INDEX OF REVISION

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	Altered where highlighted in the text.
B	References and definitions updated, qualification dossier and angular capacity test details.
C	Altered the identification of the degree of confidentiality of information to "Public" ("P"), as per guideline DI-1PBR-00337.
D	INCLUDED: references [7], [8] and [9] (receptacle drawings), in sec. 3; section 5.1 "Premises"; Section 5.2 "Key Variables"; 5.3 "Qualification Scope" (title only); Condition for the test execution (termination), sec. 7.2; Section 9 "Qualification Dossier" (minimum information and document list to be provided). ALTERED: renumbered references from ref. [2]; Scope of the full-scale fatigue test (Flexible Element), with the introduction of a second phase (test until failure). EXCLUDED: references I-ET-0000.00-0000-290-P9U-002, I-ET-0000.00-0000-970-PSQ-001 and DNVGL–SE–0745, in sec. 3. GENERAL REVISION for text clarity.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E
DATE	29/12/2017	22/02/2018	08/07/2019	12/11/2021	16/06/2023	
EXECUTION	TS8H	TS8H	TS8H	TS8H	TS8H	
CHECK	BF6I	BF6I	BF6I	TS8H	DXY4	
APPROVAL	CLZ2	CLZ2	CLZ2	CLZ2	CLZ2	

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1. INTRODUCTION

1.1. Scope of this Document

The purpose of this specification is to define the minimum technical requirements for qualification of Flexible Joints (FXJ).

For design and construction requirements for Flexible Joints, refer to references 0 and [3].

This document shall be read in conjunction with all documents listed in Section 3.

1.2. Unit of Measurements

All data shall be reported in primarily SI units; however, customary US units may also be reported for reference only.

2. DEFINITIONS AND ABBREVIATIONS

2.1. Definitions

PETROBRAS	PETRÓLEO BRASILEIRO S.A. – PETROBRAS Where referred to in this Specification, it means both the Company itself and its employees authorized to communicate with CONTRACTOR or SUPPLIER
SUPPLIER	The organization providing the Flexible Joint and/or Conical Receptacle under the Purchase Order directly to the PETROBRAS or to its CONTRACTOR for riser EPCI or FPU Contract
CONTRACTOR	The companies responsible for the engineering, procurement, construction, installation and comissioning of riser system for the Project.
PARTIES	The companies directly involved in the Flexible Joint design and fabrication, with power to propose modification over design and manufacturing aspects. By definition they are: PETROBRAS, CONTRACTOR and SUPPLIER
BID	Offer of setting a price within a riser EPCI contract process (or Flexible Joint purchase process, in direct PETROBRAS purchase)

Work	All work to be performed by the SUPPLIER under the Purchase Order, including all duties and obligations undertaken by the SUPPLIER
Flexible Element	Flexible laminated bearing moulded with interleaved layers of an elastomeric compound bonded with high strength steel reinforcements (spun plates).
Flexible Joint	Refers to the entire assembly including the upper flange or neck and the forged extension with tapered section (e.g. Fig. 1.1, of ref. [3]).
Project	Scope of activities performed by the PARTIES to design, construct and install the riser system for a specific field and host FPU.
Shall	Indicates a mandatory requirement
Should	Indicates a preferred course of action
May	Is used where alternatives are equally acceptable

2.2. Abbreviations

The following abbreviations are used on the document:

CFD	Computational Fluid Dynamic
C–Mn	Carbon–Manganese Steel (Carbon Steel)
CS	Carbon steel
FAT	Factory Acceptance Test
FE	Finite Element
FEA	Finite Elements Analysis
FPU	Floating Production Unit. In general meaning herein this specification, it is understood as the larger structure where the hang–off system in attached
FXJ	Flexible Joint
HPHT	High Pressure High Temperature
ID	Internal Diameter
OD	Outer Diameter
PO	Purchase Order
RGD	Rapid gas Decompression
SI	Système International (International System of Units)
WT	Wall Thickness

3. REFERENCES

All equipment supplied under the scope of this specification shall be in conformance to the latest editions of the design codes, standards, and PETROBRAS' documents listed hereafter in this section. In addition to these references, Project Specification shall be considered, and shall take precedence with respect to this specification and references cited herein.

Ref. n°	Document number	Title
[1]	--- (1)	Project Technical Specification
	~~--- (1)~~	~~Project Material Requisition/ Data Basis~~
[2]	--- (1)	Flexible Joint Design Data Sheet/ Data Basis
	~~I-ET-0000.00-0000-290-P9U-002~~	~~Flexible Joint and Hang Off Adaptor Specification~~
[3]	I-ET-0000.00-0000-290-P9U-003	Flexible Joint Design and Fabrication
	~~I-ET-0000.00-0000-970-PSQ-001~~	~~Procedure and Personnel Qualification and Certification~~
[4]	DNVGL–RP–F101	Submarine Pipeline Systems
	~~DNVGL-SE-0745~~	~~Verification and Certification of Submarine Pipeline~~
[5]	DNVGL–RP–A203	Technology Qualification
[6]	ASTM D471 – 06	Standard Test Method for Rubber Property – Effect of Liquids
[7]	I-DE-0000.00-0000-140-P9U-001	Conical Receptacle "Type A" – Basket Profile Dimensions
[8]	I-DE-0000.00-0000-140-P9U-002	Conical Receptacle "Type B" – Basket Profile Dimensions
[9]	I-DE-0000.00-0000-140-P9U-003	Conical Receptacle "Type C" – Basket Profile Dimensions

(1) Project reference number to be informed within a Project Document List, to be released during Riser EPCI BID phase or purchase order.

4. CONFLICT OF INFORMATION AND DOCUMENT APPROVAL

In the event of any conflict between this specification or any other specification and associated requisition forms, or with any of the applicable codes and regulations arise, written clarification shall be sought from PETROBRAS before proceeding with the Work. SUPPLIER shall provide PETROBRAS with a written request of clarification. PETROBRAS' decision shall be final regarding interpretation of requirements.

All deviations to this specification and other referenced specifications or attachments listed in this specification shall be made in writing and shall require written approval by PETROBRAS prior to the execution of the work.

The Flexible Joint shall be designed and manufactured in accordance with the regulations applicable for service offshore Brazil.

5. FLEXIBLE JOINT TECHNOLOGY QUALIFICATION

Qualification of the product for the intended service is required since:

- No track record of supply/ qualification for conditions similar to the Project is presented;
- New design, novel technology not yet qualified is offered;
- New material not used in the same conditions (mainly elastomeric compound) is used;
- Original qualification test documents are not accessible for revision;
- SUPPLIER fails to demonstrate Third Party involvement, with report or statement, which cover the content of ref. [5] or similar requirements.

SUPPLIER shall demonstrate that all materials proposed for the Flexible Joint are compatible with and qualified for the design service conditions (including design temperatures, pressures and the chemical composition of the pipeline products). It should also be taken into account any hazards of the external environment (e.g.: sea water; ozone attack, external corrosion mechanisms, marine atmosphere).

5.1. Premises

CONTRACTOR shall produce a "Qualification Dossier", summarizing the documents mentioned in the paragraph above, to be included within Project's documentation for future references. PETROBRAS will evaluate the documentation submitted by the INTERESTED PARTY and, at its discretion, determine whether the product in question can be considered as Qualified. Section 9 presents the minimum list of documents and information to be delivered to PETROBRAS.

The Qualification shall be demonstrated by either of the following ways:

i. Track record of previous qualification tests may be accepted, provided that it complies with the design described in sec. 1.3 of ref. [3], and the provisions of this Specification, and were performed under conditions that encompass those of the Project.

ii. Track record of FXJ supply may be accepted, provided that it complies with the FXJ design described in sec. 1.3 of ref. [3], and can demonstrate effective operation for at least 03 years under conditions that encompass those of the Project.

iii. New or modified design concepts, different from the description given in in sec. 1.3 of ref. [3], as well as materials type or grade or analysis/calculation methods that were not previously supplied to or assessed by PETROBRAS, or design not under conditions that encompass those of the Project, shall be qualified, as per applicable scope of this Specification, in sec. 5.2. Any design qualification shall be completed prior to the beginning of the Work.

    a. Bellow barrier shall be preferably specified for the Project. The nonuse of bellow barrier, the use of modified bellow design, or the employment of different barrier type (e.g., double elastomeric barrier), if considered, shall be qualified, per Key Variables from I to VII.

Dimensional Compatibility Assessment shall be carried out for the FXJ and PETROBRAS' Standard Receptacles of ref. [7], [8] and [9], for Project with this support. This Assessment, indicating the minimum compactible Receptacle Size per FXJ function, shall be included within the "Qualification Dossier". Dimensional incompatibilities are not acceptable.

Every test performed and the related documentation to be submitted for evaluation by PETROBRAS shall present evidence of witnessing by a third party or by a PETROBRAS inspector (own or outsourced).

Any relevant document related to product previous qualification program, declared by SUPPLIER as proof of confidence in the design, including test procedures, acceptance criteria and results shall be submitted for PETROBRAS review and comment before the beginning of the Work.

All documents related to the qualification of any new product, proposed by PETROBRAS or the other Parties for the Project, including test procedures, third-party statement, acceptance criteria and detailed qualification plan (including test program and schedule), shall be submitted to PETROBRAS for approval before the beginning of the Work.

PETROBRAS acceptance of previous qualification presented by SUPPLIER, as well as proposed qualification programs for the Project does not waive SUPPLIER and CONTRACTOR from the responsibility to deliver products perfectly fitted for the Project service, based on Project specification and any other information provided by PETROBRAS.

5.2. Key Variables

The following specific conditions of Table 1 shall be considered for qualification demonstration:

Table 1 – Key Variables.

Key Variable	Specific Conditions Requiring a New Qualification	Qualification Tests
I. Maximum overall temperature	Product previously supplied or tested at overall maximum temperature below that of Project.	Sections 6, 7.3 and 8.2
II. Maximum overall pressure	Product previously supplied or tested at overall maximum pressure below that of the Project.	Sections 6 and 7.3
III. Minimum temperature	Product previously supplied or tested for minimum temperature higher that of the Project.	Sections 6.1
IV. Maximum overall cocking angle	Product previously designed/tested for overall maximum cocking angle below that of the Project.	Section 8.1
V. Mean operating conditions	Product previously supplied or tested at both mean pressure and mean temperature below that of the Project.	Sections 6.2, 6.4, 7.1 and 7.3
VI. Material specification (elastomeric)	Change in material specification from previous test/ projects, or test results.	Sections 6, 7.1 and 7.3
VII. Design specification (Bellow)	Change in material specification, design, forming or welding process or geometry from previous test/ projects.(1)	Section 7.2
	Nonuse of bellow barrier or the employment of different barrier type.(1)	Sections 6.2, 7.1 and 7.3
VIII. Welding procedure (WoL)	Change in the welding procedure, or any of the essential variables listed in table C-2 of appendix C of ref. [4].	Section 7.4.1 and 7.4.3.2 of ref. [3]
	Consideration of the CRA layer strength contribution in design if not pre-qualified.	Section 5.3 of ref. [3]
	Absence of proper sulfide corrosion test results	Sec. 7.4.3.3 of ref. [3]
IX. NDT procedures // initial flaw size detection capability (WoL)	Change in the NDT procedure used for flaw detection and sizing in the weld overlay to a non-qualified/validated procedure.	Section 6.14 of ref. [3]
	The initial flaw height, calculated as a non-detected full circumferential flaw in ECA, is lower than the PoD 90%|95% of the qualified NDT procedure used for the volumetric inspection of the WoL.	Section 6.14 of ref. [3]

(1) Provisions of sec.5.1–iii–a shall be observed.

5.3. Qualification Scope

Material qualification, design qualification and complementary design qualification ("Extended Factory Acceptance Testing").

The following qualifications shall be performed before Flexible Joint supply:

- Elastomeric Material Testing (physical properties, fatigue curve by small scale test, ageing and chemical degradation, RGD), as per sec. 6;
- Full Scale Fatigue Test – Flexible Element, as per sec.7.1;
- Full Scale Fatigue Test – Bellow, as per sec. 7.2;
- Validation of software for strain in rubber layers analysis, as per sec. 7.3;
- Maximum Angle Capacity (if not covered by FAT rotational stiffness measurement), as per sec. 8.1;
- Thermal Mapping (when Project design temperature is closer to a qualified limit), as per sec. 8.2.

All materials used in the fabrication of the Flexible Joint shall be successfully submitted to qualification testing in accordance with accepted standards (API RP 2RD in particular) or approved SUPPLIER procedures. PETROBRAS shall have access to the material test results for verification prior to commencement of production operations.

6. ELASTOMERIC MATERIAL QUALIFICATION

Qualification tests shall be executed in order to guarantee that Flexible Joint specified and manufactured will fulfil all Project designed life requirements.

Any different elastomer compound shall be tested, according to Key Variable VI. The test samples shall be identified by lot, batch, or roll number (as applicable), compound type and test date. The results of these tests shall be considered to determine the acceptance criteria for elastomer batch validation tests required on ref. [3].

6.1. Elastomer Compound Physical Properties

Any compound shall be tested in order to verify:

- Density;
- Hardness;
- Tensile and shear strength;
- Ultimate elongation;
- Tear strength;
- Shear modulus;
- Bond strength to metallic reinforcement;
- Shear behavior under loads;
- Bulk modulus;
- Bonded compression strain;
- Lubricated compression strain;
- Resistance to degradation by ageing;
- Resistance to seawater and external pressure;
- Creep;
- Bonding between two compounds (in case of Flexible element made of 2 different rubbers);
- Thermal properties;

In case a direct contact of the elastomer with conveyed fluid is assumed, the following tests are also required:

- Sensitivity to RGD (depressurization rate, fluid, temperature, pressure, layer thickness);
- Sensitivity to hydrocarbons (including gas permeation);
- Sensitivity to other chemicals;
- Sensitivity to sand abrasion (as applicable);
- Gas permeation.

Additional tests required by API RP 2RD section 7.6.1.6 shall also be performed, where applicable.

6.2. Elastomer Fatigue Curve

SUPPLIER shall select fatigue curves obtained in conditions that closely match that of the design (mainly temperature and shear strain). This test may be waived if SUPPLIER demonstrates that the material fatigue curves were already raised for the same elastomer compound, covering the Project condition of temperature, pressure and loadings (elastomer static and dynamic shear strain).

Furthermore, at least 03 samples of material shall be tested in the project conditions for maximum loads (static condition) and cyclic loads (fatigue condition). SUPPLIER may propose results of previous test of identical elastomers for acceptance by PETROBRAS. Results from previous tests shall only be considered when the test conditions (temperature, pressure, fluid composition) are characteristic of those identified in ref. [2]. These tests shall involve simple or multiple shear specimens in which the bonding between elastomer and steel shall also be evaluated. No detachment in the bonded interface with metal is permitted.

6.3. Effects of Fluids

The effect of conveyed fluid on elastomer ultimate mechanical properties (tensile and shear strength), as well as change in mass or volume shall be tested and its effects on FXJ design shall be predicted, as per ref. [6]. These effects shall be evaluated to cover the whole temperature range expected for the project.

6.4. Ageing and Chemical Degradation

Elastomer chemical compatibility with fluids similar to Project conveyed fluids of ref. [2] shall be studied.

Measure shear modulus as a function of ageing time at temperature.

If an emersed Flexible Joint is required for a Project, as per ref. [1] and ref. [2], provisions to mitigate possible harmful effects of oxygen and gas commonly present in high concentration in industrial atmosphere, like ozone or sulphur oxides (SOx), as well as UV radiation (direct/ indirect) shall be demonstrated. If special surface coating or cover system is used, the effectiveness of such system shall be qualified.

6.5. Rapid Gas Decompression

Effects of RGD on elastomeric compounds with depressurization rate of at least 70 bars/min (tests on small scale samples after oil soaking).

Fluids compatible with Project conveyed fluids of ref. [2] shall be testes. Gas permeation test shall be included.

7. DESIGN QUALIFICATION SCOPE

The qualification proposed on this section intends to qualify the company's design methodology, and not the final product itself. Because of that, it is not necessary to perform these tests for each different FXJ, since the limits presented on each test are respected.

7.1. Flexible Element Full Scale Fatigue Testing

The objective of such a test is to validate the fatigue evaluation methodology and the selected fatigue curve for the flexible element, and to attest the robustness of the methodology (design margin from methodology predicted to actual failure). SUPPLIER shall demonstrate the predictability of the FXJ design life by executing a full-scale fatigue test of the flexible element.

The test shall be performed in at least two phases: phase 1) test up to a damage fraction equivalent to 1 (one) according to SUPPLIER design methodology, and phase 2) test up to the actual failure of the Flexible Element.

For test Phase 1, SUPPLIER shall create loading blocks, for the accelerated test condition, and apply them into a final fabricated (full-scale) flexible element. The loading blocks shall respect the following requirements:

i. Sufficient loading blocks to reach a damage fraction equivalent to 1.0 (predicted failure by the same methodology applied to the Project) shall be applied;

ii. The loading blocks shall reproduce as much as possible the same proportion of damage by fatigue source (variation of angle, axial load, pressure, etc) of the Project. Creep or stress relaxation effect on fatigue behaviour shall be considered. It is not acceptable to apply only one loading mode during the test;

iii. If necessary, the variation of axial load may be replaced by internal pressure variation.

After the test Phase 1, the Flexible Element shall be submitted to stiffness measurement (rotational and/or axial stiffness, which fits the SUPPLIER methodology), hydrostatic test and visual inspection. The acceptance criteria shall be:

iv. No significant variation in axial stiffness or less than 20% variation on rotational stiffness;

v. No exposure of internal reinforcements to the environment;

vi. No leak of test fluid.

This test shall be performed in the cases foreseen in sec. 5.2.

Afterward, for test Phase 2, SUPPLIER shall continue the full-scale fatigue test until the actual failure of the Flexible Element, given the contrary to any statement of sec. 7.1–iv, –v and –vi occur, to test the robustness of the design methodology.

After the test Phase 2, the flexible element shall be submitted to stiffness measurement (rotational and/or axial stiffness, which fits the SUPPLIER methodology), hydrostatic test, visual inspection, and dissection. The stiffness (rotational and/or axial stiffness, which fits the SUPPLIER methodology), percentage of total applied fatigue blocks with respect to the predicted (damage fraction 1.0) and visual aspect of the failure indication on the elastomer surface.

7.2. Bellow Fatigue Testing

The objective of such a test is to validate the fatigue evaluation methodology and the selected fatigue curve for the Bellow. Fatigue life shall be based upon field proven design method and validated by a full-scale testing on similar bellows design and geometry (i.e. diameters, size of the convolutions, thickness and number of metal plate layers). Test shall be carried out until Bellows failure, denoted by leaking of internal fluid/ loss of pressure.

This test shall be performed in the case foreseen in sec. 5.2 (Key Variable VII).

7.3. Flexible Element Sizing Methodology and Hiperelastic Law

In order to determine high local stress locations and the fatigue life evaluation of all components of the flexible joints, SUPPLIER shall provide a study for the non-linear behaviour of the flex element, with calibrated Rivlin parameters. Validation report or third-party verification report of the methodology shall be presented.

Third-party validation of calculation software/ methodology to size the flexible element and to predict the stiffness shall be presented.

8. EXTENDED FACTORY ACCEPTANCE TEST

8.1. Angular Capacity Test

SUPPLIER shall perform an angle capacity test, to demonstrate that the FXJ design can accommodate the Project maximum (dynamic) top angle, as per ref. [2]. The test shall be performed during the FAT (during stiffness measurement or in a dedicated test), at least for the first produced FXJ of each type.

If necessary, this test may be performed without the Bellow.

8.2. Thermal Mapping

Resultant temperature at elastomer layers, to be used to size the Flexible Element, may be given by a thermal CFD analysis or empirical relations. The CFD thermal model's input data and analysis premises or empirical relations shall be presented to PETROBRAS. Bore fluid and seawater temperatures, as well as heat transfer coefficients are presented in ref. [2], and shall be considered in a conservative way in the model.

In case calculated temperature profile, in any elastomer layer, results closer to an upper bound technological limit of the elastomeric material selected for any load case, SUPPLIER shall specify and execute a full-scale thermal mapping of the assembled Flexible Joint to confirm that the predicted temperature profile at the elastomer. At least the temperature of the Flexible Element nearest to the Extension (both for the first and the last layer), and of the bore and external mean shall be measured.

NOTE: SUPPLIER should demonstrate that no creep or other harmful effect to the elastomer layers will be anticipated as a result of the temperature derived from the CFD thermal analysis with or without the use of a thermal barrier. In this case, the thermal mapping test can be waived.

9. QUALIFICATION DOSSIER

The Qualification dossier shall contain the following reports and information:

i. Track record of supply and qualification, highlighting the TRL or operation duration to Project date.

   a. Provide a summary of the operating conditions of the previously supplied/ qualified FXJ, following sec. 5.1–i, –ii and –iii: maximum/mean operating pressure and temperature, minimum temperature and maximum overall cocking angle, correlating them with the scenarios of Project, as per ref. [2]. Include for information on the summary: ID/ OD, function, hydrostatic pressure, bellows (yes/no), thermal barrier (yes/no) and Inconel cladding in the Extension (yes/no);

ii. Evaluation table of the Key Variables listed in sec. 5.2 by Project conditions of ref. [2], stating which conditions may be require further qualification, or justification for any requested test waiver, whether applicable.

iii. Qualification Summary of the tests related in sec. 6, sec. 7 and sec. 8 (this last if applicable), with results and third-party statement or witness records.

iv. Statement on Compatibility with Project's Receptacle, if present for the Project.