PETROBRAS	TECHNICAL SPECIFICATION	N°: I-ET-3000.00-1500-29B-PAZ-006
	CLIENT: -	SHEET: 1 of 33
	JOB: -	-
	AREA: -	-
-	TITLE: QUALIFICATION OF SUBSEA UMBILICALS	SUB/ES/CIT
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INDEX OF REVISION

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	Original
A	All pages, including document title
B	General revision
C	Differentiation between verification and residual tests on functional components Possibility to perform maximum tensile load, torsion balance and axial stiffness tests in combination Inclusion of crush test Changes on fatigue tests procedures Minor changes on the text along the document
D	Incorporation of the qualification tests for metallic tubes and thermoplastic hoses
E	Refs. [2] and [3] changed Medium Voltage (MV) changed to High Voltage (HV) Changes on verification tests for HV cables during fatigue tests
F	Ref. [1] changed Changes on crush (section 5.6.5.5) and fatigue (sections 5.6.5.6 and 5.6.5.7) tests procedures Annex A included

	REV. 0	REV. F	REV. G	REV. H	REV. I	REV. J
DATE	SEP/2010	23/08/2024				
EXECUTION	FBA	CJME				
CHECK	YR / AAG	CSMP				
APPROVAL	CASP	TRNN				

CONTENTS

1 Scope

This specification defines the qualification program of subsea umbilicals to be supplied to PETROBRAS. Functional component prototypes and umbilical prototypes must be qualified according to this specification and the documents referenced herein. It is applicable to subsea umbilicals either for static or dynamic service.

This specification does not apply to umbilicals for completion/workover riser systems. However, the functional components of such equipment may be qualified according to the stated herein in the lack of specific documentation.

2 References

Note: for the documents referenced on section 2.1, the indicated revision must be adopted. For the documents referenced on section 2.2, SUPPLIER shall adopt the revision indicated on project-specific documentation.

2.1 International Standards

[1] API SPEC 17E, 5th Edition (2017-07), *Specification for Subsea Umbilicals*

[2] IEC 60793-1-40, Edition 2.0 (2019-03), *Optical fibres: Attenuation measurement methods*

2.2 PETROBRAS specifications

[3] I-ET-3000.00-1500-700-PEK-004, *High-voltage electrical power cable for subsea umbilical*

[4] I-ET-3000.00-1519-29B-PZ9-002, *Low voltage/signal electric cables and terminations for subsea umbilical systems*

3 Terms, abbreviated terms and definitions

PETROBRAS adopts the same terms, abbreviated terms and definitions as in [1], with the amendments and supplements defined in this section.

3.1 Terms and definitions

abandonment cap
accessory specially designed to protect electric cable and optical-fiber cable terminations in case of temporary lay-down of the subsea umbilical on the seabed for later retrieval

accumulated fatigue damage
theoretical value that accounts the fatigue damage due to the fluctuating stresses on the subsea umbilical materials. In this specification, unless otherwise stated, the accumulated fatigue damage is always related to fatigue design curves. In this specification, subsea umbilical accumulated fatigue damage (or simply accumulated fatigue damage, or AFD) is always related to the component (functional or structural) with the highest accumulated fatigue damage

aged
condition of umbilical components (functional and structural) at the end of a prototype qualification test

design tensile load
maximum tensile load multiplied by the utilization factor associated to the failure mechanism that infringes the stress criterion or causes loss of performance considering the Normal Operation load condition. Due to the different utilization factors, the maximum tensile load and the design tensile load may be defined by different components

design water depth
water depth specified by PETROBRAS for which the umbilical must be designed to, independently of the operational water depth

fluid conduits
thermoplastic hoses and metallic tubes within a subsea umbilical

high voltage
voltages equal to or greater than 1 kV

hydraulic control hose
thermoplastic hoses intended for control functions

independent verification agent
party or group independent from MANUFACTURER and PETROBRAS

MANUFACTURER
subsea umbilical manufacturer

maximum allowable fatigue damage
maximum allowable fatigue damage for umbilicals with metallic tubes is AFD = 0.10. For umbilicals without metallic tubes, maximum allowable fatigue damage is AFD = 0.33

may
verbal form used to indicate a course of action permissible within the limits of this specification

must
verbal form used to indicate requirements strictly to be followed in order to conform to this specification

prototype
product which concept, constituent materials, design methodologies, manufacturing processes and/or prototype testing results have not been reviewed and accepted by an IVA and which performance has not been approved by PETROBRAS through results of theoretical complementary analyses and of prototype qualification tests. Considering an already qualified product, PETROBRAS understands that any change on configuration, geometry, dimensions, constituent materials, material suppliers and/or manufacturing equipment may imply in a new qualification program, i.e., the modified product is a prototype

sample failure

for a functional component prototype, it is its loss of performance due to the load(s) applied on a qualification test. For an umbilical prototype, it is the loss of performance of an umbilical component – functional or structural – or an umbilical ancillary equipment due to the load(s) applied on a qualification test

shall

verbal form used to indicate requirements strictly to be followed in order to conform to this specification

should

verbal form used to indicate that a provision is not mandatory, but is recommended as good practice

structural components

components responsible to sustain the tensile loads in a subsea umbilical. Typical ones are steel wires, metallic tubes and fiber-reinforced plastic rods

SUPPLIER

subsea umbilical supplier. In some cases SUPPLIER and MANUFACTURER may be the same entity

test rig

apparatus specially designed to perform one or more tests

3.2 Abbreviated terms

AFD	accumulated fatigue damage
DWD	design water depth
HV	high voltage
IVA	independent verification agent

4 Communication between SUPPLIER and PETROBRAS

Unless otherwise informed, communication relative to technical matters of subsea umbilical qualification processes (request for information, clarifications, technical discussions etc.) shall be sent to the e-mail address *qualificacao.umb@petrobras.com.br*.

Documents that need PETROBRAS approval in the process [test procedures (section 5.4), Qualification Plan (section 5.6.2) and Qualification Report (section 5.7)] shall be sent via Petrobras document management system. PETROBRAS will give guidance to SUPPLIER on how to use the system.

5 Qualification program

The qualification program must follow the requirements of [1], considering the replacements, amendments and supplements stated on this specification and on the documents referenced herein.

Functional component prototype qualification and subsea umbilical prototype qualification must be performed according to the requirements presented on section 5.5 and section 5.6 respectively. PETROBRAS considers a completed umbilical qualified only when both are successfully finished.

The qualification of a subsea umbilical and its functional components is a necessary activity for the reliable application of the product. It consists of evaluating and attesting that the product has the minimum characteristics to ensure its safe use for the intended functional requirements (hydraulic power, chemical injection, electrical power and/or communication).

Whenever a qualification test fails, PETROBRAS shall be informed as soon as possible. If feasible, the prototype should not be disassembled from the test rig and no further action should be taken until SUPPLIER, IVA and PETROBRAS come to an agreement on how to treat the event. PETROBRAS reinforces the need of technically based arguments for the evaluation of the test failure.

5.1 Objectives

The first objective of the qualification program is to evaluate the feasibility of the subsea umbilical to operate on a scenario (or scenarios) defined by PETROBRAS – withstanding the loads for which it is designed to and that it has the properties it is predicted to have – through the execution of qualification tests. If a qualification test result does not comply with the respective acceptance criterion(a), SUPPLIER may try to demonstrate that the prototype is fit-for-purpose according to the design methodology, subject to PETROBRAS approval. Otherwise, the product must be redesigned, and the new prototype must go through the whole qualification program. The qualification tests results shall not be understood as the structural capacity of the prototype.

The second objective of the qualification program is optional to MANUFACTURER and it is intended to validate the design methodology applied to define the properties and structural capacity of functional components and/or subsea umbilicals. This validation will establish the range and application limits to which the design methodology is suitable and will support the definition of similarity between functional components and subsea umbilicals. The minimum requirements for a design methodology validation can be found in Annex A.

5.2 Independent verification agent

The qualification program must be followed by an IVA, to be contracted by SUPPLIER. The selected IVA must have demonstrated experience on the design, manufacturing and testing of subsea umbilicals.

The IVA shall fully review the documentation generated under the scope of the qualification program. The IVA analysis on any document must be prior to PETROBRAS review, i.e., only when IVA and SUPPLIER come to an agreement on the content of any document, this shall be sent to PETROBRAS. In the cases where SUPPLIER performs any changes on a document due to PETROBRAS comments on it, this new version must be sent to the IVA for another round of reviewing.

The IVA must witness all the tests within the scope of the qualification program, whether it is for a functional component prototype or an umbilical prototype. SUPPLIER and IVA are free to decide if the IVA will attend the test facilities or if it will remotely witness the tests, by any means they mutually agree.

On the completion of the qualification program, the IVA must issue a certificate summarizing the results of the qualification process and demonstrating that the proposed product fulfills the requirements of this specification.

If MANUFACTURER intents to validate a design methodology (as described on section 5.1), then the IVA has additional duties to perform, which are described on Annex A.

5.3 Tests schedule

The schedule for the execution of qualification tests must be provided to PETROBRAS. Due to its inherent nature, usually the tests schedule is very dynamic in the course of a qualification program, so PETROBRAS must be kept updated of the changes on the schedule. PETROBRAS must be informed of any test date at least 15 (fifteen) days in advance if the test is going to be performed in Brazil. For tests being performed in other countries, PETROBRAS must be informed of any test date at least 45 (forty-five) days in advance.

PETROBRAS may witness or not the qualification tests at its own discretion and will inform SUPPLIER. Nevertheless, as stated on section 5.2, the IVA must witness all the tests within the scope of the qualification program.

5.4 Test procedures

Specific procedures for the qualification tests required on this technical specification and the documents referenced herein must be presented to PETROBRAS, for both functional component prototypes and for umbilical prototypes.

The procedure for a specific test must be available to PETROBRAS at least 15 (fifteen) days before the execution of the test itself. As stated on section 5.2, the IVA analysis on any procedure must be prior to PETROBRAS review on it.

Test procedures must fulfill the test requirements defined on sections 5.5 and 5.6 – including dissection when applicable – and must have PETROBRAS approval prior to the start of the respective qualification test.

5.5 Functional component prototype qualification

5.5.1 High voltage electric cables

The qualification of a high voltage electric cable and its abandonment caps shall follow the requirements of [3].

5.5.2 Low voltage electric cables

The qualification of a low voltage electric cable, its connectors and abandonment caps shall follow the requirements of [4].

5.5.3 Metallic tubes

The metallic tube designs must be qualified considering the functional requirements (i.e., DWP, inner diameter, DWD, conveyed fluid, service life etc.) specified in the applicable documentation. At least the tests stated on [1] must be performed. PETROBRAS and MANUFACTURER may agree to perform additional tests to better investigate failure modes applicable to the proposed design concept, including welds.

5.5.4 Optical-fiber cables

MANUFACTURER shall refer to project-specific documentation where the qualification requirements of an optical-fiber cable, its connectors and abandonment caps are established.

5.5.5 Thermoplastic hoses

The thermoplastic hose designs must be qualified considering the functional requirements (i.e., DWP, inner diameter, DWD, conveyed fluid, service life etc.) specified in the project documentation. At least the tests stated on [1] must be performed, with the changes and exceptions specified on sections from 5.5.5.1 to 5.5.5.4.

5.5.5.1 Impulse test

Impulse test may be performed with the test fluid at ambient temperature.

5.5.5.2 Cold bend test

Petrobras understands that it is not necessary to perform the cold bend test to qualify a hose design.

5.5.5.3 Collapse

For hydraulic control hoses, the test must be performed according to [1] for characterization only.

For HCR hoses, the test pressure must be increased until it reaches 150% of the static head due to external hydrostatic pressure at the DWD (disregarding the static head due to the conveyed fluid). At that point, this pressure level must be maintained for a minimum period of 60 (sixty) minutes, during which no collapse must be noted. After that, the test pressure shall be raised up until the hose sample collapses.

5.5.5.4 Volumetric expansion

For HCR hoses, the test must be performed according to [1] for characterization only.

For hydraulic control hoses, the maximum allowable values presented in Table 1 and Table 2 must be considered as acceptance criteria for this test.

Table 1 - Maximum allowable values for the volumetric expansion of 3/8" ID hydraulic control hoses

Pressure [psi (bar)]	Maximum allowable volumetric expansion [cm³/m (cm³/ft)]
3,000 (207)	5.67 (1.72)
5,000 (345)	7.56 (2.30)
7,500 (517)	9.66 (2.94)
10,000 (690)	11.76 (3.58)

Table 2 - Maximum allowable values for the volumetric expansion of 1/2" ID hydraulic control hoses

Pressure [psi (bar)]	Maximum allowable volumetric expansion [cm³/m (cm³/ft)]
3,000 (207)	10.03 (3.06)
5,000 (345)	13.45 (4.10)
7,500 (517)	17.16 (5.23)
10,000 (690)	20.90 (6.37)

5.6 Umbilical prototype qualification

Umbilical prototype qualification tests subject the umbilical samples to predefined loads in order to verify its mechanical properties and/or to evaluate the specified design limits in terms of extreme loads and fatigue.

5.6.1 General requirements

Some of the umbilical prototype qualification tests have acceptance criteria defined by PETROBRAS. SUPPLIER may propose to extend the ranges of these criteria, provided that this proposal is strictly based on technical arguments. Additionally, it may suggest modifications on the test methodologies described hereafter – in order to suit them to available facilities and equipment, due to personnel safety reasons etc. – or even the inclusion of new tests to better investigate failure modes that may be applicable to the adopted design. The test shall start only after SUPPLIER and PETROBRAS come to an agreement on these modifications and inclusions. The IVA should join these discussions.

Umbilical prototype samples must be representative of the manufacturing process of the product. The end terminations used on the qualification tests must have the outer sheath locking system required for the umbilical, and a failure of this system invalidates the qualification test. The end terminations may be specially designed for the umbilical prototype qualification tests, either to make the assembling on the test rig feasible or to facilitate their dissection, but they must have similar dimensions to those to be supplied to PETROBRAS, especially with relation to the inner conic surface.

All tolerances expressed in percentage within this specification are relative to direct reading and do not account the uncertainties of the measuring equipment.

5.6.2 Qualification Plan

The Qualification Plan shall provide information that will enable IVA and PETROBRAS to follow and evaluate the results of the umbilical prototype qualification tests detailed on section 5.6.5. It must be available to PETROBRAS at least 15 (fifteen) days before the start of the first qualification test.

Expected results informed on the Qualification Plan shall be compared to test results on the Qualification Report (section 5.7). Thus, SUPPLIER should detail the adopted methodologies to calculate these expected results by informing the assumed theory, technical references, software tools etc.

The minimum required information for each umbilical prototype qualification test is detailed on sections from 5.6.5.1 to 5.6.5.7.

5.6.3 Functional components verification tests

Functional components shall be subjected to verification tests as part of the umbilical prototype qualification tests, and the requirements of when they shall be performed are stated on section 5.6.5. When possible and convenient, they may be performed with the umbilical prototype sample assembled on the test rig.

5.6.3.1 Fluid conduits

The fluid conduits within the sample shall be subjected to a proof pressure test following the same parameters as defined in [1] for the FAT, i.e., 1.50 x DWP for the thermoplastic hoses and 1.25 x DWP for the metallic tubes, over a minimum period of 4 (four) hours. These pressurization values shall be continuously monitored and recorded.

5.6.3.2 High voltage electric cables

HV cables within the umbilical sample shall be subjected to the following verification tests:

- DC conductor resistance
- partial discharge
- voltage and
- insulation resistance at ambient temperature

NOTE: insulation resistance at ambient temperature test procedure is described below:

1) clean up all three cable ends where the insulation tester probe will be fixed;

2) electrically interconnect all three metallic screens and two cable cores and the guard terminal to drain any surface current between the conductor under test and the metallic screen;

3) fix one probe of the insulation tester on the free cable core and the other probe on the other point electrically interconnected to the metallic screens and the other two cable cores;

4) perform the test applying 5kV dc voltage for 10 minutes using an insulation tester capable to register the test current and the insulation resistance continuously throughout the test. Also register the ambient temperature. It shall be presented a graph current x insulation resistance x test time or a table with the values. It must be marked the results for 30 (thirty) seconds, 1 (one) minute and 10 (ten) minutes;

5) repeat steps 1 to 4 for the other two cable cores in order to complete the insulation test of phases against each other and the earth;

6) there are no acceptance criteria for insulation resistance at ambient temperature test. Significant changes in the results (before and after the umbilical prototype qualification test) require cause investigation.

5.6.3.3 Low voltage electric cables

LV cables within the sample shall be subjected to the following verification tests:

- DC conductor resistance and
- DC insulation resistance

DC insulation resistance test shall be performed without the requirements of immersion in town-mains water under pressure, hence the 22 (twenty-two) hours waiting time is unnecessary.

Acceptance criteria defined in [1] apply to both tests.

5.6.4 Functional components residual tests

Functional components shall be subjected to residual tests as part of the umbilical prototype qualification tests, and the requirements of when they shall be performed are stated on section 5.6.5. Residual tests shall be performed on component samples extracted from aged umbilical prototype samples during dissection.

5.6.4.1 High voltage electric cables

HV cables within the sample shall be subjected to the following residual test:

- tan δ measurement (see following Notes 1, 2 and 3)

NOTE 1: tan δ measurement test must be performed only for cables of rated voltage 6/10 (12) kV and above.

NOTE 2: a tan δ measurement test shall be performed on an unaged cable sample from the same cable spool used to manufacture the umbilical prototype samples. This value shall be used as a reference for comparison with the results of aged samples (see Note 3).

NOTE 3: there are no acceptance criteria for this test. Significant changes in the results (before and after the umbilical prototype qualification test) require cause investigation.

5.6.4.2 Metallic tubes

After the subsea umbilical prototype qualification test, one sample shall be taken from each tube within the umbilical bundle and the following residual tests shall be performed:

- visual and dimensional check;
- pressure test;
- burst test and
- non-destructive examination of the welds

The same procedures and acceptance criteria defined in [1] and on section 5.5.3 of this specification for unaged representative samples apply for these residual tests. All samples shall be subjected to visual and dimensional check. All welds shall be subjected to NDE. Two samples shall be subjected to pressure test and the remaining samples shall be subjected to burst test.

5.6.4.3 Thermoplastic hoses

After the subsea umbilical prototype qualification test, one sample shall be taken from each thermoplastic hose within the umbilical bundle and the following residual tests shall be performed:

- visual and dimensional check;
- leakage test;
- burst test;
- collapse test (only for HCR hoses) and
- volumetric expansion test (only for hydraulic control hoses)

The same procedures and acceptance criteria defined in [1] and on section 5.5.5 of this specification for unaged representative samples apply for these residual tests, except for the volumetric expansion test. For volumetric expansion tests performed on hoses as a functional component residual test, the 5 (five) days preconditioning period at DWP is not necessary. All samples shall be subjected to visual and dimensional check. For the other tests, the number of samples is defined according to Table 3 and Table 4.

Table 3 - Distribution of HCR hose samples for residual tests

	Number of HCR hose samples to be tested		
Total number of HCR hoses within the umbilical	**Leakage test**	**Collapse test**	**Burst test**
Less than 3	PETROBRAS shall be consulted		
3 or 4	1	1	remaining sample(s)
More than 4	1	2	remaining sample(s)

Table 4 - Distribution of hydraulic control hose samples for residual tests

	Number of hydraulic control hose samples to be tested		
Total number of hydraulic control hoses within the umbilical	**Leakage test**	**Volumetric expansion test**	**Burst test**
Less than 3	PETROBRAS shall be consulted		
3 or 4	1	1	remaining sample(s)
More than 4	2	1	remaining sample(s)

5.6.5 Umbilical prototype qualification tests

5.6.5.1 Maximum tensile load test

5.6.5.1.1 Objective

Evaluate the performance of the umbilical prototype under pure tension when loaded up to the theoretical maximum tensile load.

5.6.5.1.2 Guidelines

The minimum sample length must be at least equal to 2 (two) lay lengths, considering the structural component with the longest lay length. This sample length must disregard the lengths inside the end terminations (i.e., it shall be measured between the bottom faces of the end terminations).

Prior to the execution of the umbilical prototype test itself, HV and LV cables shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3.

The umbilical prototype sample shall be assembled on a test rig with one end fixed and the other free to rotate. The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2). Then the fluid conduits shall be pressurized up to the DWP. This pressure value shall be maintained during the whole test (see section 5.6.5.1.3).

After preloading the sample and pressurizing the fluid conduits, the tensile load shall be increased from the preload tension up to the theoretical maximum tensile load. The ramp-up shall be divided in a minimum of 10 (ten) load blocks, with approximately equal increments. Within each load block, the tensile load shall be increased at a rate sufficiently low in order to not introduce shock loads, and the hold time duration at each load step must be at least 5 (five) minutes, except for the last block – where the theoretical maximum tensile load is reached. Hold time duration for the last block must be at least 60 (sixty) minutes. After that period, the prototype sample shall be

unloaded. The ramp-down shall adopt the same load blocks adopted for loading the sample, including the hold time duration time of at least 5 (five) minutes at each load step. Within each load block, the tensile load shall be decreased at a rate sufficiently low in order to not introduce shock loads.

After unloading the sample, the functional components shall be subjected to the verification tests specified on section 5.6.3.

Lastly the sample shall be dissected following the guidelines stated on section 5.6.6. A HV cable sample shall proceed to the residual test specified on section 5.6.4.1.

5.6.5.1.3 Sample monitoring

- It must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test;
- fluid conduits must be pressurized at DWP during the test and the pressure values must be continuously monitored and recorded. It is allowed to use a pressure supply unit to maintain the fluid conduits internal pressure within the defined range (see section 5.6.5.1.4);
- HV and LV cables electrical continuity must be continuously monitored during the test. HV conductors may be connected in series for this measurement. LV conductors may be connected in series for this measurement and
- optical-fiber cables must be subjected to continuous monitoring of their attenuation throughout the test, according to Method A specified in [2].

5.6.5.1.4 Acceptance criteria

- no sample failure at any step of the test, including verification tests on functional components and dissection appraisal and
- fluid conduits internal pressure must be maintained during the test, with a maximum variation of ± 500 psi.

5.6.5.1.5 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- drawings of the end terminations that will be mounted on the test sample;
- load blocks as required on section 5.6.5.1.2. It shall be clearly stated the number of load blocks and the load increments within these blocks and
- theoretical maximum tensile load

5.6.5.2 Torsion balance test

5.6.5.2.1 Objective

Measure the rotation characteristics and evaluate the performance of the umbilical prototype under pure tension when loaded up to the design tensile load.

5.6.5.2.2 Guidelines

The minimum sample length must be at least equal to 2 (two) lay lengths, considering the structural component with the longest lay length. This sample length must disregard the lengths inside the end terminations (i.e., it shall be measured between the bottom faces of the end terminations).

Prior to the execution of the umbilical prototype test itself, HV and LV cables shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3.

The umbilical prototype sample shall be assembled on a test rig with one end fixed and the other free to rotate, with a rotation measurement system mounted on it. The rotation measurement system must have a minimum resolution of 0.1 deg. Rotation of the sample must be measured by means of two points over the most external layer of structural components within the umbilical, using devices that do not induce significant radial compression over the prototype structure. For armoured umbilicals, the most external layer of structural components is typically the most external layer of armour wires. In situations where this identification is not obvious, SUPPLIER, IVA and PETROBRAS must come to an agreement on how to measure the twist of the sample. Special caution shall be taken on where to place the measuring devices, in order to avoid the influence of end effects.

The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2). Then the fluid conduits shall be pressurized up to the DWP. This pressure value shall be maintained during the whole test (see section 5.6.5.2.3).

The sample shall be kept under this preload tension and with fluid conduits pressurized at DWP for a minimum of 15 (fifteen) minutes. After that time, the rotation measurement system must be reset.

After preloading the sample, pressurizing the fluid conduits and resetting the rotation measurement system, the tensile load shall be increased from the preload tension up to the theoretical design tensile load. The ramp-up shall be divided in a minimum of 5 (five) load blocks, with approximately equal increments. Within each load block, the tensile load shall be increased at a rate sufficiently low in order to not introduce shock loads, and the hold time duration at each load step must be at least 5 (five) minutes, except for the last block – where the theoretical design tensile load is reached. Hold time duration for the last block must be at least 15 (fifteen) minutes.

After 15 (fifteen) minutes under the design tensile load, the prototype sample shall be unloaded down to the preload tension. The ramp-down shall adopt the same load blocks adopted for loading the sample, including the hold time duration time of at least 5 (five) minutes at each load step. Within each load block, the tensile load shall be decreased at a rate sufficiently low in order to not introduce shock loads. When the preload tension is reached, the sample must be kept under this load for a minimum of 15 (fifteen) minutes.

On all load blocks, after the hold time, the rotation shall be measured and informed on the Qualification Report (section 5.7.2). These values are for information only, except for the readings made under the design tensile load and the preload tension after unloading, for which the acceptance criteria stated on Table 5 apply.

Loading and unloading cycles to achieve stable rotation readings are allowed, as long as the tensile load is increased at a rate sufficiently low in order to not introduce shock loads.

After 15 (fifteen) minutes under preload tension, the functional components shall be subjected to the verification tests specified on section 5.6.3.

Lastly the sample shall be dissected following the guidelines stated on section 5.6.6. A HV cable sample shall proceed to the residual test specified on section 5.6.4.1.

5.6.5.2.3 Sample monitoring

- It must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test;
- if possible, the sample rotation should be monitored and recorded in a continuous manner;
- fluid conduits must be pressurized at DWP during the test and the pressure values must be continuously monitored and recorded. It is allowed to use a pressure supply unit to maintain the fluid conduits internal pressure within the defined range (see section 5.6.5.2.4);
- HV and LV cables electrical continuity must be continuously monitored during the test. HV conductors may be connected in series for this measurement. LV conductors may be connected in series for this measurement and
- optical-fiber cables must be subjected to continuous monitoring of their attenuation throughout the test, according to Method A specified in [2].

5.6.5.2.4 Acceptance criteria

- maximum sample measured rotation as per Table 5;

Table 5 - Acceptance criteria for sample rotation

At design tensile load (°/m)	At preload tension, after unloading (°/m)
0.4	0.2

- no sample failure at any step of the test, including verification tests on functional components and dissection appraisal and
- fluid conduits internal pressure must be maintained during the test, with a maximum variation of ± 500 psi.

5.6.5.2.5 Considerations

The torsion balance test may be performed in combination with the maximum tensile load test, with the same umbilical sample. In this case, MANUFACTURER is free to propose any test procedure that fulfills the requirements of sections 5.6.5.1 and 5.6.5.2, but the following remarks apply:

1) if MANUFACTURER performs the torsion balance test following the guidelines on section 5.6.5.2.2 until the sample is unloaded, kept under the preload tension for at least 15 (fifteen) minutes, have its rotation measured, verification tests on functional components executed, and only after that the maximum tensile load test is performed following the guidelines on section 5.6.5.1.2 (including verification tests, dissection and residual test on HV cables), it means that if a functional component fails during the maximum tensile load test and dissection indicates that no other failure has occurred, then the intermediate verification tests validate the torsion balance test. For any other procedure, a sample failure at any step of the maximum tensile load test (including verification tests, dissection and residual test on HV cables) means that both tests (torsion balance and maximum tensile load) failed.

2) if MANUFACTURER performs the torsion balance test following the guidelines on section 5.6.5.2.2 until the sample is loaded up to the design tensile load, kept under that load for a minimum of 15 (fifteen) minutes, have its rotation measured and then the tensile load is ramped up to the theoretical maximum tensile load following the guidelines on section 5.6.5.1.2, the load blocks must be carefully defined since the design tensile load becomes one

load step to reach the theoretical maximum tensile load, and the minimum number of load blocks defined on sections 5.6.5.1.2 and 5.6.5.2.2 must be considered.

5.6.5.2.6 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- drawings of the end terminations that will be mounted on the test sample;
- load blocks as required on section 5.6.5.2.2. It shall be clearly stated the number of load blocks and the load increments within these blocks;
- design tensile load and
- if the test is going to be performed in combination with the maximum tensile load test. In such case, the minimum information from both tests (sections 5.6.5.1.5 and 5.6.5.2.6) must be on the Qualification Plan.

NOTE: it is desirable to have the expected rotation values on the Qualification Plan.

5.6.5.3 Axial stiffness test

5.6.5.3.1 Objective

Measure the axial stiffness of the umbilical prototype and compare it to the provided theoretical value(s).

5.6.5.3.2 Guidelines

The minimum sample length must be at least equal to 2 (two) lay lengths, considering the structural component with the longest lay length. This sample length must disregard the lengths inside the end terminations (i.e., it shall be measured between the bottom faces of the end terminations).

The umbilical prototype sample shall be assembled on a test rig with one end fixed and the other free to rotate, with an elongation measurement system mounted on it. The elongation measurement system must have a minimum resolution of 1.0 mm. Elongation of the sample must be measured by means of two points over the most external layer of structural components within the umbilical, using devices that do not induce significant radial compression over the prototype structure. For armoured umbilicals, the most external layer of structural components is typically the most external layer of armour wires. In situations where this identification is not obvious, SUPPLIER, IVA and PETROBRAS must come to an agreement on how to measure the elongation of the sample.

The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2).

A load-up method (number of load blocks, loading increments and hold times duration) to perform the test shall be proposed by SUPPLIER. Loading and unloading cycles to achieve stable elongation readings are allowed, as long as the tensile load is increased at a rate sufficiently low in order to not introduce shock loads. Additionally, it must be informed at which tension range the tension-displacement relationship is deemed to be valid (notably at lower tensions the axial stiffness behaviour is erratic). As stated on section 5.4, the test procedure must have PETROBRAS approval prior to the test execution. Both the theoretical and the experimental axial stiffnesses must be presented in a graphical form (Tension x Displacement) on the Qualification Report (section 5.7.2).

5.6.5.3.3 Sample monitoring

- It must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test and
- if possible, the sample elongation should be monitored and recorded in a continuous manner.

5.6.5.3.4 Acceptance criterion

Experimental value(s) obtained in the test must be within ± 15% of the provided theoretical value(s) for every point on the Tension x Displacement graph.

5.6.5.3.5 Considerations

The axial stiffness test may be performed in combination with the torsion balance test. In this case, the following remarks apply:

1) the load blocks, loading increments and hold times duration of the axial stiffness test will be the same as for the torsion balance test.

2) the axial stiffness test will be performed with functional components continuously monitored, as required for the torsion balance test (section 5.6.5.2.3).

3) a sample failure at any step of the torsion balance test (including verification tests, dissection and residual test on HV cables) invalidates the axial stiffness test.

Moreover, as stated on section 5.6.5.2.5, the torsion balance test may be performed in combination with the maximum tensile load test, i.e., it is allowed to perform the 3 (three) tests with the same umbilical prototype sample. In such case, the remarks on section 5.6.5.2.5 apply.

5.6.5.3.6 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- drawings of the end terminations that will be mounted on the test sample;
- load-up method as required on section 5.6.5.3.2. It shall be clearly stated the number of load blocks and the load increments within these blocks;
- theoretical axial stiffness value(s) in a Tension x Displacement graphical form and
- if the test is going to be performed in combination with the torsion balance test. In such case, the minimum information from both tests (sections 5.6.5.2.6 and 5.6.5.3.6) must be on the Qualification Plan.

5.6.5.4 Bending stiffness test

5.6.5.4.1 Objective

Measure the bending stiffness of the umbilical prototype and compare it to the provided theoretical value(s).

5.6.5.4.2 Guidelines

If possible, the minimum sample length should be equal to at least 1 (one) lay length – as specified in [1] – considering the structural component with the longest lay length. This sample length must disregard the lengths inside the fixing mechanisms adopted to perform the test.

The umbilical prototype sample shall be subjected to a transverse load and flexed down to the specified MBR. The bending radius measurement system must have a minimum resolution of 1.0 mm.

A load-up method (number of load blocks, loading increments and hold times duration) and a test setup to perform the test must be proposed by SUPPLIER. Loading and unloading cycles to achieve stable readings are allowed, as long as the transverse load is increased at a rate sufficiently low in order to not introduce shock loads. It must be informed at which moment range the moment-curvature relationship is deemed to be valid. As stated on section 5.4, the test procedure must have PETROBRAS approval prior to the test execution.

The test shall be performed twice on the same umbilical prototype sample: considering a certain bending plane, the load-up method must be applied on the sample on 2 (two) opposite directions (180 deg from each other). Both sets of measurements and results shall be separately presented on the Qualification Report (section 5.7.2). Both the theoretical and the experimental bending stiffnesses must be presented in a graphical form (Moment x Curvature), also on the Qualification Report.

5.6.5.4.3 Sample monitoring

If possible, the applied load and bending radius should be monitored and recorded in a continuous manner.

5.6.5.4.4 Acceptance criterion

Experimental value(s) obtained in the test must be within ± 20% of the provided theoretical value(s) for every point on the Moment x Curvature graph.

5.6.5.4.5 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- load-up method as required on section 5.6.5.4.2. It shall be clearly stated the number of load blocks and the load increments within these blocks and
- theoretical bending stiffness value(s) in a Moment x Curvature graphical form.

5.6.5.5 Crush test

5.6.5.5.1 Objective

Evaluate the performance of the umbilical prototype under tensile and crushing loads, combined with each other, according to the capacity curve of tension versus maximum crushing provided by MANUFACTURER.

5.6.5.5.2 Guidelines

The test is divided in 3 (three) stages:

- on Stage 1, the prototype sample shall be subjected to a preload tension and the respective maximum crushing load according to the provided tension x crushing capacity curve;
- on Stage 2, the prototype sample shall be loaded up to halfway between the preload tension and the design tensile load. The crushing load must be equal to the respective maximum crushing load according to the provided tension x crushing capacity curve and
- on Stage 3, the prototype sample shall be loaded up to the design tensile load. The crushing load must be equal to the respective maximum crushing load according to the provided tension x crushing capacity curve.

Table 6 summarizes the applicable loads on each stage of the test.

Table 6 - Loads for the crush test stages

Test stage	Tensile load	Crushing load
Stage 1	preload tension	respective maximum crushing load according to the capacity curve of tension versus maximum crushing
Stage 2	halfway between the preload tension and the design tensile load	
Stage 3	design tensile load	

The test may be performed on 1 (one), 2 (two) or 3 (three) prototype samples. When performing 2 (two) or all 3 (three) stages on the same sample, they must be executed on different sections of the sample, at least 1 m apart from each other. Additionally, these sample sections must also be at least 1 m apart from the end terminations.

The crushing loads shall be applied by a device that simulates the tensioner of a laying vessel with 4 (four) tracks, each track with a minimum length of 1 m and a shoe contact angle of 160 deg.

Thus, considering the distance requirements and the minimum length for the tracks of the crushing device, the minimum sample lengths disregarding the lengths inside the end terminations (i.e., measuring between the bottom faces of the end terminations) are:

- 3 m, if only 1 (one) test stage is performed on the prototype sample;
- 5 m, if 2 (two) test stages are performed on the prototype sample and
- 7 m, if all 3 (three) test stages are performed on the prototype sample.

Prior to the execution of the umbilical prototype test itself, HV and LV cables of the sample(s) shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3.

The umbilical prototype sample(s) shall be assembled on a test rig with one end fixed and the other free to rotate. The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2). Then the fluid conduits shall be pressurized up to 1,000 psi, simulating the installation condition. This pressure value shall be maintained in all stages of the test (see section 5.6.5.5.3).

For stages 2 and 3, the tensile and crushing loads should ideally be applied/relieved on small increments, following the tension x crushing capacity curve. If this kind of automation is not available, then load steps must be proposed to reach the tensile and crushing loads respective to each stage. These load steps must be available on the Qualification Plan (section 5.6.2).

For each test stage, after reaching the respective tensile and crushing loads, the sample must stay under this condition for a minimum period of 60 (sixty) minutes, within a reasonable load variation range. After that time, the sample shall be unloaded.

If only 1 (one) stage is supposed to be performed on the sample, then the HV and LV cables of the sample shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3, and then proceed the sample to dissection following the guidelines stated on section 5.6.6, when the component samples for the residual tests shall be extracted and the tests performed following the requirements of section 5.6.4.

However, if 2 (two) or all 3 (three) stages are to be performed on the sample, then the test shall proceed to the next stage without verification testing. HV and LV cables of the sample shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3 only after all predicted stages have been performed on the sample. Then the sample shall be dissected following the guidelines stated on section 5.6.6, when the component samples for the residual tests shall be extracted and the tests performed following the requirements of section 5.6.4.

It is important to emphasize that when performing 2 (two) or all 3 (three) test stages on the same sample, a failure at any step of the test (including verification tests, dissection and residual tests) invalidates the results from all stages executed on that sample.

5.6.5.5.3 Sample monitoring

- it must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test;
- the applied crushing load must be measured and continuously monitored and recorded throughout the test;
- fluid conduits must be pressurized at 1,000 psi during the test and the pressure values must be continuously monitored and recorded. It is allowed to use a pressure supply unit to maintain the fluid conduits internal pressure within the defined range (see section 5.6.5.5.4);
- HV and LV cables electrical continuity must be continuously monitored during the test. HV conductors may be connected in series for this measurement. LV conductors may be connected in series for this measurement and
- optical-fiber cables must be subjected to continuous monitoring of their attenuation throughout the test, according to Method A specified in [2].

5.6.5.5.4 Acceptance criteria

- no sample failure at any step of the test, including verification tests, dissection appraisal and residual tests and
- fluid conduits internal pressure must be maintained during the test, with a maximum variation of ± 500 psi.

5.6.5.5.5 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- number of samples that will be used in the test and which test stages will be performed on each of them;
- sample(s) total length(s);
- drawings of the end terminations that will be mounted on the test sample(s);
- capacity curve of tension versus maximum crushing, as defined in the project documentation;
- tension-crushing pairs for the test stages as required on section 5.6.5.5.2 and

- proposed load steps within each test stage as required on section 5.6.5.5.2.

5.6.5.6 Tension and bending dynamic fatigue test

5.6.5.6.1 Objective

Evaluate the behaviour of the umbilical prototype when subjected to tensile and bending cyclic loads, combined with each other, until fatigue failure is reached.

5.6.5.6.2 Guidelines

The minimum sample length must be at least equal to 2 (two) lay lengths, considering the structural component with the longest lay length. This sample length must disregard the lengths inside the end terminations (i.e., it shall be measured between the bottom faces of the end terminations).

Prior to the execution of the umbilical prototype test itself, HV and LV cables shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3.

The umbilical prototype sample and its bend stiffener shall be assembled on a test rig with one end fixed and the other free to rotate. The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2). Then the fluid conduits shall be pressurized up to the DWP. This pressure value shall be maintained until umbilical prototype failure (see section 5.6.5.6.3).

The test is divided in 3 (three) different phases, namely Maximum Service Life Phase, Maximum Fatigue Life Phase and Damage Phase. On the Maximum Service Life Phase, AFD must be led from 0.00 to maximum allowable fatigue damage. On the Maximum Fatigue Life Phase, AFD must be led from maximum allowable fatigue damage to 0.90. Then, if fatigue failure is not reached, the test enters the Damage Phase. On the Damage Phase, AFD must be led from 0.90 until fatigue failure is reached.

MANUFACTURER must propose the number of load blocks for the test and, for each load block, the tension-angle pairs, the number of cycles and associated fatigue damage. For the Maximum Service Life Phase, the minimum number of load blocks is 2 (two) and the minimum required number of cycles is 200,000 (two hundred thousand). For the Maximum Fatigue Life Phase, the minimum number of load blocks is 4 (four) and the minimum required number of cycles is 1,000,000 (one million). The Damage Phase must have at least 1 (one) load block, and there is no requirement for a minimum number of cycles within this(these) block(s). Table 7 summarizes the requirements for the different phases. PETROBRAS emphasizes that, in every load block, the prototype sample must be subjected to tensile and bending loads; load blocks with only tensile loads are not acceptable. Additionally, the tension-angle pairs must differ from each other in the different load blocks.

Table 7 - Phase requirements for dynamic fatigue tests

Test Phase	AFD (from – to)	Minimum number of load blocks	Minimum number of cycles
Maximum Service Life	0.00 – 0.10 or 0.33	2	200,000
Maximum Fatigue Life	0.10 or 0.33 – 0.90	4	1,000,000
Damage	0.90 – fatigue failure	1	not applicable

At the end of the Maximum Service Life Phase (i.e., AFD = maximum allowable fatigue damage) and at the end of the Maximum Fatigue Life Phase (i.e., AFD = 0.90), the application of dynamic loads must be stopped and the functional components shall be subjected to the verification tests specified on section 5.6.3 except the voltage and partial discharge tests on HV cables (section 5.6.3.2). There is no requirement to perform verification tests after fatigue failure is reached.

Test frequency must not exceed 1.0 Hz, with a recommended value of 0.2 Hz.

There shall be provided means to monitor and identify the sample failure, especially when it is related to an armour failure. In the course of the test, it is a MANUFACTURER's decision when dynamic loading must stop and the prototype sample be disassembled from the test rig.

Lastly the sample shall be dissected following the guidelines stated on section 5.6.6.

5.6.5.6.3 Sample monitoring

- It must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test;
- the applied angle must be continuously monitored and recorded throughout the test;
- the number of cycles must be recorded throughout the test;
- fluid conduits must be pressurized at DWP during the test and the pressure values must be continuously monitored and recorded. It is allowed to use a pressure supply unit to maintain the fluid conduits internal pressure within the defined range (see section 5.6.5.6.4);
- HV and LV cables electrical continuity must be continuously monitored during the test. HV conductors may be connected in series for this measurement. LV conductors may be connected in series for this measurement and
- optical-fiber cables must be subjected to continuous monitoring of their attenuation throughout the test, according to Method A specified in [2].

5.6.5.6.4 Acceptance criteria

- no sample failure (including verification tests on the functional components) during Maximum Service Life and Maximum Fatigue Life phases and
- fluid conduits internal pressure must be maintained during the test, with a maximum variation of ± 500 psi.

5.6.5.6.5 Considerations

In order to accelerate the test execution, it is allowed to adopt fatigue mean curves for the load blocks on the Damage Phase, i.e., only for AFD > 1.00.

5.6.5.6.6 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- drawings of the end terminations that will be mounted on the test sample;

- load blocks as required on section 5.6.5.6.2. It shall be clearly stated the number of load blocks, the tension-angle pairs within these blocks and the associated fatigue damage for both mean and design fatigue curves for all umbilical components.

5.6.5.7 Tension-to-tension dynamic fatigue test

5.6.5.7.1 Objective

Evaluate the behaviour of the umbilical prototype when subjected to pure tensile cyclic loads until fatigue failure is reached.

5.6.5.7.2 Guidelines

The minimum sample length must be at least equal to 2 (two) lay lengths, considering the structural component with the longest lay length. This sample length must disregard the lengths inside the end terminations (i.e., it shall be measured between the bottom faces of the end terminations).

Prior to the execution of the umbilical prototype test itself, HV and LV cables shall be subjected to the verification tests specified on sections 5.6.3.2 and 5.6.3.3.

The umbilical prototype sample shall be assembled on a test rig with one end fixed and the other free to rotate. The tensile load shall be slowly applied until it reaches the minimum value enough to keep the sample at a stable straight position. This preload tension must be recorded and informed on the Qualification Report (section 5.7.2). Then the fluid conduits shall be pressurized up to the DWP. This pressure value must be maintained until umbilical prototype failure (see section 5.6.5.7.3).

The test is divided in 3 (three) different phases, namely Maximum Service Life Phase, Maximum Fatigue Life Phase and Damage Phase. On the Maximum Service Life Phase, AFD must be led from 0.00 to maximum allowable fatigue damage. On the Maximum Fatigue Life Phase, AFD must be led from maximum allowable fatigue damage to 0.90. Then, if fatigue failure is not reached, the test enters the Damage Phase. On the Damage Phase, AFD must be led from 1.00 until fatigue failure is reached.

MANUFACTURER must propose the number of load blocks for the test and, for each load block, the tension values (minimum and maximum), the number of cycles and associated fatigue damage. For the Maximum Service Life Phase, the minimum number of load blocks is 2 (two) and the minimum required number of cycles is 200,000 (two hundred thousand). For the Maximum Fatigue Life Phase, the minimum number of load blocks is 4 (four) and the minimum required number of cycles is 1,000,000 (one million). The Damage Phase must have at least 1 (one) load block, and there is no requirement for a minimum number of cycles within this(these) block(s). Table 7 summarizes the requirements for the different phases.

At the end of the Maximum Service Life Phase (i.e., AFD = maximum allowable fatigue damage) and at the end of the Maximum Fatigue Life Phase (i.e., AFD = 0.90), the application of dynamic loads must be stopped and the functional components shall be subjected to the verification tests specified on section 5.6.3 except the voltage and partial discharge tests on HV cables (section 5.6.3.2). There is no requirement to perform verification tests after fatigue failure is reached.

There shall be provided means to monitor and identify the sample failure, especially when it is related to an armour failure. In the course of the test, it is a MANUFACTURER's decision when dynamic loading must stop and the prototype sample be disassembled from the test rig.

Lastly the sample shall be dissected following the guidelines stated on section 5.6.6.

5.6.5.7.3 Sample monitoring

- It must be adopted a direct way of measuring the applied tension and continuously monitor and record it throughout the test;
- the number of cycles must be recorded throughout the test;
- fluid conduits must be pressurized at DWP during the test and the pressure values must be continuously monitored and recorded. It is allowed to use a pressure supply unit to maintain the fluid conduits internal pressure within the defined range (see section 5.6.5.7.4);
- HV and LV cables electrical continuity must be continuously monitored during the test. HV conductors may be connected in series for this measurement. LV conductors may be connected in series for this measurement and
- optical-fiber cables must be subjected to continuous monitoring of their attenuation throughout the test, according to Method A specified in [2].

5.6.5.7.4 Acceptance criteria

- no sample failure (including verification tests on the functional components) during Maximum Service Life and Maximum Fatigue Life phases and
- fluid conduits internal pressure must be maintained during the test, with a maximum variation of ± 500 psi.

5.6.5.7.5 Considerations

In order to accelerate the test execution, it is allowed to adopt fatigue mean curves for the load blocks on the Damage Phase, i.e., only for AFD > 1.00.

5.6.5.7.6 Minimum required information on the Qualification Plan

- respective test procedure (reference to its coding number);
- longest lay length for a structural component within the umbilical structure;
- total sample length;
- drawings of the end terminations that will be mounted on the test sample;
- load blocks as required on section 5.6.5.7.2. It shall be clearly stated the number of load blocks, the tension pairs within these blocks and the associated fatigue damage for both mean and design fatigue curves for all umbilical components.

5.6.6 Samples dissection

After umbilical prototype qualification tests, the samples shall proceed to dissection – except for the axial stiffness and bending stiffness tests. For the maximum tensile load, torsion balance and crush tests, the objective when dissecting the samples is to look for unpredicted failures in the umbilical components, since these are non-destructive tests. On the other hand, for the samples from the dynamic fatigue tests, dissection aims to verify if the predicted failure mode actually occurred.

Care must be taken when disassembling the samples from the test rigs, in order to not cause damages that are not related to the test loads and may lead to a mistaken evaluation. The prototype samples must be fully inspected, i.e., the umbilical body, the end terminations and the bend stiffener from the tension and bending dynamic fatigue test.

Sample bodies shall be completely stripped down, allowing access to the umbilical components. For the functional components, inspection shall look for excessive wear and unexpected behaviour of these components within the umbilical bundle, unless a possible failure was detected by the monitoring system during the test (including verification tests); in such cases, dissection shall clearly define the umbilical section where the failure occurred and possibly determine the root cause for it.

Special focus must be given to the strength members of the samples, such as steel wires and fiber-reinforced rods, since these are not directly monitored during the tests. Dissection shall fully inspect these components looking for wear, deformation, buckling, cracks, rupture, and any other possible damages.

It is important to emphasize that the dissection of the umbilical body includes the sections inside the end terminations. It is allowed to cut off both extremities of the sample to make it easier to remove the end terminations and get access to the umbilical components therein. Again, special care shall be taken in order to not cause damages that are not related to the test loads and may lead to a mistaken evaluation.

The end terminations shall be inspected too, including their outer sheath locking system. The product applied to anchor the strength members – usually resin – shall be inspected looking specially for voids and other defects that may happened during material injection inside the end terminations.

The bend stiffener from the tension and bending dynamic fatigue test shall be disassembled from the umbilical sample and its inner and outer surfaces must be inspected looking for wear, cracks, or any other damages. Before removing the sample from the test rig, the neutral and/or the bending plane(s) must be marked on the outer sheath for investigation of the sample failure. After disassembling the bend stiffener, marking some other distinguished sections on the outer sheath may also help during the failure investigation, such as the end of the metallic insert, the beginning and the end of the tapered region, and the stiffener end.

NOTE: in some cases, the end of the metallic insert is coincident with the beginning of the tapered region and/or the end of the tapered region is coincident with the stiffener end.

All relevant observations made during dissection must be documented and presented on the Qualification Report (section 5.7.2).

5.7 Qualification Report

The Qualification Report gathers the results of all the qualification tests performed on a prototype and compares them to the respective acceptance criteria defined on this specification and documents referenced herein.

Sections 5.7.1 and 5.7.2 detail the minimum required information on a Qualification Report, either for a functional component or a subsea umbilical prototype qualification.

5.7.1 Functional component prototype Qualification Report

- functional component drawing and data sheet;
- respective test procedures (reference to their coding numbers);
- test results with acceptance criteria (when applicable) and
- all comments made by the IVA during the qualification process, including the Qualification Report.

5.7.2 Subsea umbilical prototype Qualification Report

Every subsea umbilical prototype qualification test is followed by the dispatch of a test report, to be sent to PETROBRAS as soon as possible, compiling all information relative to the specific test. The objective of the subsea umbilical prototype Qualification Report is to gather the information from all subsea umbilical qualification tests in one single document.

For any subsea umbilical, at least the following information must be on the Qualification Report:

- subsea umbilical drawing and data sheet;
- reference to the coding numbers of the Qualification Reports of the functional components within the umbilical bundle;
- all comments made by the IVA during the qualification process, including the Qualification Report.

Additionally, sections from 5.7.2.1 to 5.7.2.7 detail the minimum required information on the Qualification Report for each umbilical prototype qualification test.

5.7.2.1 Maximum tensile load test

- respective test procedure (reference to its coding number);
- results from the functional components verification tests performed before the umbilical qualification test, with acceptance criteria (when applicable);
- adopted preload tension value;
- evidence of the sample monitoring, with acceptance criteria;
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2) were followed, including hold time durations;
- results from the functional components verification and residual tests performed after the umbilical qualification test, with acceptance criteria (when applicable) and
- dissection appraisal

5.7.2.2 Torsion balance test

- respective test procedure (reference to its coding number);
- results from the functional components verification tests performed before the umbilical qualification test, with acceptance criteria (when applicable);
- adopted preload tension value;
- evidence of the sample monitoring, with acceptance criteria;
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2**Erro! Fonte de referência não encontrada.**) were followed, including hold time durations;
- sample rotation values in all load blocks, with acceptance criteria according to Table 5;
- results from the functional components verification and residual tests performed after the umbilical qualification test, with acceptance criteria (when applicable) and
- dissection appraisal

NOTE: if the torsion balance test was performed in combination with the maximum tensile load test, the minimum information required on sections 5.7.2.1 and 5.7.2.2 may be presented together on the Qualification Report.

5.7.2.3 Axial stiffness test

- respective test procedure (reference to its coding number);
- adopted preload tension value;
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2) were followed and
- theoretical and the experimental axial stiffnesses presented in a graphical form (Tension x Displacement).

NOTE: if the axial stiffness test was performed in combination with the torsion balance test, the minimum information required on sections 5.7.2.2 and 5.7.2.3 may be presented together on the Qualification Report.

5.7.2.4 Bending stiffness test

- respective test procedure (reference to its coding number);
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2) were followed and
- theoretical and the experimental bending stiffnesses presented in a graphical form (Moment x Curvature).

5.7.2.5 Crush test

- respective test procedure (reference to its coding number);
- results from the functional components verification tests performed before the umbilical qualification test, with acceptance criteria (when applicable);
- adopted preload tension value;
- evidence of the sample monitoring, with acceptance criteria;
- evidence that the tension-crushing pairs proposed on the Qualification Plan (section 5.6.2) were followed, including the time during which the loads were applied;
- results from the functional components verification and residual tests performed after the umbilical qualification test, with acceptance criteria (when applicable) and
- dissection appraisal

5.7.2.6 Tension and bending dynamic fatigue test

- respective test procedure (reference to its coding number);
- results from the functional components verification tests performed before the umbilical qualification test, with acceptance criteria (when applicable);
- adopted preload tension value;
- evidence of the sample monitoring, with acceptance criteria;
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2) were followed;

- results from the functional components verification tests performed during the umbilical qualification test – at hold points defined in 5.6.5.6 – with acceptance criteria (when applicable) and
- dissection appraisal

5.7.2.7 Tension-to-tension dynamic fatigue test

- respective test procedure (reference to its coding number);
- results from the functional components verification tests performed before the umbilical qualification test, with acceptance criteria (when applicable);
- adopted preload tension value;
- evidence of the sample monitoring, with acceptance criteria;
- evidence that the load blocks proposed on the Qualification Plan (section 5.6.2) were followed;
- results from the functional components verification tests performed during the umbilical qualification test – at hold points defined in 5.6.5.7 – with acceptance criteria (when applicable) and
- dissection appraisal

5.8 Qualification certificate

As stated on section 5.2, if the qualification program is successfully accomplished, the IVA must issue a certificate testifying that the prototype fits the requirements of this specification and the documents referenced herein.

PETROBRAS will issue its own certificate for internal control, referencing the IVA certificate. It may be made available to MANUFACTURER upon request.

Annex A

Design Methodology Validation

A.1 Objective

The validation of a design methodology aims to establish the range and application limits to which it applies, demonstrating that, relative to the relevant failure modes and mechanisms, it can reliably predict the loads and conditions that the product will be subjected to and their effects on it. The design methodology validation process is applicable for both the functional components and the completed subsea umbilical.

Depending on the established range of application, a validated design methodology can reduce (or even eliminate) the scope of qualification tests on future prototypes.

A.2 Design methodology review

If MANUFACTURER intends to validate a design methodology, this process shall be followed by PETROBRAS and an IVA to be contracted by MANUFACTURER. Together they will review, evaluate and verify all aspects relative to the design methodologies under validation.

The IVA shall establish the range and application limits for each design methodology and shall verify that the manufacturing and quality assurance processes are controlled in such a way that the design requirements are met within this range. The IVA shall have complete knowledge of all packages of MANUFACTURER's methodologies and criteria. A design methodology validation shall cover the validation of methods, procedures and tools adopted by MANUFACTURER at least for:

a) Functional component design (sequence of layers, sizing, material selection etc.) and the definition of its properties (burst capacity of hoses, collapse resistance of tubes, stress/strain limit of copper conductors, attenuation of optical-fiber cables etc.);

b) Subsea umbilical design (cross-sectional arrangement, lay-up, sizing, material selection etc.) and the definition of its properties [axial, bending and torsional stiffnesses, umbilical weight (fluid conduits empty or full, in air or in water, interstices flooded or not), umbilical capacity curves (tension x curvature, tension x crushing), structural damping etc.];

c) Global analysis (static and dynamic global analysis, extreme-load, fatigue-load and installation, determination of imposed loads, etc);

d) Structural analysis (determination of stresses and strains on umbilical components, deformation and twist on the subsea umbilical, contact pressures, friction factors etc.);

e) Service life analysis (fatigue, corrosion-fatigue, corrosion, ageing etc.);

f) Interference analysis (assessment of minimum distance to neighbouring risers, umbilicals and mooring lines);

g) On-bottom stability analysis (assessment of the stability of umbilicals in static service due to environmental loads);

h) Electrical system analysis (assessment of the electrical system performance, especially to establish the levels of induced voltages between multiple HV power circuits, between HV power circuits and any LV power/signal cables and between HV power circuits and any other electrically conductive materials within the umbilical);

i) Thermal analysis (assessment of the temperature distribution throughout the umbilical cross-section, especially when HV cables are in the bundle);

j) Design of end termination (end termination body, anchoring system, outer sheath locking system etc.);

k) Design of bend stiffener (structural frame and body, prediction of stresses and strains, fatigue life etc.);

l) Design of buoyancy modules (structural frame, clamping system, loss of buoyancy over time etc.).

m) Functional component and/or subsea umbilical manufacturing and assembling methods, including control of processes, acquisition and treatment of the manufacturing data;

n) Prototype development and qualification, including evaluation of experimental data and representativeness of samples and test procedures;

o) Evidence of the qualification of MANUFACTURER's suppliers (i.e. sub-vendors) and the quality control process of their products.

MANUFACTURER shall demonstrate that its manufacturing and assembling methods are controlled in such a way that the functional component and/or subsea umbilical calculated properties will be repeatedly achieved in different production batches.

MANUFACTURER shall perform tests in small, medium and/or full-scale samples to demonstrate that the predictions of its design methodology are in accordance with test results. A design methodology validation shall encompass, at least, the qualification tests determined on this technical specification and the documents referenced herein, but it is not restricted to these; IVA, MANUFACTURER and/or PETROBRAS may suggest new tests to verify the ability to predict the product behaviour and to validate safety factors. MANUFACTURER can present results from previous tests for a design methodology validation. However, the tests performed with this intent shall have adequate instrumentation and monitoring to allow the comparison between the predicted product behaviour and the measured results, as well as to identify possible local effects.

MANUFACTURER shall provide evidence of the robustness of its quality control process over the functional components or subsea umbilicals manufactured on its own plants and especially over the sub-vendors, either for raw material (thermoplastics, synthetic fibers etc.) or completed components (metallic tubes, electric cables etc.).

PETROBRAS role in a design methodology review is to guarantee that it will be based on sound engineering methods following the requirements of this specification and to pursuit an isonomic treatment between processes involving different manufacturers and/or different independent verification agents.

A design methodology will be considered validated when MANUFACTURER demonstrates that it is capable of correctly predicting the product behaviour (globally and locally) in a way that the associated design rules and criteria provide appropriate safety margins. This includes the validation of the safety factors adopted in the design.

If, at any time, failure analysis demonstrates that the design methodology or the design tools have failed to predict the product behaviour correctly, the design methodology concerning that specific failure mode shall be considered non-validated. The relative design methodology and tools shall go through the validation process again, considering the new data and shall only be considered validated after the proper corrections are implemented.

A.3 Design parameters

The validation of a design methodology leads to the definition of ranges of application for the design parameters. Each design parameter has a specific validated range depending on how the design methodology addresses the applicable failure modes. Table 8 presents a tentative list of design parameters and failure modes that PETROBRAS

understands as relevant for a possible definition of validated ranges for the functional components and the completed subsea umbilical.

Table 8 - Tentative list of relevant design parameters and failure modes

Product	Design parameters	Failure Modes
Electric cables	• Layers dimensions (including conductor's nominal cross-sectional area) • Layers materials and materials supplier • Number of cores in the LV cables (pairs or quads) • Number of cables in a sub-bundle (e.g. three HV cable cores, four LV cable quads etc.) • External pressure (usually related to the water depth) • Cable supplier • Manufacturing process (equipment and/or manufacturing plant)	• Buckling • Strain • Deformation • Fatigue • Permeability to water • Poor splice properties • Wear due to abrasion/friction • Wear due to UV radiation
Metallic tubes	• Inner diameter • Wall thickness • Design pressure • External pressure (usually related to the water depth) • Tube material • Tube supplier • Manufacturing process (equipment and/or manufacturing plant)	• Buckling • Burst • Collapse due to crushing loads • Collapse due to the water depth • Compatibility • Corrosion • Erosion • Fatigue • HISC • Ovalization • Poor welding properties • Wear due to abrasion/friction • Yielding (including temperature derating)
Optical-fiber cables	• Layers dimensions • Layers materials and materials supplier • Number of fibers • External pressure (usually related to the water depth) • Cable supplier • Manufacturing process (equipment and/or manufacturing plant)	• Bleeding and evaporation of filling compounds • Buckling • Collapse due to crushing loads • Collapse due to the water depth • Deformation • Fatigue • Permeability to water • Poor splice properties • Wear due to abrasion/friction • Wear due to UV radiation

Table 8 *(continued)*

Product	Design parameters	Failure Modes
Thermoplastic hoses	• Inner diameter • Design pressure • External pressure (usually related to the water depth) • Layers dimensions • Layers materials and materials supplier • Hose supplier • Manufacturing process (equipment and/or manufacturing plant)	• Ageing • Burst • Collapse due to crushing loads • Collapse due to the water depth • Compatibility (particulate generation, especially oligomers) • Corrosion of the carcass (for HCR hoses) • Dimensional changes (in length and volumetric) • Ovalization • Overbending • Permeability • Wear due to abrasion/friction • Wear due to UV radiation
Subsea umbilicals	• Number of components (functional and/or structural) • Dimensions of components, functional and/or structural (e.g. ID, WT, cross-sectional area etc.) • Layers dimensions (inner sheath(s), armouring and outer sheath) • Design pressure of fluid conduits • External pressure (usually related to the water depth) • Manufacturing process (equipment and/or manufacturing plant)	• Global buckling • Local buckling • Clashing (interference with neighbouring risers, structures and/or subsea equipment) • Corrosion (especially for steel wires) • Deformation (including excessive torsion) • Electromagnetic interference • Fatigue • Hydrogen embrittlement (especially for the steel wires) • On-bottom instability • Poor welding properties (especially for the steel wires) • VIV • Wear due to abrasion/friction • Wear due to UV radiation • Yielding

A.4 Design Methodology Verification Report

The Design Methodology Verification Report summarizes the results of all the tests performed in order to define the range and application limits to which a design methodology is suitable. For every report validating a design methodology, the IVA shall include a list of the objective evidence used as a basis for the review, such as design reports, tests results, manufacturing trials and analyses performed by MANUFACTURER to calibrate or support that specific design methodology, manufacturing process or material.

Whether for a functional component or a subsea umbilical, at least the following information shall be on the Design Methodology Verification Report:

- the functional component or subsea umbilical under evaluation;
- respective test procedures (reference to their coding numbers);
- tests results;
- factory location and
- statement confirming that the design methodologies have been evaluated and validated through correlation tests and predicted failure modes, materials qualification has been confirmed and manufacturing processes have been assessed.

Additionally, it shall include the IVA assessment of:

- the product concepts, including their range of use;
- the design methodologies and design tools;
- the used materials;
- the manufacturing processes;
- the manufacturing plants, including specific manufacturing limitations and
- the quality control process, including sub-vendors.

The Design Methodology Verification Report shall be approved by PETROBRAS and the Design Methodology Validation Certificate (refer to section A.5) shall be issued only after this approval.

A.5 Design Methodology Validation Certificate

The IVA shall issue a certificate describing the limits and constraints of the design methodology, which shall reference the specific reports used to generate them and shall address specific details of the review and verification process. It shall also contain the detailed information that supports the ranges and limits defined in the certificate.

Design methodologies shall be considered validated for a certain range of use if the IVA has sufficient evidence that MANUFACTURER predictions are confirmed through a comprehensive set of tests and complementary analysis, taking into account the design methodology uncertainties and the capability and variations of the manufacturing processes, which shall be properly identified. The Design Methodology Validation certificate shall include a section with a clear correlation between:

- the applicable failure modes and mechanisms;
- the applicable tools for the design against each failure mode/mechanism and the valid version of these tools;
- the range of use and limitations of each tool for each relevant design parameter and
- any key remarks or comments.