includes installing the winch, and its associated rigging, including the load monitoring and umbilical functional testing equipment, and preparing the hang-off arrangement;

e) check of communications facilities.

15.4.3 Weather window for pull-in

The availability of a suitable weather window shall be established prior to initiating operations. The required window shall take account of the predicted duration of the pull-in and lay operations, vessel and equipment capabilities and the results of installation analyses regarding sea state versus umbilical loading.

Site-specific weather and wave forecasts, updated on a daily basis, shall be available on the lay vessel.

Due regard shall be given to the length of time for which the vessel can remain at one location without causing damage to the deployed umbilical due to localized flexing at the point of overboarding.

15.4.4 Initiation of pull-in operations

Following successful completion of the host facility preparatory activities described in 15.4.2, the pull-in operation may proceed, and the vessel may approach the host facility.

On entering the zone around the host facility, vessel operations shall become subject to all the regulatory requirements that pertain to operations on the host facility, including obtaining the necessary permits.

15.4.5 Visual survey

Following the arrival of the lay vessel in the vicinity of the host facility, a visual check of the seabed and I- or J-tube entrance shall be carried out by either ROV or diver. The purpose of this is to check both the physical condition of the I-tube or J-tube, and the seabed conditions and profile on the route into the I- or J-tube to confirm the findings of the pre-installation survey.

If the I- or J-tube is fitted with a blind flange at the bottom, it is also necessary to remove this flange. A transponder may be attached to the I- or J-tube bellmouth at this time if one is required for subsequent operations.

The identity, position and condition of the messenger wire shall be established at this stage. If the messenger wire is attached to a clump weight, the exact position of the clump weight shall be determined. This operation is particularly important if there is more than one I- or J-tube in close proximity, and hence more than one clump-weighted messenger wire. It is also essential to ensure that there is no possibility of two or more messenger wires becoming entangled in subsequent operations.

15.4.6 Recovery of the messenger wire

On the host facility, the winch pull-in wire shall be fastened to the messenger wire at the top of the I-tube or J-tube. The bottom end of the messenger wire shall then be attached to the wire of the winch positioned on the deck of the lay vessel. The deck winch shall then be used to recover the messenger wire onto the deck of the vessel as the host-facility winch pays out.

NOTE 1 It may be necessary to use significant tension when the messenger wire is attached to a diaphragm in the I- or J-tube bellmouth.

NOTE 2 Once the end of the messenger wire is on the vessel deck, the clump weight (if present) is removed and the recovery procedure continued until the end of the pull-in wire is on the deck. The end of the umbilical can then be attached to the wire.

15.4.7 Umbilical pull-in

The pull-in head shall be overboarded from the vessel and the umbilical paid out from the vessel. The vessel position shall be adjusted to produce the required catenary so that the umbilical enters the I- or J-tube at the correct angle and that the umbilical is not dragged excessively along the seabed or subjected to overbending.

Monitoring of the pull-in operation shall be undertaken using

a) the tension monitoring equipment on the host facility,

b) the tension monitoring equipment on the vessel,

c) the ROV visually monitoring the umbilical in the vicinity of the I-or J-tube entry, to establish the catenary shape, extent of seabed contact (if any), umbilical bend radius and umbilical twist,

d) the amount of umbilical paid out.

Pull-in tension shall be carefully monitored and compared with the previously calculated values. Any increase in tension above that previously agreed shall result in suspension of the operation and investigation of the cause of the increase.

At the point at which the pull-in head is about to enter the J-tube bellmouth, particular emphasis shall be placed on the information provided by the ROV video camera, in order to remove any possibility of the pull-in head snagging at this time. Similar care shall also be taken as the I- or J-tube seal and bend stiffener (if they are pre-installed on the umbilical) approach the I- or J-tube entrance and their required position in the I- or J-tube. Small vessel movements may be required at this point to ensure that entry is unimpeded.

15.4.8 Securing the umbilical on the host facility

On arrival at the relevant deck level, the umbilical shall be securely fastened.

NOTE The permanent hang-off arrangement, either a mechanical termination of the armour wires or resin encapsulation of the wires, can be fitted as soon as the pull-in is completed, if the termination has not been attached to the umbilical prior to the pull-in. Alternatively, if the permanent method would take a long period of time, the fastening can be made temporarily (using split clamps, chinese fingers, etc.) so that the testing and lay can proceed without delay. The permanent hang-off can be constructed later.

15.4.9 I- or J-tube sealing and chemical protection

All chemicals used, and their ultimate combination within the tube, shall be confirmed at an early stage as compatible with the umbilical materials with which they come into contact.

If the umbilical hang-off does not seal the top of the I- or J-tube it may be necessary to fit a suitable top seal. The top seal and hang-off arrangements shall have provision for the introduction of chemical treatments, if required.

The bottom of the I- or J-tube may be sealed, although this is installation-specific. The seal may already be in place at the end of the pull-in operation if pre-installed onto the umbilical prior to the pull-in. In some cases the seal is operational at the end of the pull-in without any further intervention. On other occasions it may be necessary for some form of intervention by diver or ROV to make the seal operative. In situations where there is no pre-installed seal, it is necessary to fit it after the pull-in and hang-off have been completed.

Chemical inhibitors, biocides and oxygen scavengers may be introduced into the I- or J-tube to provide protection to the I- or J-tube material.

15.4.10 Second end pull-in

This operation is required in the case of host facility-host facility umbilicals, and also in the case where the lay of a host facility-subsea umbilical commences at the subsea end. The I- or J-tube pull-in at the second end, although similar in many ways, can be more complicated than a pull-in operation at the start of the lay due to the presence of the umbilical which has already been laid and the catenary to the vessel.

The procedures used shall include close tension control and visual monitoring of the catenary, the seabed umbilical subject to displacement and the entrance to the I- or J-tube.

15.4.11 Movement of vessel away from the host facility

In the case of a first end pull-in, the lay vessel shall proceed to lay the umbilical along the planned route in order to clear the immediate vicinity of the host facility as soon as the pull-in is complete. Simultaneous lay and bury operations will necessitate launching of the burial vehicle prior to the lay-away, unless this has been done prior to the pull-in. Whilst this is under way, host-facility connection of umbilical test and monitoring equipment shall be carried out, if the monitoring is being undertaken from the host facility. Commencement of the main lay of the umbilical along the route beyond the immediate vicinity of the host facility shall not proceed without confirmation that the umbilical testing has been satisfactorily completed, the monitoring equipment is connected and operational, and pressurization (if applicable) has been achieved unless otherwise specified in the procedures.

For a second end pull-in, the vessel shall move away at the completion of the pull-in.

15.5 Lay-down of subsea termination (first end)

If the initial part of the operation is installation of a subsea termination, this is carried out in place of the I- or J-tube pull-in operations described in the previous clauses.

Any necessary work required to prepare the seabed shall have been carried out. The termination shall be over-boarded and lowered to its designated position on the seabed. The termination shall be fitted with a transponder and light-sticks to aid position monitoring. Prior to overboarding, any pressure balance arrangement shall be confirmed as suitable for installation and service. Depending on the design of the system, the designated position may be the final position, or a subsequent pull-in to a manifold may be required. As the termination is lowered, the umbilical position and tension shall be carefully monitored and controlled to avoid the generation of slack within the umbilical length. Once the termination is on the seabed and suitably secured, the umbilical routing away from the termination shall be as designed.

As an alternative for a first end subsea termination, the lay-away method may be used. In this case the lay vessel shall pass the first end umbilical termination underneath the drilling rig and into the moonpool. In the moonpool there is a guidebase or christmas tree to which the umbilical will be connected. After relevant testing (see 15.19), the guidebase or christmas tree with umbilical connected is lowered to the wellhead and secured. After conclusion of this operation, the lay vessel shall commence the main lay-down of the umbilical along the route. At the vessel selection stage, it shall already have been verified that the vessel can maintain position during the above-mentioned activities under the design environmental conditions allowed for that operation.

Considerable care shall be taken if the termination is of a design which can give rise to the presence of significant hydrodynamic forces, due to currents, vessel heave or the wake from thrusters. These forces can induce large rates of twist into the umbilical by virtue of termination rotation.

15.6 Lay route

The umbilical lay route shall be shown on umbilical route alignment charts. These charts shall show the way-points, the coordinates of changes in direction of the route and the corridor within which the umbilical shall be laid. The charts shall also detail the extent and location of any additional protection required (e.g. tubular protectors or mattressing), the presence of other umbilicals and risers, pipelines and pipeline crossings and dimensioned target areas for lay-down of the umbilical subsea terminations.

15.7 Handling requirements for the main lay

The major mechanical requirements during the main lay shall be to avoid

a) introduction of excessive slack in the vicinity of the touch-down position, by virtue of low tension/large departure angle, to preclude the possibility of loop formation,

b) infringing the minimum bend radius at the touch-down point,

c) introduction of large rates of twist into the umbilical, to reduce the probability of loop formation and bird-caging,

d) application of excess tension, which may overstress the umbilical,

e) flexing the umbilical, close to the overboarding point, where catenary loads are at their maximum, and at the touch-down point for extended periods to exclude the likelihood of fatigue failures of the umbilical structure.

15.8 Vessel positioning to achieve required touch-down

The umbilical touch-down point shall be continually visually monitored by the ROV to verify that the umbilical is being laid within the required corridor as defined on the route alignment charts. This shall be achieved by means of reference to the ROV's on-board acoustic transponder. The ROV high-resolution sonar (if fitted) can also be used to confirm by reference to other seabed features that the umbilical remains within the defined corridor. If the ROV suffers technical problems of a nature which means that it cannot carry out the monitoring function, then the lay shall be stopped.

It is particularly important to control length when the vessel is altering course. In the situation where the route is curved, the vessel is moved from one alter-course point to the next by entering the coordinates of each location using the umbilical lay reference, allowing for umbilical touch-down layback. The ROV shall monitor the touch-down position to ensure the umbilical continues to be laid in the correct corridor.

If a crab lay is undertaken, the offset between the vessel and the touch-down point, as indicated by the ROV transponder, should be used to make an estimate of the effects of currents and tides so that the route can be altered to take account of this.

NOTE 1 Subsea beacons laid during the pre-installation survey can assist with positioning at critical points along the route.

NOTE 2 If the vessel is headed in the direction of lay with the umbilical being laid over a stern chute, any deviation of the umbilical lead from directly astern of the vessel route due to the presence of cross-currents or tides can easily be estimated. If it is considered necessary, a small vessel offset can be applied at any subsequent turn point to take account of any tidal current.

NOTE 3 In very deep water, the touch-down point may have to be monitored with side-scan sonar or ROV deployed from a separate survey vessel.

15.9 Control and monitoring of length laid

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

— detect whether excessive umbilical length is being laid,

— allow the lay of a fixed umbilical length over the planned route whilst ensuring correct positioning of the subsea terminations in the pre-determined lay-down target area.

A computation of the umbilical length paid out shall be made continuously.

As each umbilical marking passes a specified datum mark on the vessel, a navigation fix shall be taken and the following information recorded and/or calculated:

a) time and date;

b) reference number of the navigation fix;

c) coordinates of overboarding point;

d) coordinates of touch-down point;

e) distance along route as laid [kilometre point (KP)];

f) marked umbilical length at datum;

g) equipment reading of umbilical length measurement;

h) overlength since last calculation;

i) cumulative overlength;

j) distance to end of lay;

k) umbilical remaining inboard of datum mark;

l) catenary tension at overboarding point;

m) mean umbilical pay-out rate.

NOTE 1 Some of this information can be pre-calculated to facilitate simple rapid checks that the lay is proceeding as planned.

NOTE 2 Details regarding length control at completion of lay are given in 15.12.

15.10 Integrity monitoring during lay

15.10.1 General

Integrity monitoring may be undertaken from the host facility if the first operation is an I- or J-tube pull-in. In situations where the first operation is a lay of a subsea termination, integrity monitoring shall be carried out from the installation vessel.

15.10.2 Electric cables

The conductor continuity shall be continuously monitored during the lay operation. If there is any loss of continuity, the operation shall be halted and a DC conductor resistance test on the individual cables shall be carried out in accordance with 7.7.3.

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

15.10.3 Optical fibre cables

Each optical fibre shall be continuously monitored using an OTDR. If there is a significant change in attenuation, or a loss in continuity, the operation shall be halted and the cause of the fibre problem investigated.

15.10.4 Hoses/tubes

Each hose/tube shall be pressurized to a gauge pressure of 7,0 MPa (1 015 psi) unless otherwise specified in the manufacturer's written specification, and this pressure shall be locked in for the duration of the umbilical lay. The pressure in each hose/tube shall be continually recorded. If there is any unexplainable loss of pressure, or if the behaviour of one hose/tube string relative to the rest is markedly different, the operation shall be halted, and the cause of the pressure loss investigated.

In some circumstances it might not be possible to provide the pressurization; this should be agreed between purchaser and manufacturer.

15.10.5 Visual inspection

The umbilical shall be examined visually during deployment for signs of distortion, kinking, surface damage, bird-caging of armour wires, or other defects defined in the installer's written specification. The examination shall be over 100 % of the umbilical length.

15.11 Burial operations

15.11.1 General

Ploughing or trenching, if required, shall be performed as a single-pass operation. If the required burial depth is not achieved then the required protection shall be provided by other means. Application of the additional protection shall be carried out so as not to put the umbilical at any risk.

Deployment/recovery of ploughs and trenchers shall not take place within a radius of 50 m (152 ft) of any subsea facility.

15.11.2 Monitoring during the burial operation

The burial operation shall be continuously monitored both by the on-vehicle instrumentation and from the surface, using both ROV and surface survey, navigational, and sonar systems.

As a minimum, the following parameters shall be monitored:

a) the tow force (for a plough);

b) loads induced on the umbilical;

c) configuration of the umbilical in front of, and through, the vehicle;

d) burial depths;

e) vehicle and vessel positions;

f) area ahead of the vehicle, for obstructions.

If at any time the instrumentation or visual inspections indicate that damage to the umbilical might have occurred, the installer shall interrupt the trenching or ploughing operation and perform a diver and/or ROV video survey of the damaged area.

15.11.3 Interaction with umbilical

The minimum bend radius of the umbilical during the burial operation shall not be less than that specified in the manufacturer's written specification.

15.12 Approach to subsea termination position (second end)

As the subsea termination lay-down position is approached, arrival at the correct point shall be ensured by carefully monitoring the lay distance remaining and gaining or losing route length over umbilical length as required. A transponder shall be deployed on the termination during lay-down to give accurate positioning at seabed touch-down.

Any contingency plans for route deviations shall have been agreed prior to mobilization, as part of the initial development of procedures.

Having continually compared the umbilical length deployed with the position on the route, the length of umbilical remaining to be deployed in comparison with the planned route distance still to go shall be assessed approximately 1,0 km to 2,0 km (0,62 miles to 1,24 miles) from the lay-down target area. If necessary a revised route to accommodate the umbilical length remaining shall then be produced. This procedure shall be repeated and the route revised at appropriate distances [typically 100 m to 200 m (328 ft to 656 ft) initially, reducing to 25 m (82 ft) when within 200 m (656 ft) of the lay-down position]. By adoption of this technique, any residual umbilical length can be used up gradually, thereby avoiding the need to deal with large amounts of excess umbilical length in the area where the termination is to be put down. If the umbilical is to be buried, it is desirable to bury as much as possible so as to minimize the length requiring alternative protection.

Alternatively, in the case of congested areas, the approach adopted might be to limit putting excessive length on the seabed. In this case the umbilical is laid towards the final way-point at a short, measured distance from the final target. It can then be determined what the actual overlength of the umbilical is. Subsequently, in the field, the overlength can be reduced, the umbilical terminated and testing carried out.

15.13 Lay-down of subsea termination

The dimensions and location of the target area for the termination lay-down shall be marked on the route alignment chart and physically on the seabed with a transponder. In soft soil conditions, a mattress should be laid as part of the pre-installation work.

The final lay-down of the umbilical shall be carried out so that the umbilical lies on the seabed with the extra length arranged in an "S", a "C" or other configuration so that the pull-in does not cause the umbilical to infringe its minimum bend radius.

NOTE A pre-deployment test of the umbilical and subsea termination may be carried out, although if the previous testing and monitoring activities are satisfactory, the slightly increased risk to the umbilical may make this activity unnecessary.

Preparations shall now be made to overboard the termination. Light sticks and a transponder shall be attached to the end of the winch wire or crane hook and/or the termination to facilitate a properly controlled deployment of the end termination onto its target area.

The termination shall be lowered into the water, with the vessel manoeuvring as required to maintain the desired umbilical lay-down route. As the termination approaches the sea bed, the installer shall confirm that the correct lay-down location and orientation shall be achieved without compromising the integrity of the umbilical. If necessary, the termination shall be raised from the sea bed and repositioned.

15.14 Pull-in of subsea termination

In the case of a multi-coupler arrangement, the act of pulling the termination into its final position shall cause the functional connections to be made. Alternatively, the functional connections shall be made by jumper hoses and/or cables; this is effected after pull-in.

The angular orientation of the termination with respect to the subsea structure is particularly critical in the case of a multi-coupler arrangement.

A detailed procedure shall be prepared for the final stages of pull-in depending on the particular design. Factors to be considered include

a) details of mechanical fastening,

b) installation of cathodic protection straps.

Once the termination is in the specified final position, the necessary mechanical fastenings shall be installed. In the case of a multi-coupler arrangement, this completes the connections and hence the pull-in. If jumpers are to be used, these shall be installed paying due attention to any temporary jumper connections that may be required as part of the flushing or test procedures.

15.15 Pipeline crossings

The design of any pipeline crossing shall include positive separation between pipe and umbilical.

As the lay vessel approaches the crossing area, the location of the crossing shall be checked. Visual observation of the area by ROV (and use of sonar) shall also be undertaken, and the touch-down point carefully monitored over the crossing. A transponder shall be installed at the crossing to ensure that an accurate location fix can be made, thereby achieving the correct placing of the umbilical at the crossing point.

For burial operations, it shall be necessary to transfer the plowshare/cutter back to the surface of the seabed short of the crossing point and to return the vehicle back to the vessel deck and secure it there for the crossing. No attempt shall be made to fly the plough/trencher over the pipeline; it shall be fastened on deck during the crossing. Ploughing/trenching shall then be restarted on the other side of the crossing.

Further protection shall be added to ensure that the umbilical is not exposed to damage at the crossing.

15.16 Arming of weak link

The arming of the weak links, if fitted, shall be carried out on completion of

a) burial of the umbilical by plough or trencher (if required),

b) second end pull-in and hook-up of termination,

c) attachment of any weak-link restraints to the structure.

However, the above shall be done before the installation test, which in this context may be a post-pull-in test or a final system functional test.

15.17 Post-lay survey

In the case of a simultaneous lay-and-bury operation, the post-lay and post-burial surveys shall be combined.

The post-lay survey shall be carried out (usually by the installer) in order to confirm the as-laid position of the umbilical, and to confirm the absence of damage to the umbilical.

The survey shall be carried out either as a separate operation using visual observation from an ROV if a lay and post-burial operation is undertaken, or from the plough/trencher if a simultaneous lay-and-bury operation is performed.

The video recording shall include a display overlay showing the camera-position coordinates and heading.

15.18 Post-burial survey

A survey of the entire route of the umbilical immediately following burial shall be undertaken. (This is normally carried out by the installer.) The survey shall show that the burial operation has been carried out in accordance with the specified requirements.

The survey shall be carried out by ROV and should include the following:

— a video survey of the entire length of the umbilical route;

— identification of the positions of any unburied or unsupported lengths of the umbilical.

If shown to be necessary, the installer shall carry out suitable remedial work. In these circumstances, the relevant areas shall be surveyed again by video.

The documentation shall include the following items:

a) a written report of the survey findings;

b) a full set of video tapes of the survey;

c) charts showing the as-buried position and depth of burial of the umbilical.

15.19 Post-pull-in test

These tests shall be performed, if practicable, once the subsea termination has been pulled into its final position.

In the case of a multi-coupler arrangement, the act of pulling the termination into its final position shall cause the functional connections to be made. In this event, the post-pull-in test becomes the post-hook-up test.

These tests include:

a) electrical (see 14.5.2);

   1) DC conductor resistance;

   2) insulation resistance;

b) optical fibres (see 14.5.3);

   1) OTDR;

c) hydraulic (see 14.5.4);

   1) hose proof-pressure/decay test;

   2) tube pressure test.

For testing of subsea-to-subsea installations, a suitable temporary termination shall be manufactured to allow looping of all electrical and hydraulic services for testing purposes. If such a unit is supplied it should be diver- or ROV-operable.

15.20 Post-hook-up test

These tests shall be performed, if practicable, once the subsea functional connections have been made. Care shall be taken that these tests cause no damage to the control system.

These tests include:

a) electrical (see 14.5.2);

   1) DC conductor resistance;

   2) insulation resistance.

b) optical fibres (see 14.5.3);

   1) OTDR

c) hydraulic (see 14.5.4);

The test pressure for the post-hook-up hydraulic tests shall be $1{,}0 \times$ DWP for control lines, and $1{,}1 \times$ DWP for chemical lines.

   1) hose proof pressure/decay test;

   2) tube pressure test.

15.21 Retrieval of installation aids

The installer shall be responsible for retrieving all temporary subsea and host-facility installation aids after successful completion of installation of the umbilical.

15.22 Contingencies

The installer shall carry out a risk assessment study to cover foreseeable occurrences, including common mode failures, and produce suitable procedures.

The decision to implement all actions in connection with contingency procedures shall be the responsibility of the authority designated within the procedures.

15.23 Repairs

Each repair shall be installation-specific. Repair procedures shall be prepared and qualified, prior to the commencement of the installation, for the repair of the umbilical.

At the time at which damage is suspected, the installation operation shall be suspended to permit investigation and assessment of the problem. If required, testing shall be undertaken to assess the nature and extent of the problem, and the exact location of any fault.

Parameters such as vessel and touch-down positions, date, time and environmental conditions when the lay operation is suspended, shall be noted for reference in any subsequent investigation.

15.24 Post-installation survey

The installer shall carry out a survey along the entire subsea route of the umbilical, including the I- or J-tube bellmouth(s) and subsea termination. The survey shall be carried out using a side-scan sonar and/or a video camera mounted on an ROV, and equipped with a remote monitor so that the survey can be viewed as it takes place.

The survey shall verify that the umbilical and associated accessories (e.g. seals, weak link, bend restrictor, protection) have been installed in accordance with the specification requirements, and that all temporary installation aids have been removed.

The post-installation survey shall also include all umbilical terminations and anchor points, which shall be inspected for leakage and damage.

The recording shall include a display/overlay showing the equipment position coordinates and heading, so that the as-laid position of all items is recorded.

If the survey shows that the installation requirements specification has not been met, the installer shall undertake appropriate remedial work.

NOTE The various surveys (post-lay/post-burial) may be combined into a single post-installation survey, provided that the integrity of the system is not compromised.

Annex A
(informative)

Information to be provided in a purchaser's functional specification

A.1 General

This annex provides guidelines for information to be provided in a purchaser's functional specification for an umbilical system, which references this part of ISO 13628 as the detailed standard for the design, manufacture, test and installation of the umbilical to be incorporated in the umbilical system. These guidelines, set out below, are not intended to be mandatory, but are intended as a convenient reference such that the umbilical manufacturer is provided with sufficient information to ensure the umbilical is correctly designed for its intended function.

Functional requirements not specifically required by the purchaser which may affect the design, materials, manufacturing, testing, installation deployment and operation of the umbilical/umbilical system should be specified by the manufacturer in the manufacturer's written specification.

The purchaser should specify project-specific design requirements and considerations within a purchaser's functional specification, which may be based on the following clauses.

A.2 Information to be provided

A.2.1 Scope of development

The manufacturer should be aware of the scope of the development for which the umbilical system is intended and where it is incorporated as part of the development. This should be provided by means of narrative description and schematic arrangement drawings.

Additionally, the manufacturer should also be aware of the proposed installation sequence and method by which the umbilical system will be installed.

A.2.2 Scope of supply

The scope of supply in respect of the umbilical system should be clearly defined, including but not limited to the following:

a) number and lengths, including spare lengths, of each umbilical design;

b) type of terminations/ancillary equipment required, including repair joint kits, buoyancy attachments.

A.2.3 Applicable codes, standards and regulations

Applicable codes, standards and regulations that apply to the design, manufacture and test of the umbilical/umbilical system or could have an influence, should be clearly defined. This should cover national, international and purchaser specifications. Additionally, any purchaser requirement amendments to this part of ISO 13628 should be clearly stated.

A.2.4 Operating environment

The relevant operating environment applicable to the design, installation and operation of the umbilical and the umbilical system should be clearly defined. This should address the following, including but not limited to:

a) **fishing:** intensity and methods used at location;

b) **location:** geographical data for the installation location;

c) **water depth:** design water depth, variations over umbilical location and tidal variations;

d) **seawater data:** minimum and maximum temperatures;

e) **temperature:** minimum and maximum air temperature during storage, installation and operation; storage/operation including localized areas where extreme temperatures are to be experienced, e.g. floating production system turret with the umbilical adjacent to high-temperature flowlines; environmental temperature (impact of adjacent flowlines carrying flowing fluids);

f) **survival conditions**;

g) **sea-bed conditions:** description, density, shear strengths, friction coefficients, seabed scour, sand waves and variations along umbilical route;

h) **marine growth:** maximum values and variations along length;

i) **ice:** maximum ice accumulation, or drifting icebergs and ice floes;

j) **current data:** as a function of water depth, direction and return period, and including the known effects of local current phenomena;

k) **wind data:** direction, speeds, frequencies;

l) **wave data:** significant and maximum waves, associated periods, wave spectra as a function of direction and return period;

m) **vessel information** and response amplitude operators; turret motion.

NOTE Further environmental data will be required to carry out installation and service analysis.

A.2.5 Specific purchaser requirements

A.2.5.1 General

The following requirements specific to the purchaser's field development requirements should be clearly defined.

A.2.5.2 Service life

The required service life, and not the required manufacturer's mechanical warranty (guarantee) or design life, should be stated.

A.2.5.3 Target reliability data

The required target for the system reliability should be stated.

A.2.5.4 Umbilical length

The required umbilical length for each umbilical system, including manufacturing tolerance, should be stated.

NOTE Installation considerations normally dictate the negative length tolerance as zero and the positive length tolerance as + 1 %.

A.2.5.5 Functional requirements

The number, type, size and duty rating of each component design should be stated.

A.2.5.6 Umbilical characteristics

If umbilical characteristics are important to overall system performance, these should be clearly defined.

For static umbilicals, this is normally limited to maximum working load, maximum mass, minimum bend radius if these are likely to impact on the shipment and/or installation equipment.

For dynamic umbilicals, this should address, in addition, the following:

a) submerged weight/diameter ratio per metre of length ($N \cdot mm^{-1} \cdot m^{-1}$) taking into account filling of the interstices with seawater.

b) buoyancy attachment (number off, location, upthrust);

c) loads and minimum bend radii at key interfaces (generally resulting from mathematical modelling of the installed configuration in connection with sea currents and vessel motions).

A.2.5.7 Component characteristics

If component characteristics are important to overall system performance, these shall be clearly defined.

NOTE For electric cable, this is normally limited to attenuation, characteristic impedance, capacitance, inductance and cross-talk where the umbilical incorporates separate power and signal cores. For optical fibres this is limited to attenuation. For hoses, this is normally limited to volumetric expansion and resistance to external hydrostatic pressure as defined by measured collapse pressure. For tubes, it is limited to material selection.

A.2.5.8 Service fluids

The purchaser should specify the control fluid, injected fluids for continual and occasional chemical treatments (dosages, exposure times, concentrations and frequency) and possible produced fluids (composition of individual phases). In the specification of the internal fluid composition, the following fluids, as a minimum, should be defined:

a) liquids, including water, oil composition and alcohols;

b) injected chemical products including alcohols, and inhibitors for corrosion, hydrate, paraffin, scale and wax;

c) corrosive agents, including bacteria, chlorides, organic acids and sulfur-bearing compounds;

d) aromatic components;

e) gases, including oxygen, hydrogen, methane and nitrogen;

f) all parameters which define service conditions, including partial pressure of hydrogen sulfide and carbon dioxide, acidity (pH) of aqueous phase, TAN (in accordance with ASTM D 664 or ASTM D 974) and water content (produced water, seawater and free water).

A.2.6 One-off functional requirements

Functional requirements which have to be met only once, but which are necessary for the installation or operation of the umbilical/umbilical system, should be stated.

A.2.7 Interfaces

Interface areas between the umbilical and mating arrangements should be clearly defined. The connector requirements for both end terminations in the umbilical should be specified. This should include connector type, welding specification, seal type and sizes.

Interface details including, but not limited to, the following should be specified:

a) purchaser-supplied pull-in and connection tools, terminations and mating test connectors, etc.;

b) geometric, dimensional and imposed loading data;

c) purchaser-supplied installation aids and equipment;

d) structures to which the umbilical will be connected, including fixed and floating host facilities, subsea christmas trees and manifolds.

A.2.8 Installation requirements

The purchaser should specify performance requirements for installation services to be provided, considering the following as a minimum:

a) for installation by the purchaser, the purchaser should specify any requirements on load restrictions, clamping/tensioner loads, overboarding chute requirements, installation tolerances and any other facility limitations;

b) for installation by the manufacturer, the purchaser should specify any requirements for season, environment, vessel limitations, installation tolerances, restrictions due to conflicting activities, and installation scope (including trenching, burial, testing, inspection, surveying and documentation).

The purchaser should specify any requirements for recoverability and reusability of the umbilical within its service life.

Annex B
(informative)

Umbilical testing

B.1 Schedule of tests to be performed as part of the manufacturer's quality assurance programme

Tables B.1 to B.5 give reference to the subclause in this part of ISO 13628 containing the relevant information.

Table B.1 — Electric cables/electric cable elements

Test to be performed	Verification	Component acceptance	Delivery acceptance [a]	Umbilical acceptance
Visual and dimensional characteristics	7.6.1	7.7.1	—	—
Conductor resistance	7.6.2	7.7.3	7.7.12 a)	11.3 a)
Resistivity of screening layers	7.6.3	—	—	—
Insulation resistance	7.6.4	7.7.4	7.7.12 b)	11.3 b)
High voltage DC	7.6.5	7.7.5	7.7.12	11.3 c)
High voltage AC	7.6.6	—	—	—
Complete voltage breakdown	7.6.7	—	—	—
Partial discharge	7.6.8	—	—	—
Inductance characteristics	7.6.10	7.7.6	—	11.3 d)
Capacitance characteristics	7.6.11	7.7.7	—	11.3 d)
Attenuation characteristics	7.6.12	7.7.8	—	11.3 d)
Characteristic impedance	7.6.13	7.7.9	—	11.3 d)
Cross-talk	—	7.7.10	—	11.3 e)
Spark test	—	7.7.2	—	—
Time-domain reflectometry	—	7.7.11	—	11.3 f)

[a] These tests are to be undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

Table B.2 — Optical fibre cables

Test to be performed	Verification	Component acceptance	Umbilical acceptance
Visual and dimensional characteristics	—	7.8.8.1	—
Transmission characteristics	7.8.7.1	—	—
Mechanical characteristics	7.8.7.2	—	—
Environmental resistance	7.8.7.3	—	—
External pressure	7.8.7.4	—	—
Optical time-domain reflectometry	—	7.8.8.2	11.4

Table B.3 — Hoses

Test to be performed	Verification	Component acceptance	Delivery acceptance [a]	Umbilical acceptance
Visual and dimensional characteristics	7.9.7.3	7.9.8.1	—	—
Change in length	7.9.7.4	7.9.8.4	—	—
Leakage	7.9.7.5	—	—	—
Burst test – liner	—	7.9.8.3	—	—
Burst test – hose	7.9.7.6	7.9.8.5	—	—
Proof pressure/decay	—	7.9.8.6	7.9.8.7	11.5 a)
Impulse	7.9.7.7	—	—	—
Cold bend	7.9.7.8	—	—	—
Collapse	7.9.7.9	—	—	—
Volumetric expansion	7.9.7.10	—	—	—
End fitting anti-rotation	7.9.7.11	—	—	—
Fluid compatibility	7.9.7.12	—	—	—
Permeability	7.9.7.13	—	—	—
Flow test	—	—	—	11.5 b)
Dynamic response [b]	—	—	—	11.5 c)
Fluid cleanliness	—	—	—	11.5 d)

[a] These tests are to be undertaken if the components involve transportation from the component manufacturer's facility to the umbilical manufacturer's facility.

[b] Optional tests to be undertaken if specifically requested by the purchaser.

Table B.4 — Tubes

Test to be performed	Verification	Component acceptance	Umbilical acceptance
Visual and dimensional characteristics	7.10.6.2	7.10.7.1	—
Tensile test	7.10.6.3	—	—
Flattening	7.10.6.4	—	—
Hardness test	7.10.6.5	—	—
Flaring	7.10.6.6	—	—
Chemical analysis	7.10.6.7	—	—
Corrosion	7.10.6.8	—	—
Burst test	7.10.6.11	—	—
Proof pressure	—	—	11.6 a)
NDE	7.10.6.9	7.10.7.2	—
Flow test	—	—	11.6 b)
Fluid cleanliness	—	—	11.6 c)

Table B.5 — Umbilicals

Test to be performed	Verification	Component acceptance	Umbilical acceptance
Visual and dimensional characteristics	—	11.2	11.2
Tensile	10.2.2	—	—
Bend stiffness[a]	10.2.3	—	—
Crush	10.2.4	—	—
Fatigue	10.2.5	—	—

[a] Optional tests to be undertaken if specifically requested by the purchaser.

B.2 Schedule of tests to be performed as part of the installer's load-out and installation programme

Tables B.6 to B.9 give reference to the subclause in this part of ISO 13628 containing the relevant information.

Table B.6 — Electric cables

Test to be performed	Pre-load-out [a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Conductor resistance	14.5.2.1	14.11 a) 1)	—	15.19 a) 1)	15.20 a) 1)
Insulation resistance	14.5.2.2	14.11 a) 2)	—	15.19 a) 2)	15.20 a) 2)
High voltage DC	—	14.11 a) 3) [b]	—	—	—
Continuity	—	—	15.10.2	—	—

[a] These tests are only required for umbilicals stored for periods in excess of three months.

[b] Required for cables with ratings in excess of 1 kV.

Table B.7 — Optical fibres

Test to be performed	Pre-load-out [a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Optical time domain reflectometry	14.5.3	14.11 b) 1)	15.10.3	15.19 b) 1)	15.20 b) 1)

[a] These tests are only required for umbilicals stored for periods in excess of three months.

Table B.8 — Hoses

Test to be performed	Pre-load-out [a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Proof pressure/decay	14.5.4.2	14.11 c) 1)	—	15.19 c) 1)	15.20 c) 1)
Pressure integrity	—	—	15.10.4	—	—

[a] These tests are only required for umbilicals stored for periods in excess of three months.

Table B.9 — Tubes

Test to be performed	Pre-load-out [a]	Post-load-out	Installation monitoring	Post-pull-in	Post-hook-up
Proof pressure/decay	14.5.4.3	14.11 c) 2)	—	15.19 c) 2)	15.20 c) 2)
Pressure integrity	—	—	15.10.4	—	—

[a] These tests are only required for umbilicals stored for periods in excess of three months.

Annex C
(informative)

Hose and tube preferred sizes

Table C.1 — Preferred hose size/pressure ratings

Nominal bore		DWP		Minimum burst pressure	
mm	(in)	MPa	(psi)	MPa	(psi)
6,3	(1/4)	20,7	(3 000)	82,8	(12 000)
9,5	(3/8)	20,7	(3 000)	82,8	(12 000)
12,7	(1/2)	20,7	(3 000)	82,8	(12 000)
15,9	(5/8)	20,7	(3 000)	82,8	(12 000)
19,0	(3/4)	20,7	(3 000)	82,8	(12 000)
25,4	(1)	20,7	(3 000)	82,8	(12 000)
31,8	(1 1/4)	20,7	(3 000)	82,8	(12 000)
38,1	(1 1/2)	34,5	(5 000)	138,0	(20 000)
6,3	(1/4)	34,5	(5 000)	138,0	(20 000)
9,5	(3/8)	34,5	(5 000)	138,0	(20 000)
12,7	(1/2)	34,5	(5 000)	138,0	(20 000)
15,9	(5/8)	34,5	(5 000)	138,0	(20 000)
19,0	(3/4)	34,5	(5 000)	138,0	(20 000)
25,4	(1)	34,5	(5 000)	138,0	(20 000)
6,3	(1/4)	51,7	(7 500)	206,9	(30 000)
9,5	(3/8)	51,7	(7 500)	206,9	(30 000)
12,7	(1/2)	51,7	(7 500)	206,9	(30 000)
6,3	(1/4)	69,0	(10 000)	275,9	(40 000)
9,5	(3/8)	69,0	(10 000)	275,9	(40 000)
12,7	(1/2)	69,0	(10 000)	275,9	(40 000)

Table C.2 — Preferred tube size

Nominal bore	
mm	(in)
6,3	(1/4)
9,5	(3/8)
12,7	(1/2)
15,9	(5/8)
19,0	(3/4)
25,4	(1)
31,8	(1 1/4)
38,1	(1 1/2)
50,8	(2)
63,5	(2 1/2)
76,2	(3)
88,9	(3 1/2)
101,6	(4)

Annex D
(normative)

Characterization tests for hoses and umbilicals

D.1 Hose

D.1.1 Volumetric expansion test

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

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

Test samples shall not be less than 3 m (9,8 ft) in length between end fittings and shall not be tested within 24 h of completion of manufacture of the hose. Prior to undertaking volumetric expansion measurements, precondition the hose by pressurizing the hose sample with water or other compatible incompressible fluid to the DWP. Maintain the DWP for a period of 5 d, during which the pressure shall be lowered to atmospheric pressure and returned to the DWP once per day. After completing the 5 d pressure cycle, test the sample for volumetric expansion three times within 48 h using the following procedure, and select the pressure ranges starting at the highest pressure.

Define the pressure range for the volumetric expansion measurement, from the DWP down to nominally 10 % of the DWP. The pressure steps shall be in 7,0 MPa (1 015 psi) decrements down to the nominally 10 % DWP level. Connect the test assembly between the test manifolds, taking care not to introduce twist into the hose. Fill the system and test sample with water or other incompressible and compatible fluid and purge to eliminate any entrapped air.

One hour (± 5 min) before measuring the volumetric expansion, pressurize the test sample to the DWP (± 5 %) at a uniform rate of pressure rise, and ensure the fluid level is set correctly in the burette.

On reaching the DWP, open control valve, see Figure D.1, and allow the hose to depressurize into the burette in a controlled manner, until the first pressure level is reached. Close the control valve and record the displaced volume in the burette.

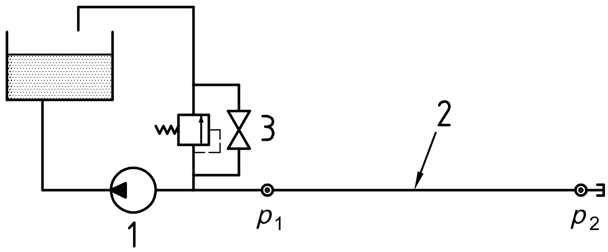
Repeat the procedure for the remaining predetermined pressure levels, allowing a period of 45 s (± 5 s) to elapse between each stage of depressurization. If necessary, withdraw fluid to maintain the pressure at the selected level. The volumetric expansion measurements shall be recorded within 5 s of reaching the defined incremental measurement level.

The measured results taken from the burette readings may be expressed as either true volumetric expansion (TVE) or apparent volumetric expansion (AVE), in terms of cubic centimetres per metre (cubic inches per foot) or percentage volume change.

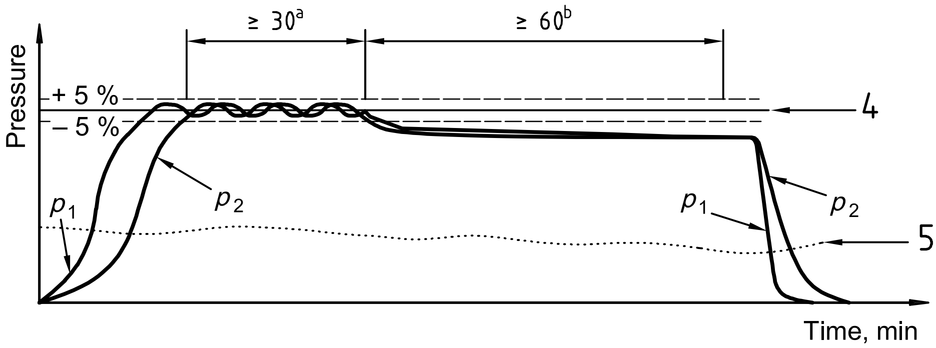
AVE is the volume of fluid collected in the burette, without correction, i.e. by not subtracting from the measured result the calculated change in test fluid volume for the same pressure changes. TVE is the volume of fluid collected in the burette to which corrections have been made so that the measured volume change applies to the hose structure only.

NOTE 1 Specification of a time period to measure the fluid displacement from the hose sample is needed to systematically account for the viscoelastic behaviour of the hoses. The bulk of the fluid will escape from the hose in a few seconds. However, the remainder will come out over a reasonable time.

NOTE 2 There is a difference in volumetric expansion measurements measured over short and long time intervals. A set of volumetric expansion measurements made with significantly differing drainage times from data point to data point will have poor repeatability. A slight difference in the slope of the volumetric expansion vs. pressure curves is likely, depending on the drainage time used. Therefore, in order to make comparable measurements, and to achieve the best volumetric expansion measurement accuracy, a fixed drainage time must be used.



a) Test arrangement



b) Pressure vs. time during test

Key

1 Pump
2 Hose under test
3 Control valve
4 Test pressure
5 Temperature

p_1 is the pressure at the hose outlet.

p_2 is the pressure at the remote end of the hose.

[a] Period during which the pressure is maintained at ± 5 %. See 7.9.8.6.

[b] Period during which the pressure is allowed to decay. See 7.9.8.6.

Figure D.1 — Proof pressure/decay test arrangement

D.1.2 Dynamic hose response test

D.1.2.1 General

This test method specifies the procedure for determining the dynamic response characteristics of a thermoplastic hose. The test is designed to simulate emergency shutdown of subsea equipment and provides information for the simulation of hydraulic performance. The test shall be performed on the specified hose(s) in the completed umbilical when stored on a reel or carousel. A typical test set-up is shown in Figure D.2.

D.1.2.2 Test procedure

Each nominated hose within the umbilical shall be connected in turn to the hydraulic supply and filled with the specified control fluid. The size of the vent valve and jumper hose connecting the vent valve to the vent fluid reservoir tank shall be chosen to offer minimal resistance to the discharge flow.

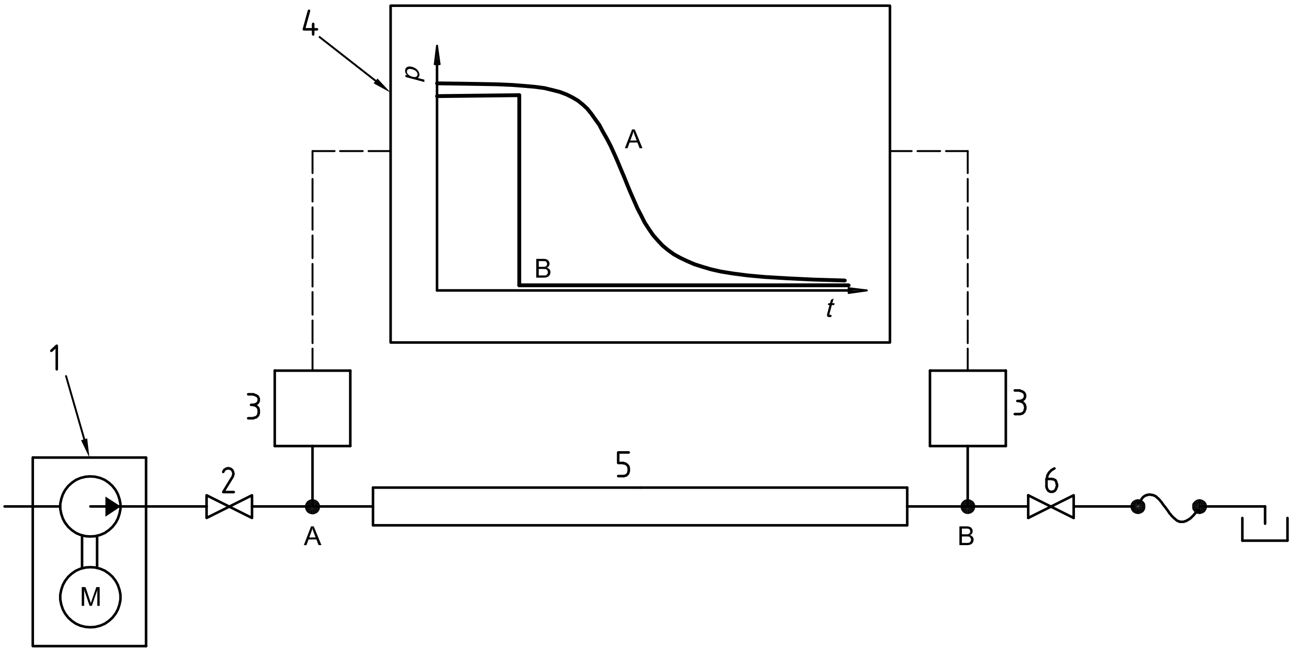
This procedure shall be repeated a further two times for each hydraulic control hose in the umbilical to be subjected to this test.

Alter bleeding air from the hose, close the full-flow vent valve at the remote end of the umbilical. Pressurize the hose to the DWP, with the rate of pressure rise and decay no greater than 1,0 MPa (150 psi) per min, and allow the pressure to stabilize for 5 min ± 10 s. Repressurize the hose to the DWP and again allow the pressure to stabilize. Repeat this procedure until the pressures at ends A and B of the hose remain within 2 % of each other, and within 3 % of the maximum working pressure, for a period of 5 min ± 10 s.

At the end of the final stabilization period and with the charge valve closed at the supply end of the umbilical and the recorder running, rapidly open the vent valve.

The recorder should remain running until the pressure at end A is within 1 % of the pressure at end B or the pressure at end A no longer continues to fall.

The air temperature and test fluid temperature shall be recorded.



Key

1 Hydraulic power supply
2 Charge valve
3 Pressure transducer
4 Strip chart recorder with typical pressure/time trace
5 Umbilical
6 Vent valve

Figure D.2 — Schematic arrangement of test set-up for dynamic response of hoses

D.2 Umbilical bend stiffness test

A sample of the completed umbilical shall be subjected to a series of bending regimes to allow its inherent stiffness to be determined. This is an optional test, and the information generated shall not form part of acceptance/rejection criteria unless stated otherwise in the manufacturer's written specification.

For umbilicals containing hoses, the stiffness shall be obtained for the following conditions:

a) hoses pressurized to the recommended installation value;

b) all hoses pressurized to a common value as stated in the manufacturer's written specification.

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

The bend stiffness shall be measured on a specimen length with a minimum sample length of not less than 2 m (6,56 ft).

One end of the umbilical shall be anchored with all the components locked to produce a built-in end condition. Transverse load increments shall be applied to the other end, and the deflection shall be measured 30 s ± 5 s after load application. No more than a further 30 s ± 5 s shall elapse before applying the next load increment. The load shall be decreased in a similar manner. Bend stiffness shall be calculated using the engineer's beam-bending theory, and the sectional modulus values obtained for the sample length shall be recorded.

Annex E
(informative)

Fatigue testing

The test regimes shall be in accordance with the manufacturer's written specification, taking into account installation and service parameters. The testing shall be designed so that in conjunction with analysis the required service life will be demonstrable, with, if required, a suitable margin of safety to cover any uncertainties in the design analysis and information.

An umbilical intended for static service after installation shall be verified by demonstrating that the design can withstand the loads and flexures experienced primarily during the installation process. Normally, the most critical area is when the umbilical is overboarded during installation and may be exposed to high tensile loads and repeated flexure during the deployment. It is, however, important that thorough analysis is carried out to confirm that the most critical area is identified. A typical umbilical installation is shown in Figure E.1.

The test regime selected shall demonstrate that the umbilical will satisfy these requirements for an agreed duration and/or minimum number of load cycles as stated in the manufacturer's written specification which demonstrate the required service life.

If it is shown that flexing is the critical regime, testing to determine the fatigue resistance during installation deployment would be based upon a representative sample of umbilical being repetitively flexed to a predetermined radius and straightened whilst subject to tension by means of an applied load. The applied load and flexing frequency shall be representative of the predicted installation conditions. The sample shall withstand the specified number of flexures without impairing the umbilical functionality, or component failure. If components have been bundled using the oscillatory method, the region of umbilical that is subject to flexing shall include changes of direction in the components.

Examples of fatigue test configurations which may be suitable for this fatigue condition are illustrated in Figures E.2 and E.3. Alternatively, the manufacturer may demonstrate the suitability by means of mathematical model analysis which has been verified by comparing the theoretical calculations to the actual physical measurements and/or historical data.

An umbilical intended for dynamic service after installation shall be verified by demonstrating that the design can sustain the loads and flexures that will be imposed on the umbilical throughout its operational life. Depending on the installed configuration, typically as illustrated in Figure E.4 and host vessel motions, the umbilical may be subject to a whole spectral range of flexure conditions (typically as illustrated in Figure E.3) which may cover one or more of the following:

a) high axial load with low angles of flexing;

b) low axial load with high angles of flexing;

c) high axial load with high angles of flexing;

d) low axial load with low angles of flexing.

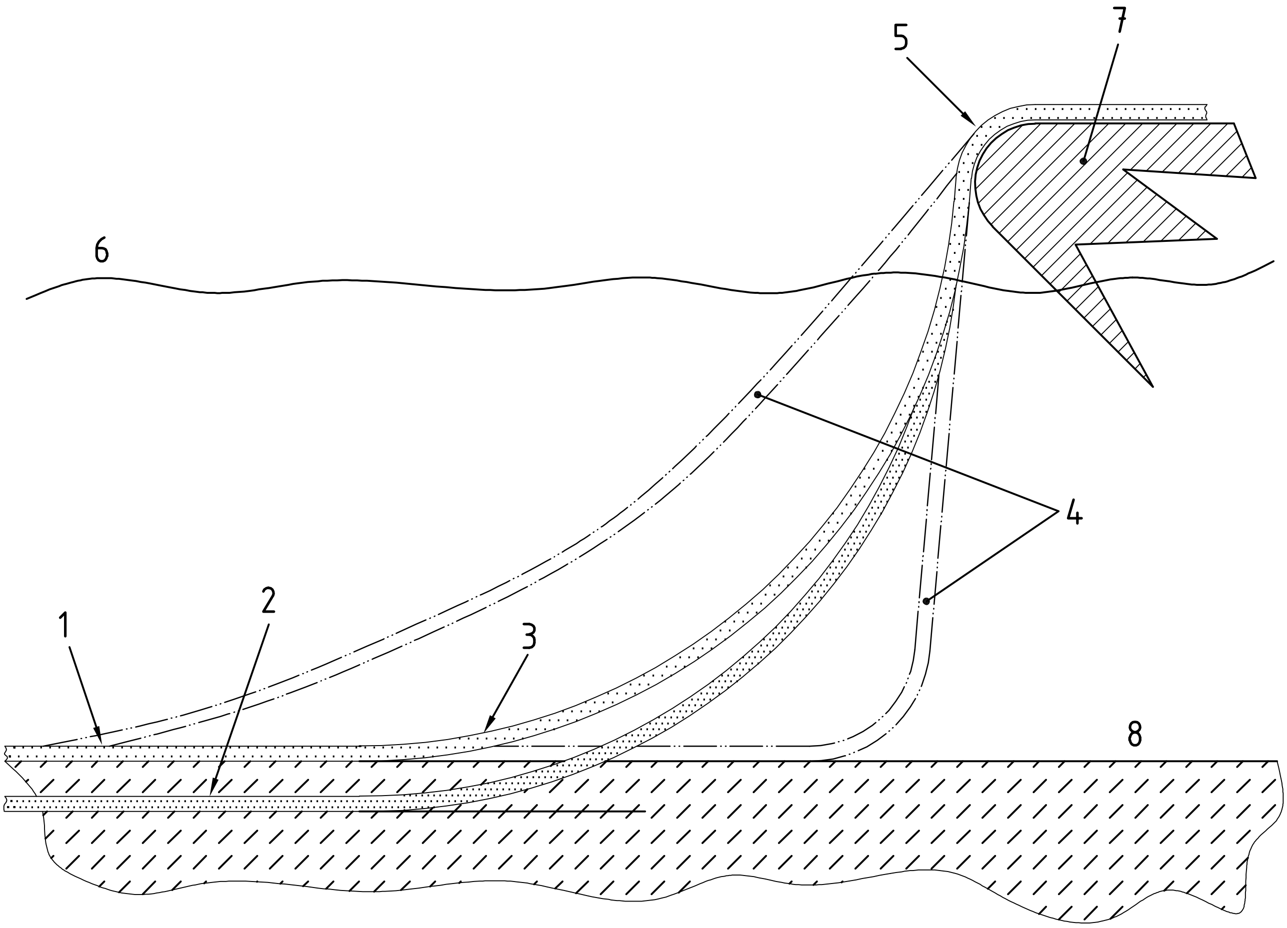
For shallow water installations, low axial loads with high angles of flexing at the vessel hang-off are to be expected. For deepwater installations, high axial loads with low angles of flexing at the vessel hang-off are to be expected. The other conditions may occur as a result of the installed configuration, e.g. mid-water buoy. As a result of these factors, a dynamic umbilical may be exposed to a wide range of environmental variables, and test regimes shall take account of such variables. The effect of such variables on the axial load within the umbilical and the degree of flexure are normally determined by analysis of the installed system. From this analysis it is possible to develop a test matrix in respect of defined fatigue motions. (See example provided in Table E.1).

The results of the analysis may show that a significant number of flex cycles occur at very low levels of angular deflection. At such levels of deflection, the cyclic stress levels in the electrical conductors and armour wires may be so low that they cannot be observed on their S-N curves. In these situations, the necessity to perform fatigue testing at such low angles should be considered. The selected test regime should, however, as a minimum, impart the same level of potentially damaging fatigue stresses to the umbilical as it is expected to withstand during its operational life.

To verify the fatigue performance of the umbilical at the vessel exit region, the umbilical should be subject to a bending under tension at a built-in end fitting test. A typical illustration of this test is given in Figure E.5. If the in-service built-in end fitting incorporates a bend stiffener or other means of strain relief, a stiffener or strain-relief device of the same design should be incorporated in the test sample.

Table E.1 — Typical test matrix for flex fatigue testing of a dynamic umbilical

Test block	**Load** kN (klbf)	**Number of cycles**	**Deflection angle** degrees	**Period** s	**Duration** d
A	250 (56,2)	$1,45 \times 10^6$	± 2	4	66,7
B	260 (58,5)	$5,1 \times 10^5$	± 3	4	23,5
C	280 (62,9)	4×10^5	± 4	5	23,0
D	300 (67,4)	$2,5 \times 10^5$	± 5	6	17,3
E	320 (71,9)	$1,7 \times 10^5$	± 6	8	15,6
F	350 (78,7)	$2,15 \times 10^5$	± 8	10	24,7
G	400 (89,9)	2 500	0 to + 10	10	0,3
H	400 (89,9)	2 500	0 to − 20	10	0,3
Total		3×10^6			**5,7 months**
Loads, angles, number of cycles and periods are illustrative only. In practice they should be derived from analysis.					



Key

1 Free-lay installation

2 Trenched installation

3 Touch-down region

4 Extreme-condition positions

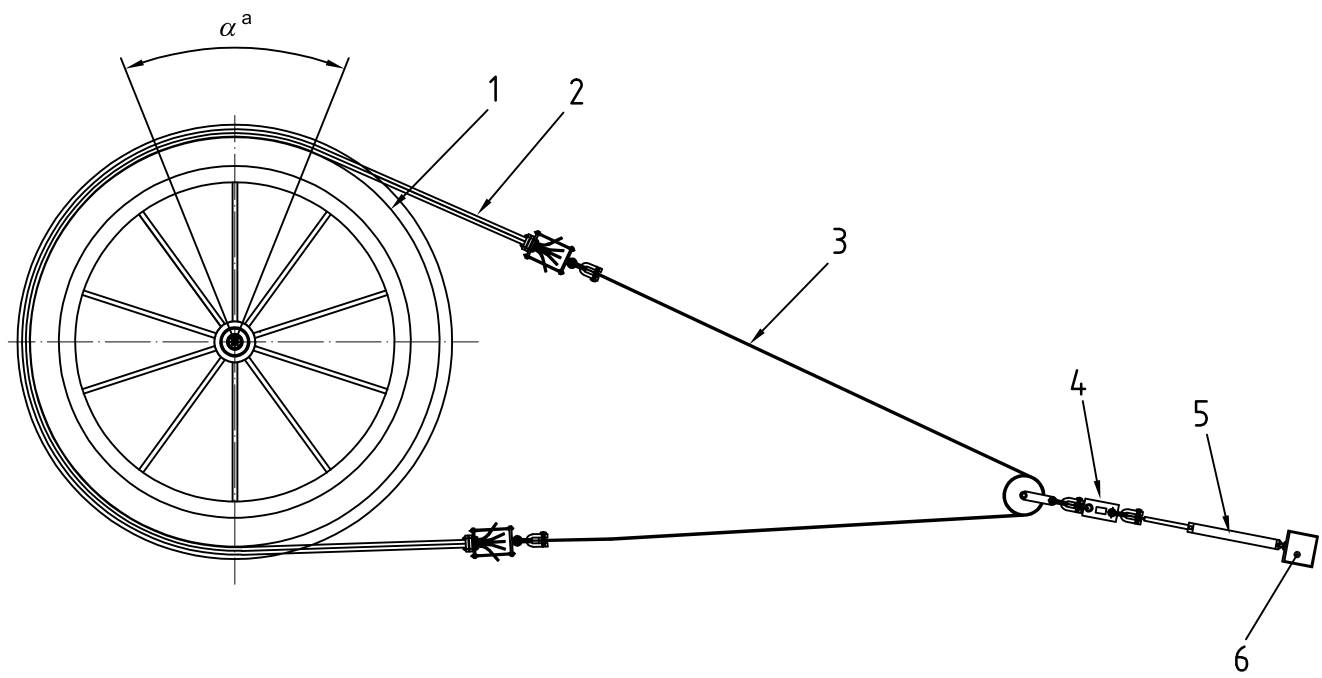
5 Region of flexing due to vessel motion and/or movement

6 Sea level

7 Installation vessel with overboarding arrangement

8 Seabed

Figure E.1 — Typical umbilical installation deployment

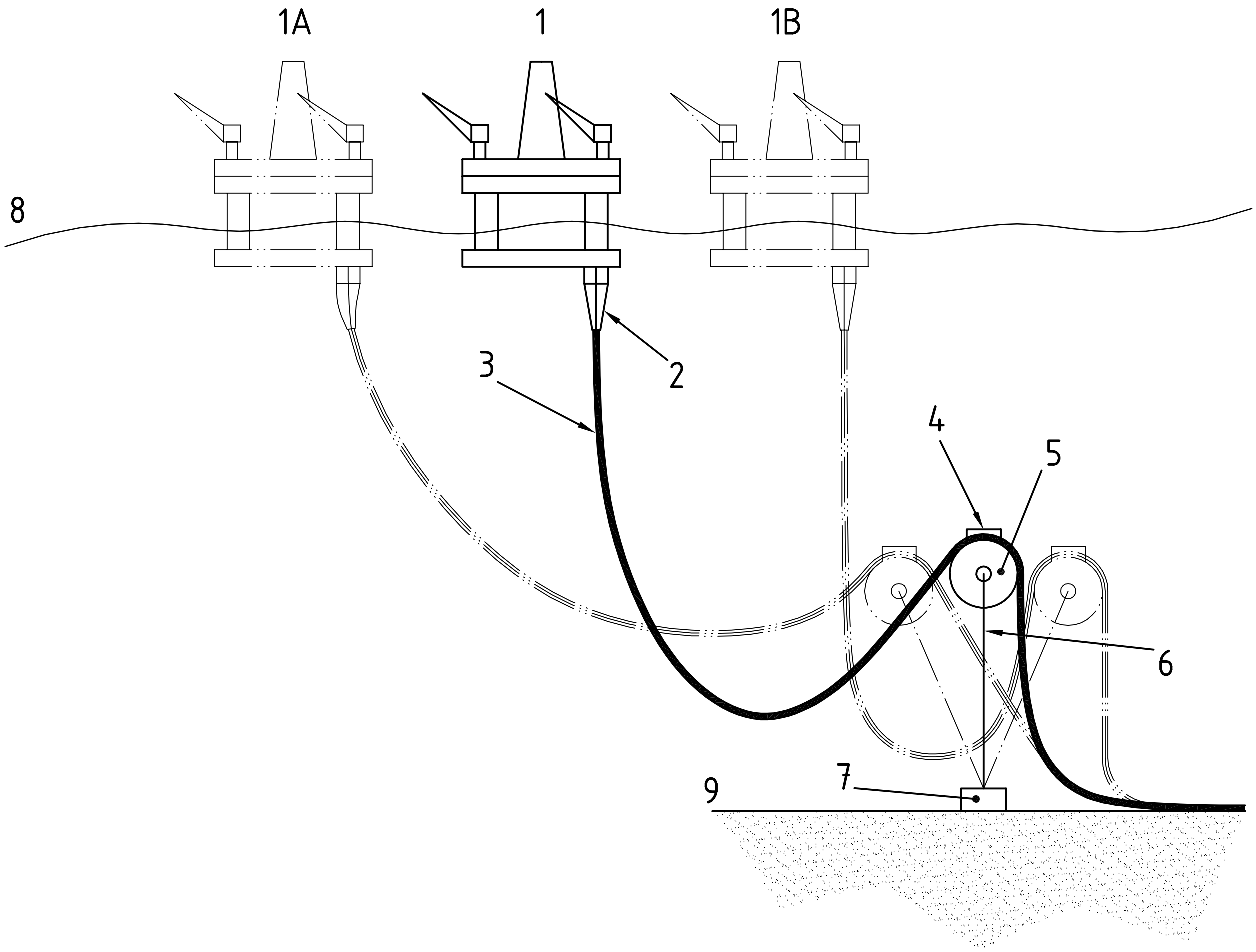


Key

1 Sheave
2 Umbilical cable
3 Wire rope
4 Load cell
5 Hydraulic ram
6 Anchorage

[a] Angle of sheave movement.

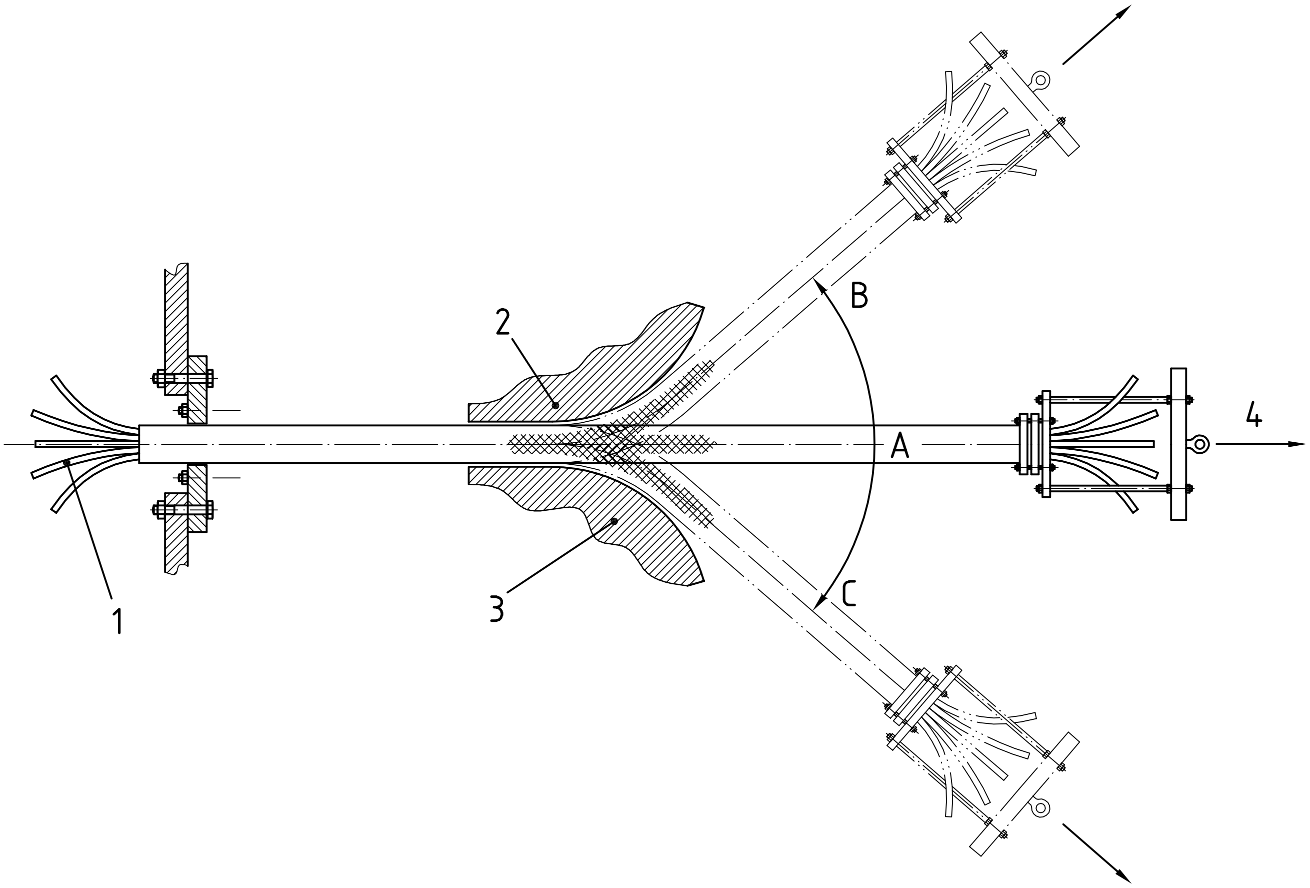
Figure E.2 — Typical arrangement for fatigue-testing an umbilical around an oscillating sheave



Key

1 Normal position
1A Far position
1B Near position
2 Bend stiffener
3 Umbilical
4 Clamp
5 Buoy
6 Tether
7 Clump weight
8 Sea level
9 Seabed

Figure E.3 — Typical arrangement for fatigue-testing an umbilical against a former



Key

1 Umbilical components

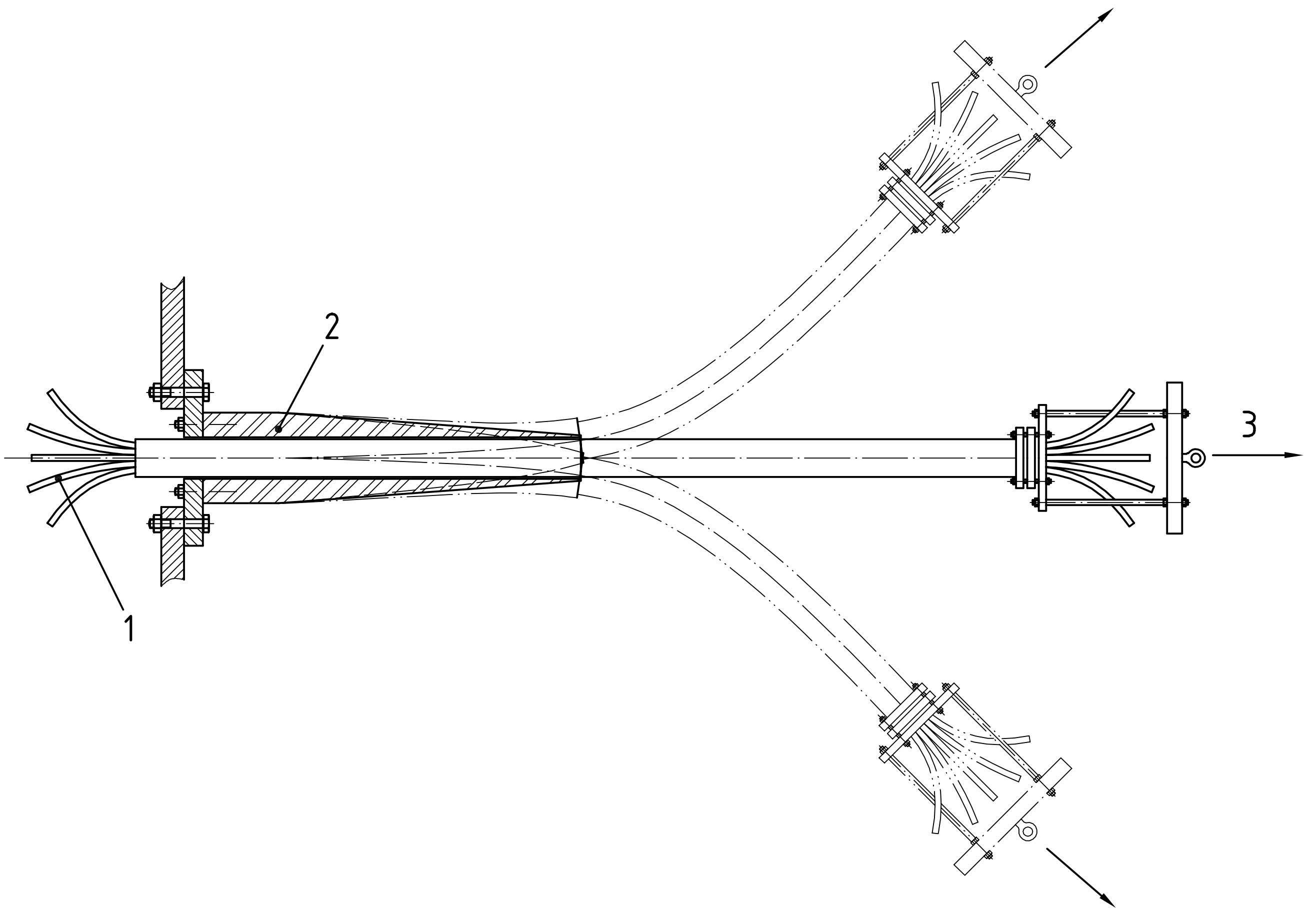
2 Former

3 Fatigue region

4 Tensile load

NOTE A-B-A involves non-reverse bending, A-B-A-C-A involves reverse bending.

Figure E.4 — Typical installed excursion configuration for an installed dynamic umbilical



Key

1 Umbilical components

2 Bend stiffener

3 Tensile load

Figure E.5 — Typical test arrangement for subjecting an umbilical to bending under tension at a built-in end fitting

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