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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
H	INCLUDED: Support–Tube as another possibility for Flexible Joint installation Hang–off, sec. 1.3 and Table 5.1; Definition for "cut–back", "Hang–off", "HOA" and "Support–Tube", sec. 2.1; Acronym for FMECA, sec. 2.2; References [3] (Project's Material Requirements) and [6] (HOA spec.) in sec. 3; Requirements for ALS3 tension–angle definition, in line with [8], load case reduction and mention to temporary extreme flow condition, sec. 6.5.1.1; Thermal assessment of the overall minimum temperature, for operating and temporary flow conditions at elastomer, sec. 6.5.1.3; Mention to a FMECA report to be issued, sec 6.5.4 and sec. 10.4; Mention to a Inspection and Maintenance Manual to be issued, sec. 6.9, 6.10 and 10.5; ALTERED: Renumbered references from ref. [3] in sec. 3 and along the document; Titles of ref. [2] and [3] in Project's reference list, sec. 3.1; Term "optional" to "optative" (supplied items) and note for confirmation of supply, Table 5.1; Id. of the Load Combinations to ULS4, ALS5 and ALS6, Table 6.1; EXCLUDED: All Receptacle requirements along the text (where indicated); References DNVGL–OS–C401, API RP 2A-WSD and ASTM A703M, sec. 3; Requirement for casting, sec. 7.4.3; "Project Management" section 10.7 (entirety). GENERAL REVISION of the text for clarity.
J	INCLUDED: Project reference [8] "Caracterização dos Fluidos Deslocados", sec. 3; Section 6.4.1.2.1 "Steady State Flow Fatigue Loading Parcel", explaining how to combine the maximum operating pressure and temperature, as informed in ref. [8], for fatigue analysis ALTERED: The title of this specification; Renumbered all the references from ref. [8]; Maximum tension vs angle combination, and internal fluid form of combination for strength analysis, in line with ref. [8], sec. 6.4.1.1; Input thermal properties data set for the conveyed fluids, sec. 6.4.1.3. EXCLUDED: remaining metions to receptacles design and fabrication requirements.
K	INCLUDED: Description for "optative item" in Definitions, sec. 2.1; abbreviations "Hs", "Tp" and "WETS", sec. 2.2; References [8] (Metocean spec), [21] (high-strength fastener spec in English), [23] (Mock-up for HOA drawing) and [27] (DNV-ST-F201); Mock-up for HOA, rubber protectant paint and protective shrould for FXJ WETS, in Scope of Supply, sec. 5.1 and 5.2; Design requirements for HOA Flexible Joints, sec. 6.1; Dimensional requirements for the annular gap for Receptacle Flexible Joints, sec. 6.3; New subsections for section 6.4.1, for better idea organization purpose; Allowed case reduction/ modification for load combination ULS1 (Temporary 1, hydrotest) and ULS3 (Maximum Operating); sec. 6.4.1.2.1; Additional strength verifications for *Bellows*; sec. 6.4.1.2.2; Complementary analyzes requirements (Body overturning, Hybernation, Pre-deployment/ WETS/ recovery and bolting), sec. 6.4.1.5; Rotational stiffness requirements, sec. 6.7; Provisions for the periodic application of a protective painting over the exposed surface of the rubber during extended atmospheric storage period, for maintenance purpose, sec. 6.8; Assessment for pig passage angle, geometry and testing, sec. 6.10; Pigging passage test in FAT, sec. 9.2.2; Conditions related to NCR issual, sec. 9.2.1 to 9.2.6; Calibration certificate for FAT requirement, sec. 9.4; Mock-up drawing and minimum information and temporary devices views (locking system, lay daown tool and protective shrould), sec. 10.6; FXJ individual product tagging formation and location, to allow easier identification of the FXJs, sec. 10.7.1. ALTERED: Schematic image for HOA in System Description, Figure 1.2; Numbering of all references from [9]; Document codes of references [20] (Weld and NDT Spec) and [25] (Alternative Flaw Acceptance Criteria Spec); Term "pre-abandonment" to "pre-deployment on seabed"; Top reference for elevation "A" at flange raised face instead of the flange tab, sec. 6.3; Numbering of sections 6.4.1.4 and 6.4.2 to 6.14; Corrosion protection requirements for CRA overlay on flange face, and tie-in bolt electrical continuity, sec. 6.13; Some rotational stiffness measurement requirements in FAT, sec. 9.2.1; Inclination of the *Extension* during hydrotest (FAT) now may be considered only on the FoaK FXJ, sec. 9.2.3; Electrical continuity criteria for FAT, sec. 9.2.6; FXJ drawing minimum information, with tagging and Extension profile detail scheme drawing, sec. 10.6. EXCLUDED: Reference [21] (high-strength fastener spec in Portuguese); Mention to exceptions to CVN requirements, sec. 8.4. GENERAL REVISION of the text for clarity.

	REV. H	REV. J	REV. K						
DATE	07/05/2021	26/04/2023	26/05/2023						
PROJECT	EISE/EDR	EDD/EDR	EDD/EDR						
EXECUTION	TS8H	TS8H	TS8H						
CHECK	CWDO	BF6J	DXY4						
APPROVAL	CLZ2	CLZ2	CLZ2						

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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	Original.
A	Altered where highlighted in the text.
B	Table 5.1 updated.
C	Updated requirements to adhere to revised DNVGL standards of [23] and [24]. Section7.4.4: added provisions of [20], [21] and [43]; revised requirements for final machined surface, pickling and corrosion test; added requirements for clad layer thickness measurement; deleted ferroxil test for iron content. For welding of porch structure: changed requirement to ref. [25]. Section 6.4: revised requirement on flange elevation and clearance; added requirement on mock–up construction and diameter transitions. Section 6.11: added pigging requirement in case of diameter transition. Section 6.15: added provisions of [21] and initial flaw size definition for ECA; Section 8.4: revised CVN test temperature. Section 8.10: altered requirement for personnel qualification for painting, acc. To [5] and TSA operator acc. to ref [55]. Section 9.2.2: amended criteria for pressure variation.
D	Detached Project's documentation. Amended coding of the [6] to the [13]. Excluded citation for ref. [22].
E	Revised where highlighted.
F	Revised Design Loading Case Matrix. Added requirement to consider the Receptacle mounting angle tolerance in sections 6.4 Dimension, 6.5.1.1 Loading Cases and 6.7 Maximum Angular Rotation. Added requirement to consider the difference between receptacle built angle and riser top angle over the maximum angular rotation in sec. 6.7. Included notes on criterion for FAT stiffness measurement in sections 6.8 and 9.2.1. Updated the template for the standard data sheet for FXJ design in APPENDIX B. General revision of the text for clarity where highlighted.
G	Added [6], renumbered other references from this. Excluded ref. [19]; Reorganized the optional scope of supply in a new sec. 5.2. Revised design loading case matrix (Table 6.1); Amended requirements in sections 6.2.2, 6.4, 6.5.1, 6.5.5.4, 6.8, 8.5, 10.4 and 10.6; Excluded Table 8.1; Excluded section 10.10; Removed "small continuous pulsations" definition; General revision of the text for clarity where highlighted.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	
DATE	27/12/17	22/02/18	02/03/18	25/06/2018	17/08/2018	09/07/19	06/09/2019	29/07/2020	
PROJECT	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	
EXECUTION	TS8H	TS8H	BF6I	TS8H/ RVYZ/ KZ04	TS8H	TS8H	BF6I	BF6I	
CHECK	BF6I	BF6I	TS8H	BF6I/ CWF8/ PNC1	BF6J	BF6I	TS8H	TS8H	
APPROVAL	CLZ2	CLZ2	CLZ2	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 functional and technical requirements for the design, material selection, manufacture, inspection, testing and delivery of *Flexible Joints* to connect rigid risers to the FPU Hang–off, as defined in sec. 2.1.

This document shall be read in conjunction with all documents listed in Section 0.

Additional or amended functional requirements for Flexible Joint and requirements for the hang–off, and hang–off interface with FPU, can be found within the Project documentation. The project detailed scope of supply, definitions of the interface with the FPU and definition of the type of top connection should also be defined in project documentation ([1] to [6]).

1.2 PROJECT DOCUMENTATION AND RESPONSABILITIES

There are, basically, two different ways Flexible Joints can be purchased to PETROBRAS projects. The way the component will be purchased implies the responsabilities between SUPPLIER, CONTRACTOR and PETROBRAS. In both cases, the procurement will happen through a competitive process (BID).

The first alternative is PETROBRAS purchasing the component directly from the SUPPLIER. In this case, the SUPPLIERs will present technical and commercial proposals directly to PETROBRAS during the BID process, and the contract will be signed between PETROBRAS and SUPPLIER. In this case, the CONTRACTOR will be contracted in a similar process, and there will be no commercial relationship between SUPPLIER and CONTRACTOR. When this purchasing strategy is chosen, PETROBRAS is responsible for supply all the final inputs to the component design, being responsible for issuing all the Project documentation ([1] to [6]). In this case, PETROBRAS is also responsible for the interface between SUPPLIER and CONTRACTOR.

Alternativelly, PETROBRAS may choose to include the FXJ procurement in CONTRACTOR's scope (this method of contract is usually referred to as EPCI). In this case, the contractual relationships are between CONTRACTOR and SUPPLIER, and between CONTRACTOR and PETROBRAS. When this purchasing strategy is chosen, the interface between the FXJ and riser is entirely within CONTRACTOR scope. The definitive inputs for component design is a CONTRACTOR responsibility. CONTRACTOR is also responsible for issuing its own version of the documents [2] to [5], as well as a FXJ specification, to SUPPLIER, in compliance with the PETROBRAS documentation.

Its highlighted that, in this second strategy, PETROBRAS may also issue in the BID process the documents of [1] to [5] based on the results of the basic design process. These documents may be used in part or in whole as reference for preliminary sizing during the BID phase, under CONTRACTOR responsiblity. Additionally, SUPPLIER shall be aware that the riser configuration to be defined by the CONTRACTOR may not be the same configuration defined by PETROBRAS in the basic design.

The definition of the final component datasheet, with definitive interface loads, is under CONTRACTOR responsibility. PETROBRAS has no responsibility for changes in design due to differences between PETROBRAS and CONTRACTOR's datasheets.

This technical specification applies to both ways of purchasing.

Scope of supply in this technical specification is amended by Material Requisition/ Data Basis regarding definition whether it includes or not any optional parts, as per Section 5.1.

1.3 SYSTEM DESCRIPTION

The *Flexible Joint* can be seated on a *Conical Receptacle* or hung on a *Support–Tube* type through a ***Hang–off Adaptor*** (HOA), designed as per [11]. The definitions of the type(s) of *Hang–off* selected for the Project is given in [2].

The *Flexible Joint* provides decoupling of bending moments between the fixed spool in the FPU from the dynamic riser motions, whilst withstanding the riser fluid operating pressure and temperature. The *Flexible Joint* incorporates an uninterrupted, piggable bore for conveyed fluid passage and is designed to withstand riser imposed bending moment, tension, shear and fatigue loads, as well as riser line pressure and temperature while allowing for angular cocking motions during the specified Project service life.

The riser *Flexible Joint* assembly includes single ***Flexible Element*** set (alternating laminations of spherically shaped rubber pads and metal *Reinforcements*), ***Body***, a tapered ***Extension*** for welding to the riser, an ***Attached Flange*** with ***Spherical Thrust***, to avoid displacement of the *Extension* upward (and the induction of excessive shear on the elastomer), and a top connection (a standard flange, neck or connector) to the FPU rigid spool. In addition, it may include a bi-diameter ***Bellows*** (to avoid the conveyed fluid to contact the elastomer) and a ***Thermal Barrier*** internally installed in the *Extension* bore nearest the *Flexible Element*, if required by the design (to compatibilize the amount of bore temperature to reach the elastomer with its qualified limits, either for high or low temperatures).

Description of the HOA main parts is given in [11].

Figure 1.1 presents a general illustration of a *Flexible Joint* detailing its main parts, and Figure 1.2 shows the FXJ installed on the two possible Hang–off systems covered by this specification. The major elements are labelled for reference and some terminologies used in this document are introduced.

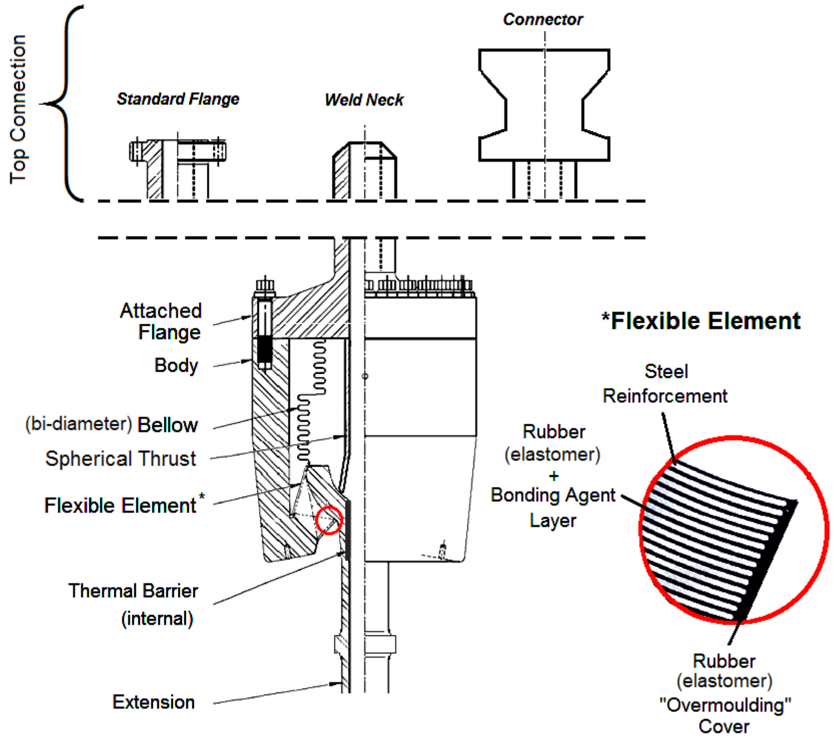

Figure 1.1 – Schematic View of the *Flexible Joint* and its Main Parts.

NOTE 1: Concept of the parts and/ or configuration depicted in Figure 1.1 may vary according to SUPPLIER design. Possible legal restriction on the use of certain part or configuration shall be observed.

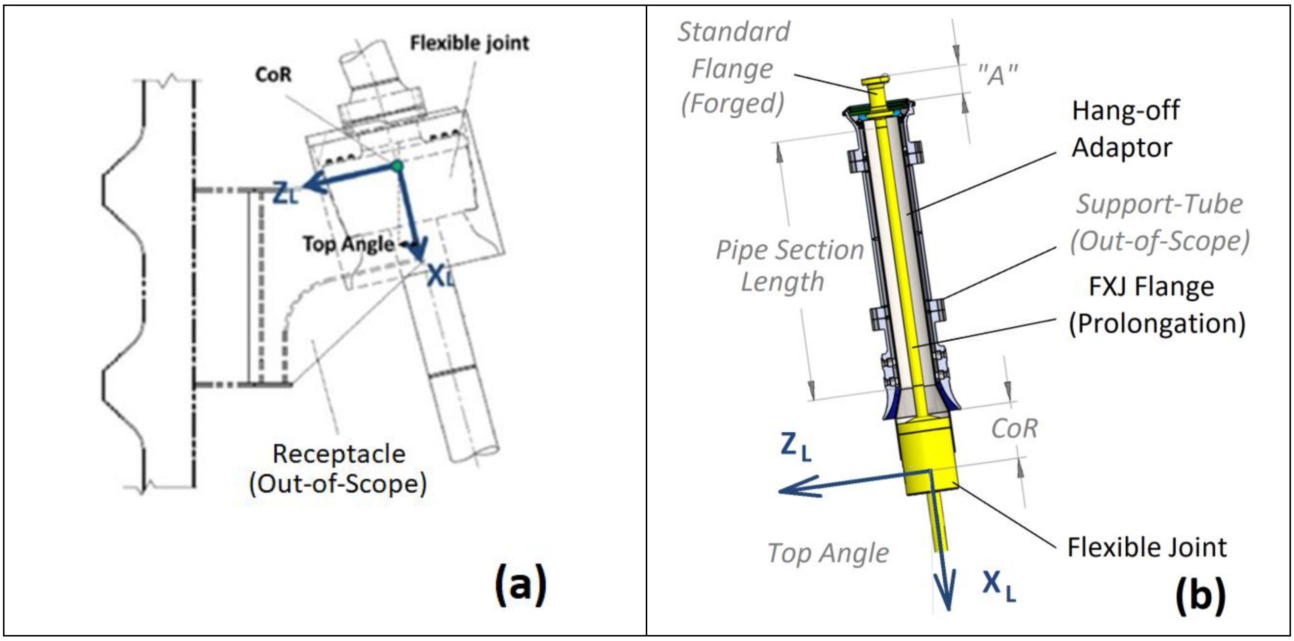

Figure 1.2 – Schematic View of the *Flexible Joint* for (a) Conical Receptacle and (b) Support–Tube. Local Coordinate System Considered for Riser Global Analysis per [18].

NOTE 2: Concept of the parts and/ or configuration depicted in Figure 1.2 may vary according to SUPPLIER design.

The function of the *Flexible Joint* is to:

- Support the riser;
- Provide an articulated interface between the FPU and the riser. This will allow for relative angular motion between the FPU and the riser, thus reducing the bending moments in the top area of the riser;
- Provide an interface between the riser and the FPU piping for fluid transportation, pressure and temperature exposure, etc;
- Allows pig to be transported between FPU piping and the riser;
- Connect riser to installation equipment (ex: pig launch receiver or pull in head) during pull–in and commissioning activities;

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 that construct the Flexible Joint and provides it under a Purchase Order directly to the PETROBRAS or through the CONTRACTOR for riser EPCI or FPU Contract
SUB–SUPPLIERS	The Party supplying materials or services to the Flexible Joint’s SUPPLIER
CONTRACTOR	The company responsible for the engineering, procurement, construction, Installation and comissioning (EPCI) of a project for riser system or for the Construction of the host FPU
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
Cutback	Uncoated area defined in terms of length at the end of the Extension or Pup Piece which is required to prevent damage to the coating system when the FXJ is welded together with the pipe sections.

EPCI	Contracting mode where the CONTRACTOR is responsible for the detailed engineering, procurement of some or all the riser components, construction, installation and commissioning of riser system.
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 from the top connection to the forged Extension with tapered section (e.g. Fig. 1.1).
Hang–off	Structure that is welded to the porch on the FPU hull and where the Flexible Joint will be hung. The Hang–off may be Conical Receptacles or Support–Tubes, and the definition the Hang–off type(s) selected for the Project is given in [2].
Hang–off Adaptor (HOA)	Tubular or thick forged device assembled onto the top of the TSJ, to interface with a Support–tube type Hang–off. Additional requirement in [11].
Optative Item	Item of supply that is not automatically included in FXJ's scope of supply for the Project. The confirmation of the inclusion of an optative item within Project Scope of Supply, becoming a mandatory item for the Project, is ascertain in ref. [2].
Project	Scope of activities performed by the PARTIES to design, construct and install the riser system for a specific field and host FPU.
(Conical) Receptacle	Steel casted or forged piece which interfaces the riser, through Body. The standard type of Conical Receptacle, if specified for the Project, is defined in [2].
Requisition	A formal written request for supply of equipment or materials
Support–Tube	Generic term that refers to the tubular type of support that requires a Hang–off Adaptor installed on top of the TSJ to interface with the support, and which can be BSN, BSMF, BSDL, RMoST and TSUDL. The type of Support–Tube, if specified for the Project, is defined in [2].
Work	All tasks to be performed by the SUPPLIER under the Purchase Order for any specific Project, including all duties and obligations undertaken by the SUPPLIER.
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 in this document:

ALS	Accidental Limit State
ASCII	American Standard Code for Information Interchange
AUT	Automatic Ultrasonic Test
Cf	Design case factor, as per [30]
CFD	Computational Fluid Dynamic
C–Mn	Carbon–Manganese Steel (Carbon Steel)
CNC	Computer Numerical Control
CoG	Centre of Gravity
CoR	Centre of Rotation
CRA	Corrosion Resistent Alloy
CS	Carbon steel
CTOD	Crack Tip Opening Displacement Test
CVN	Charpy V–Notch
DBM	Design Basis and Methodology
DC	Direct Current
DPI	Dye Penetrant Inspection
ECA	Engineering Critical Assessment
EDM	Electrical Discharge Machine
FAT	Factory Acceptance Test
FE	Finite Element
FEA	Finite Elements Analysis
FJC	Field Joint Coating
FMECA	Failure mode effects and criticality analysis
FoaK	First of a Kind
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
GA	General Assembly (Drawing)
HAZ	Heat–Affected Zone
HIC	Hydrogen Induced Crack
HPHT	High Pressure High Temperature
Hs	Wave significant height
ID	Internal Diameter
ITP	Inspection and Test Plan
L.A.S.T.	Lowest Anticipated Service Temperature
LC(s)	Load Case(s)
MPS	Manufacturing Procedure Specification

MT	Magnetic Particle Testing
NCR	Nonconformity Report
NDT(NDE)	Non-destructive Test (Non-destructive Examination)
OD	Outer Diameter
OoR	Out–of–Roundness
P/N (S/N)	Part Number (Serial Number)
pAUT	Phased Array Ultrasonic Test
PEP	Project Execution Plan
PLR	Pig Launcher and Receiver
PO	Purchase Order
PoD	Probability of Detection
QA	Quality Assurance
QAP	Quality Assurance Plan
QC	Quality Control
QHSE	Quality Health, Security and Environment
QMS	Quality Management System
QTS	Qualification Test Sample
Ra	Arithmetic Average Value of a Filtered Surface Roughness Profile
RGD	Rapid Gas Decompression
RP	Return Period
Rt	Maximum Height of the Roughness Profile (Range)
SCF	Stress Concentration Factor
SEI	Syndicat de l’Emballage Industriel (Industrial Packaging Union)
SI	Système International (International System of Units)
SLWR	Steel Lazy Wave Riser
SSC	Sulfide Stress Cracking
std	Standard Deviation
t	Wall Thickness
Tp	Wave peak period
TSA	Thermal Sprayed Aluminum
ULS	Ultimate Limit State
UNS	Unified Numbering System
UT	Ultrasonic test
UV	Ultraviolet Ray
WETS	Wet Storage
WPQT	Welding Procedure Qualification Test
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.

3.1 PROJECT'S DOCUMENTS

n°	Document number	Title
[1]	--- (1)	Project Technical Specification for Detailed Engineering
[2]	--- (1)	Project Material Requisition/ Design Basis
[3]	--- (1)	Project Material Requirements Specification
[4]	--- (1)	Project ECA Report of Flexible Joint Weld Overlay
[5]	--- (1) (2)	Project Input Data Sheet for Flexible Joint Design
[6]	--- (1)	Project Coating Assessment Specification
[7]	--- (1)	Project Metocean Data
[8]	--- (1)	Project Operational Metocean Data for Planning of Operations
[9]	--- (1)	Project Fluids and Flow Assurance Specification *("Caracterização dos Fluidos Deslocados")*

(1) Project reference number to be informed within a Project Document List, to be released during BID phase.

(2) This is the reference for the standard data sheet for Flexible Joint design, with the list of input data, constructed in accordance with main FXJ SUPPLIERS. A model of this data sheet is attached to this document in Excel format (APPENDIX B). A PETROBRAS filled version of this standard data sheet, with Project data, will be issued to CONTRACTOR or SUPPLIER during the BID phase (depending on the chosen purchasing strategy, as per sec. 1.2).

3.2 PETROBRAS'S REFERENCES

n°	Document number	Title
[10]	I-ET-0000.00-0000-290-P9U-001	Flexible Joint Qualification
[11]	I-ET-0000.00-0000-290-P9U-006	Hang–off Adaptor Specification
[12]	I-DE-0000.00-0000-140-P9U-001(3)	Conical Receptacle "Type A"
[13]	I-DE-0000.00-0000-140-P9U-002(3)	Conical Receptacle "Type B"
[14]	I-DE-0000.00-0000-140-P9U-003(3)	Conical Receptacle "Type C"
[15]	I-DE-0000.00-0000-140-P9U-004(3)	Conical Receptacle "Type A" Reduced Profile
[16]	I-DE-0000.00-0000-140-P9U-005(3)	Conical Receptacle "Type B" Reduced Profile
[17]	I-DE-0000.00-0000-140-P9U-006(3)	Conical Receptacle "Type C" Reduced Profile
[18]	I-ET-0000.00-0000-274-P9U-001	SLWR Detailed Structural Design Requirements
[19]	I-ET-0000.00-0000-970-PSQ-001	Procedure and Personnel Qualification and Certification
[20]	I-ET-0000.00-0000-210-P9U-004	Welding and NDT of Submarine Rigid Pipeline, Risers and Pipeline Components
[21]	I-ET-3000.00-1500-251-PEK-001	High-Strength Low-Alloy Steel Fasteners for Subsea Applications
	~~ET-3000.00-1500-251-PEK-002~~	~~Rastreabilidade de Fixadores de Alta Resistência para Utilização Submarina~~

[22]	I-DE-0000.00-0000-140-P56-001	Riser Top Connector Mock–up Geometry Reference
[23]	I-DE-0000.00-0000-140-P56-002	Rigid Riser Top Connector Mockup For Fitup Test - Conceptual Drawing
[24]	I-ET-0000.00-0000-219-P9U-004	CRA Weld Overlay Clad Pipe Requirements
[25]	I-ET-0000.00-0000-210-P9U-005	Alternative Flaw Acceptance Criteria of Submarine Rigid Pipeline and Riser Welds

(3) Project selected Receptacle type(s) and specific drawings(s) to be informed during BID phase.

3.3 DET NORSKE VERITAS/ GERMANISCHER LLOYD (DNVGL)

n°	Document number	Title
[26]	DNVGL–ST–F101	Submarine Pipelines Systems
[27]	DNVGL–ST–F201	Dynamic Risers
[28]	DNVGL–RP–B401	Cathodic Protection Design
[29]	REPORT NO.: 2011-3167 – REV. 02, 2013-08-20	DNV JIP Lined and Clad Pipelines, Phase 3 – Guideline for Design and Construction of Lined and Clad Pipelines

3.4 AMERICAN PETROLEUM INSTITUTE (API)

n°	Document number	Title
[30]	API RP 2RD	Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)
[31]	API Bulletin 2V	Bulletin on Design of Flat Plate Structures
[32]	API SPEC 6A	Specification for Wellhead and Christmas Tree Equipment

3.5 NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

n°	Document number	Title
[33]	NACE MR0175/ ISO 15156-2	Materials for use in H2S-containing environments in oil and gas production – Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons

3.6 AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

n°	Document number	Title
[34]	ASTM A388M	Standard Practice for Ultrasonic Examination of Steel Forgings
[35]	ASTM A694M	Standard Specification for Carbon and Alloy Steel Forgings for Pipe Flanges, Fittings, Valves, and Parts for High-Pressure Transmission Service
[36]	ASTM A707M	Standard Specification for Forged Carbon and Alloy Steel Flanges for Low-Temperature Service
[37]	ASTM E1290	Standard Test Method for Crack Tip Opening Displacement (CTOD) Fracture Toughness Measurement
[38]	ASTM E709	Standard Guide for Magnetic Particle Testing
[39]	ASTM F2338	Standard Test Method for Nondestructive Detection of Leaks in Packages by Vacuum Decay Method
[40]	ASTM G1	Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

[41]	ASTM B499	Standard Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals
[42]	ASTM E797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method

3.7 AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

n°	Document number	Title
[43]	ASME Section VIII, Division 2	ASME Boiler & Pressure Vessel Code
[44]	ASME Section IX	ASME Boiler & Pressure Vessel Code
[45]	ASME PCC 1-2010	Guidelines for Pressure Boundary Bolted Flange Joint Assembly

3.8 OTHER DOCUMENTS

n°	Document number	Title
[46]	ISO13628-4	Petroleum and natural gas industries — Design and operation of subsea production systems — Part 4: Subsea wellhead and tree equipment
[47]	EN ISO 13628-7	Petroleum and natural gas industries — Design and operation of subsea production systems — Part 7: Completion/workover riser systems
[48]	BS EN 10025 – 1	Hot rolled products of structural steels — Part 1: General technical delivery conditions
[49]	BS EN 10025 – 6	Hot rolled products of structural steels — Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition
[50]	NORSOK Standard M–501	Surface Preparation and Protective Coating

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 Join*t shall be designed and manufactured in accordance with the applicable regulations for offshore service Brazil.

5 GENERAL REQUIREMENTS

5.1 MATERIAL SUPPLIED

In general terms, it is anticipated that the supplied *Flexible Joint* will consist of the basic components listed in Table 5.1 (to be confirmed within the contractual documents).

Table 5.1 – Scope of Supply (Breakdown).

Material Description	Application	Qty per Type
Flexible Joint (NOTE 1)	Permanent Equipment	[2], [5].
Hang–off Adaptor for Support–Tube type Hang–offs (NOTE 1)	Permanent Equipment	[2]
Mock–up for Receptacle fit up test. (NOTE 2)	Construction Accessories (Optative Item)	Confirmation of supply and qty. in [2]
Mock–up for HOA fit up test. (NOTE 2)	Construction Accessories (Optative Item)	Confirmation of supply and qty. in [2]
Rubber Protectant Paint (NOTE 2)	Preservation Accessories	[2]
Samples of lower Extension forging for welding procedure qualification and CTOD (NOTE 2)	Construction Accessories	[2]
Samples of Extension forging for AUT calibration (NOTE 2)	Construction Accessories	[2]
Samples of Extension forging for fatigue test (NOTE 2)	Construction Accessories	[2]
Samples of Extension – externally coated pipe for FJC qualification test (NOTE 2)	Construction Accessories	[2]
Riser Pup Piece for riser first weld (NOTE 2)	Permanent Equipment (Optative Item)	Confirmation of supply and qty. in [2]
Centralizer piece for Flexible Joint to Receptacle interface (NOTE 2)	Permanent Equipment (Optative Item)	Defined by Supplier
Blind flange w/ seal ring, bolts and nuts (protection cap) (NOTE 2)	Handling Accessories (Optative Item)	Confirmation of supply and qty. in [2] (NOTE 2)
Handling pull-in/out device w/ seal ring, bolts and nuts (NOTE 2)	Handling Accessories (Optative Item)	Confirmation of supply and qty. in [2], [5].
Locking system/ lay down tool for lower Extension (NOTE 2)	Handling/ Installation Accessories	Confirmation of supply and qty. in [2]
Protective Bipartite Shroud for Flexible Joint WETS	Installation Acessory	Confirmation of supply and qty. in [2]
Temporary protection for installation (NOTE 2)	Installation Acessory (Optative Item)	Confirmation of supply and qty. in [2]
Monitoring devices (e.g. *Bellows* leak detection system) (NOTE 2)	Permanent Equipment (Optative Item)	Confirmation of supply and qty. in [2]
Gasket rings, studs and nuts for final topside spool assembly (NOTE 2)	Permanent Equipment (Optative Item)	Confirmation of supply and qty. in [2]
Technical assistance (during riser installation) (NOTE 2)	Onshore Daily Rates	[2]
Technical assistance (during riser installation) (NOTE 2)	Offshore Daily Rates	[2]

NOTE 1: FAT tested *Flexible Joint* assembly including *Extension*, *Body*, *Flexible Element*, top connection (including fastenings when flange), *Spherical Thrust*, bi-diameter *Bellows* (when applicable, as per Sec. 6.2.2), internal gasket, seals, Centralizer (if required, see sec. 6.3)

and anodes (if required, see sec. 6.13). HOA may be supplied separately from the Flexible joint, to allow a better handling and transportation of the set.

NOTE 2: Refer to section 5.2 for complementary scope of supply, in addition to the FXJ and HOA supplies. Optative Items defined as per sec. 2.1.

5.2 COMPLEMENTARY SCOPE OF SUPPLY

5.2.1 MOCK-UP FOR FIT-UP TEST (RECEPTACLE AND HOA)

Mock–up to be used by FPU constructor for fit up test on the yard during construction. This mock-up shall be provided with a blind flange with the same specification as the FXJ standard flange per [2] or [5] (including N_2 test port if specified). The mock up shall be able to whitstand a leak test for the topside hard pipe, with the same pressure of the riser hydrostatic test (according to [2] or [5]).

Dimensional requirements for mock-up are presented in section 6.3. Quantity of mock-ups to be supplied are defined in [2].

5.2.2 RUBBER PROTECTANT PAINT

Rubber protective paint shall be purchased, for application during FXJ atmospheric storage period, in sufficient quantity for all FXJ and reapplications if needed. See sec. 6.8 for more details. Commercial product “Age Master® No. 1” (Goodrich Aerospace) or equivalent (after PETROBRAS review) are acceptable.

5.2.3 SAMPLES OF *EXTENSION* FORGING

Samples of the lower extension forging (test rings) may be necessary to perform welding procedure qualification, AUT calibration, full scale fatigue tests and field joint coating (FJC) qualification.

Samples shall be manufactured and inspected in forging supplier with the same requirements for Extension as defined in sections 7 and 8. Test rings shall be made from the same batch as *Extension*. If weld overlay is required for *Extension* the acceptance criteria for welding qualification test rings shall meet, at least, requirements defined in ECA report [4] for first weld.

Test rings for field joint coating (FJC) qualification test does not need to fulfil forging specification. It shall fulfiill dimensional requirements and shall be submitted to the same coating procedures of the extension unit.

If welding, NDT and FJC will be performed by SUPPLIER, it is under his scope of work to define properties and quantities os samples to perform the tests.

If these acticitives will be performed by CONTRACTOR or by PETROBRAS, properties, lengths and quantities will be defined in [2].

5.2.4 RISER PUP-PIECE

Contractor may be required to provide the riser pup-piece (already welded to FXJ extension or not). The pup-piece may be used for thickness trasition between the FXJ extension and the riser, if necessary by the design. This requirement and pup-piece specification will be presented in [2].

5.2.5 CENTRALIZER PIECE FOR *FLEXIBLE JOINT* TO RECEPTACLE INTERFACE

If the outer dimension of the proposed *Body* is considerably smaller than the inner surface of the receptacle, SUPPLIER may supply a centralizer piece to properly interaface the FXJ with the Project specified Receptacle. Dimensional requirements are presented in section 6.3.

5.2.6 BLIND FLANGE W/ SEAL RING, BOLTS AND NUTS

It may be SUPPLIER's scope of supply a blind flange, its seal ring, bolts and nuts to be used as protective cover during installation. This requirement and blind flange specification will be presented in [2].

5.2.7 HANDLING PULL-IN/OUT DEVICE W/ SEAL RING, BOLTS AND NUTS

It may be SUPPLIER's scope of supply a handling and/or pull-in/out device, its seal ring, bolts and nuts to be used during installation. This requirement and device specification will be presented in [2].

5.2.8 LOCKING SYSTEM/ LAY DOWN TOOL FOR *EXTENSION*

Locking device to avoid excessive angular deflection of the *Extension* during transport, handling and installation. If WETS is required, this device shall also aim to prevent damage on the elastomer due to the exposure to external overpressure for prolonged period of time (see also Section 6.11).

This device may by required to be removed by ROV after the recovery.

Project specific requirements will be presented in [2].

5.2.9 PROTECTIVE BIPARTITE SHROUD FOR *FLEXIBLE JOINT* WETS

Rigid casing (e.g., steel plate, polymeric) to protect the FXJ *Body*, *Attached Flange* and *Top Connection* against abrasion and object drops during FXJ pre-deployment on seabed and WETS. The Shroud shall be dismountable underwater before the docking of the FXJ into the support.

5.2.10 TEMPORARY PROTECTION FOR INSTALLATION

Temporary protection to be installed on the top section of the FXJ extension ir order to protect it from impacts in FPSO structures during pull-in operations.

This protection may be required to be removed by divers or by ROV.

This requirement will be presented in [6].

5.2.11 MONITORING DEVICES (E.G. BELLOWS LEAK DETECTION SYSTEM)

Devices for monitoring specific FXJ properties. If required, properties to be monitored, device and communication specification will be presented in [2].

5.2.12 GASKET RINGS, STUDS AND NUTS FOR FINAL TOPSIDE SPOOL ASSEMBLY

It may be SUPPLIER's scope of supply the seal ring, bolts and nuts to be used in final topside spool assembly. This requirement will be presented in [2].

5.2.13 TECHNICAL ASSISTANCE (DURING RISER INSTALLATION)

SUPPLIER may be required to provide technical assistance onshore (for assembly, repair or conservation) or offshore (during riser installation). This requirement will be presented in [2].

5.3 MATERIAL SELECTION

All equipment and material manufactured and/or supplied under this Specification shall be new, of proven design, and in accordance with sound engineering fabrication and manufacturing practice. It is preferred to use existing designs or modifications that have already been qualified and accepted.

SUPPLIER shall be responsible for the selection of the materials. All materials shall be suitable for the intended service, described within Project documentation. The selected materials shall be in accordance with the relevant applicable codes, standards and specifications and be able to meet the requirements defined for the Project in [1] and [2].

The origin of all materials used in the manufacture shall be clearly identified. SUPPLIER shall submit any required material manufacturing process details, tests, examinations, inspections, and acceptance criteria for review by PETROBRAS.

The selection of the materials is a responsibility of SUPPLIER and shall be made in accordance with the:

- Relevant codes listed in this document and related Project specifications;
- Results of both the structural and the fatigue analysis;
- Maintenance-free requirement during the service life, as per Project specifications;
- Corrosion control;
- Environmental conditions (fluid medias in contact with FXJ).

The compatibility between all materials shall be checked. Materials shall not be affected by galvanic reactions and can be welded to other specified metallic pieces where necessary. In particular, the adequacy between the *Extension* and the riser materials is critical. Requirements can be found in Section 6.13 and within Project Specification.

If SUPPLIER intends to consider the weld overlay layer contributing to the strength at the *Extension*, additional requirements of the DNV Report for JIP Lined and Clad Pipelines, Phase 3 - Design and Construction of Lined and Clad Pipelines [29], and Appendix A.3 of [24], shall be fullfiled.

Additional criteria for weld overlay are presented on Section 7.4.3.

Inspection criteria shall consider as a minimum the requirements of [26].

Considering the design data, the elastomer shall be selected in order to optimise the following properties:

- Tensile and shear strengths;
- Bond strength to metallic reinforcement;
- Fatigue resistance;
- Creep resistance under permanent compression at operating temperature;
- Resistance to seawater of marine atmosphere;
- Fluid properties & composition;
- Operational pressure and temperature;
- Depressurization rates and pressure variation cycle;
- Prolonged onshore or offshore storage period, if required.

Elastomeric compound material shall be regarded as qualified for the intended Project Service, as per [10].

Additional, Project related metallic material requirements may be presented in [3].

5.4 SUPPLIER'S RESPONSIBILITY

SUPPLIER shall furnish all labor, consumables, tools, equipment and materials other than those explicitly identified as supplied by PETROBRAS required to manufacture, test and deliver. SUPPLIER shall perform all operations required for design, manufacture, inspection, testing and handling.

Nothing contained in this specification or omitted from it shall be construed as relieving the SUPPLIER of the obligation to supply the *Flexible Joints* in accordance with the functional requirements outlined herein, said to be capable of functioning properly in a riser system for the entire design period specified by PETROBRAS for the Project, without need for replacement of any of its parts.

SUPPLIER shall supply a written technical manual wherein procedures and necessary tools for storage, manipulation, and transportation of the *Flexible Joint* be detailed, with emphasis to prevent either labours from injury, or equipment and environment from damage. Such documentation shall include procedures and respective tools and consumables for inspection and maintenance during operational life of the Flexible Joint, pointing out frequencies and acceptance criteria. Herein the term maintenance shall comprise all job related to cleaning, painting or applying protective coating, repairing etc. and assembling, disassembling and/or substitution of each component of the *Flexible Joint*. Tests to be performed in order to ensure perfect assemblage shall be indicated. The documentation shall list each single part of the *Flexible Joint* and points out criteria to be observed in order to replace them when applicable.

Also, the documentation shall indicate all possible failure modes, pointing to respective technique of inspection and remedial work.

SUPPLIER shall develop a written Manufacturing Plan/Procedure, including a Quality Control/ Quality Assurance Plan (QAP), which shall be submitted to PETROBRAS for review prior to commencement of material procurement and manufacturing.

A pre-production meeting shall be held between PARTIES representatives, plus any third party inspection personnel involved. The purpose of the meeting is to ensure that all parties involved fully understand job requirements and resolve any outstanding issues prior to the beginning of the manufacturing.

PETROBRAS furnished Drawings and Specifications shall be checked by SUPPLIER immediately upon receipt, and SUPPLIER shall promptly notify PETROBRAS of any discrepancies therein.

For any requirement in question by SUPPLIER, it shall be SUPPLIER's responsibility to:

- Obtain clarification from PETROBRAS, which shall be final and binding;
- Review and resolve conflicts with PETROBRAS prior to initiation or continuation of Work.

SUPPLIER shall allow PETROBRAS and third party representatives, under SUPPLIER premises, reasonable access to all areas concerned with design, manufacture, inspection and testing during all times while Work is being performed for the Project.

SUPPLIER shall submit, or shall make available at SUPPLIER facilities, to PETROBRAS, all documents related to product qualification (including previous testing results, qualification test reports, design notes and calculations, etc.) that demonstrate the adequacy of the design to the intended service for the specific PETROBRAS' Project. In cases involving confidential, proprietary information, SUPPLIER will present the relevant documents to the designated PETROBRAS' technical representatives, under SUPPLIER premises.

SUPPLIER shall provide all reasonable facilities to PETROBRAS' inspectors, without extra charge, to satisfy the inspector that product is being manufactured in accordance with PETROBRAS's specifications. Such facilities shall include, but not limited to, office equipment and telecommunication equipment. All inspection shall be made at the place of manufacture prior to shipment. If any inspection or testing reveals details not in accordance with PETROBRAS' Specification, then SUPPLIER may demonstrate to PETROBRAS that the product still satisfies the design requirement. If SUPPLIER is unable to demonstrate this to PETROBRAS' satisfaction, then the manufacturing and/or testing procedure shall be repeated until compliance is demonstrated. All such remedial work shall be performed at SUPPLIER's cost.

In accordance with Section 10.4 (Procurement, Fabrication and Procedures Reports and Records) SUPPLIER shall furnish all data generated during the design cycle of the *Flexible Joint* including the results of the numerical analyses that will be carried out in order to fulfil the design requirements (Section 6 of the present specification) and the Project documentation response to in this specification – [1] to [5]. This documentation shall be comprised of written report, in accordance with PETROBRAS standards, and the electronic input and output files of the finite element analysis.

NOTE: Portions of the data and numerical analysis that are subject to SUPPLIER confidentiality restrictions may be omitted, provided that these are made available for discussion and review by PETROBRAS during meetings at SUPPLIER's facility, as stated above.

Equipment used for the manufacture shall be of proven design and in good operating condition.

Methods employed shall be in accordance with prudent engineering, fabrication and construction practice.

All costs including taxes are to the SUPPLIER account in undertaking the responsibilities.

Deviations from this Specification are not permitted. All proposed changes or modifications to this Specification shall be submitted in writing for PETROBRAS approval. Approved changes shall be incorporated into a revised, approved Project (purchase) specification. Disclaimers are not permitted.

5.5 UNITS OF MEASUREMENT

All data shall be reported in primarily S.I. units. Customary US units may also be reported for reference only.

6 DESIGN REQUIREMENT

6.1 GENERAL

The design adopted by SUPPLIER based on the requirements set in this document and relevant specifications shall conform to certain general design requirements stated in this section. As a minimum, the *Flexible Joint* shall meet the function as outlined in section 6.2.

SUPPLIER shall fully demonstrate the adequacy and the reliability of the *Flexible Joint* by proven methods of design. The conservatism of calculation methodology employed shall also be clearly demonstrated, and no doubt of the adequacy for the Project specific service conditions shall remain.

Whenever necessary, internationally accepted computational tools (software) shall be used to obtain accurate results that support the acceptance of the FXJ. Proprietary software may be used provided it has already been validated. PETROBRAS may ask the SUPPLIER to present evidences of this validation as per [10].

Design methodology reports and analysis results reports shall be submitted by SUPPLIER and approved by PETROBRAS before start of fabrication. Design revision cycles, including proprietary documents when necessary, can be requested by PETROBRAS under SUPPLIER premises, as per Section 5.4.

Design of the Flexible Joint System shall be in accordance with the design data in the *Flexible Joint* Design Basis [2] or Data Sheet [5], and any additional criteria necessary as a consequence of SUPPLIER proposed *Flexible Joint* operation and testing.

6.2 FLEXIBLE JOINT

As a minimum, the Flexible Joint shall be designed to meet the functional characteristics outlined below:

- The *Flexible Joint* shall accommodate the specified design conditions in terms of angular rotations, axial loads, pressures and temperatures for the required service life, as per [1] to [5];
- The *Flexible Joint* shall transfer all designed loads without presenting any of the possible failure mechanisms listed in Section 6.4.3, during the specified service life, including installation and pre-deployment on seabed (if required);
- *Flexible Joints* shall be water-tight and gas-tight in all conditions. This property has to be tested. Reference is made to Sec. 6.4.3 and 9.2.5;
- *Flexible Joint* shall be designed to be fail–safe (Sec. 6.4.3.1);

- *Flexible Joint* shall be designed to properly interface with the Project selected Receptacle design, under all load conditions. PETROBRAS standard Receptacles types are presented in [12] to [17]. Project selected Receptacle(s) is informed in Project documentation, [2] or [5];
- Corrosion allowance shall be assumed in wetted areas whenever relevant, unless CRA materials are used. Galvanic corrosion shall be regarded in the design of inner parts (see Section 6.13);
- Bolted flange connections shall be assembled and made up in accordance with a written procedure which has been qualified by test to achieve the specified bolt pretension. A general guideline on bolted flange joint assembly is given in [45];
- Bolted flange connections shall be assembled by qualified bolted-connection assemblers. Bolted connection assemblers shall be qualified by test to demonstrate that they can apply the qualified procedure and achieve the specified bolt pretension;
- When bolt coating is necessary to allow the bolt fastening, means to grant the bolt corrosion protection shall be adopted.
- Pad eyes and other lifting devices used for general handling of the equipment shall be designed in accordance with internationally accepted code (e.g. [46], 5.1.3.8);
- The tightness of the Flexible Joint bore, from the *Extension* end to the interface with Top Connection with the FPU spool (i.e., Extension including first weld and upper pipe within the *Hang-off Adaptor*), shall present reliability compactible with the welded riser pipe. The use of flanged or other mechanical connections, instead of welds, especially if occluded (inside a *Hang-off Adaptor*) shall be approved by PETROBRAS based on reliability assessment.
- Dynamic studs (*Attached Flange* or others) shall be avoided. The fixation of the FXJ onto the Hang-off Adaptor shall not count with the FXJ studs.
- The *Attached Flange* to *Body* sealing device and bolting, for a FXJ for *Hang-off Adator*, shall present a probability of failure $<10^{-4}$. Double sealing barrier, with factored probability of failure shall be used.

CONTRACTOR is responsible for defining an internationally accepted design code to guide the whole design. If any potential failure mode is not predicted on the selected code, complimentary codes shall be defined to fulfil this gap. Mixing of design codes, or mixing of requirements from different versions of the same code, shall be avoided. The design premises document shall clearly present the selected design code for each failure mode.

Flexible Joint design and material shall be regarded as qualified for the intended Project Service, as per [10], including *Flexible Element* (sec. 6.2.1), *Bellows* (sec. 6.2.2) and possible failure modes (sec. 6.4.3). Information on FXJ previous design qualifications and material selection intended to the Project shall be provided to PETROBRAS, during BID phase, as per [10], to be assessed.

The fabrication of the *Flexible Joint* shall be subject to the scrutiny, inspection, verification, qualification and documentation in accordance with SUPPLIER and industry standards as set in this specification and Project documentation;

Flexible Joint shall successfully pass the Factory Acceptance Tests set forth in this Specification (Section 9) and in the SUPPLIER's approved procedures;

6.2.1 FLEXIBLE ELEMENT

Flexible Element elastomer with supporting mechanical functions (i.e. in addition to any pressure containment) shall be protected from contact with riser high pressure hydrocarbon and other fluids content by a physical barrier to prevent:

- Gas permeation through main structural *Flexible Element* elastomer that may cause failure of the *Flexible Element* due to RGD event, and;
- Potential elastomer properties degradation by contact with un-compatible product or excessive temperature (e.g. creep in compression load).

SUPPLIER shall fully demonstrate the adequacy and the reliability of the *Flexible Element* by proven design methods. The conservatism of calculation methodology and computational tools employed shall also be clearly demonstrated, and no doubt of the adequacy for the Project specific service conditions shall remain.

An "overmoulding" cover rubber shall be provided (internal and external cover) to shield the steel reinforcements and rubber-to-metal bonds from the environmental media. The thickness of the cover rubber shall be carefully selected in order to not aggravate the effect of possible RGD (to limit formation of blister).

NOTE: For HPHT *Flexible Joint* with high gas content, SUPPLIER shall consider a beneficial combination of the design-controlled factors that potentially influence the RGD damage of rubber (i.e. proper selection of rubber compound, thickness of the rubber interlayers and thickness of the cover "overmoulding"), regardless of the use of metallic barrier, to increase reliability of the equipment in case of leak on this barrier. These assumptions shall be stated in the Design methodology and covered by qualification test, according to [10].

CONTRACTOR and SUPPLIER are requested to present all failure modes and for each, the effect of temperature ageing, chemical exposure and prior loading (typically RGD). CONTRACTOR and SUPPLIER shall clearly state for each failure mode the associated design criteria. Design criteria, defined by maximum allowable stress/strain/displacement, shall be conservatively based on:

- Test results performed on materials;
- Safety factor defined from the confidence on the tests results and influence of the following specific parameters:
  - Material ageing under operating temperature and media;
  - Material degradation due to chemical and environmental exposure;
  - Potential effect of RGD prior to the extreme loading, if the *Flexible Element* is exposed to fluid with high gas content (i.e. no *Bellows* barrier), as per sec. 6.2.1. In particular crack growth after RGD shall be considered.

SUPPLIER methodology and tools to evaluate the strain on the elastomer shall be documented and qualified according to [10].

6.2.2 BI-DIAMETER BELLOWS DESIGN

The use of nickel alloy UNS N06625 *Bellows* barrier is related to SUPPLIER design. *Bellows* barrier shall be specified for HPHT *Flexible Joint*, and when corrosive fluid or high gas content is expected. The nonuse of *Bellows* barrier for these mentioned cases, or the employment of different barrier or material shall be justified by SUPPLIER, and approved by PETROBRAS during the clarifications of the BID phase, as per [10].

The design of the *Bellows* shall be adequate for the maximum fluid velocities and pressure cycles including the operational and accidental transient flow cases (shut down, depressurization, restart, etc.).

Design calculation note shall be established considering the various combinations of loading which may exist and making provision for a differential pressure between the two faces of the convolution even when it does exist in upset condition only.

Design of the *Bellows* shall consider the following loadings:

- Extreme loading due to combination of pressure, cone angle, tension and temperature;
- Fatigue loading due to pressure fluctuation, tension and angle variation;
- Potential effect of a fast decompression, according to supplied transient profiles of pressure and temperature (though appropriate time domain finite element model).

In addition, SUPPLIER shall define the potential cause of *Bellows* failure.

SUPPLIER shall specify the following data:

- Design conditions actually considered [1];
- Material of the convolution and welded transition pieces (“flanges”);
- Geometry and thickness of the convolution;
- Any other main features deemed necessary.

Fatigue life of the *Bellows* shall be based upon field proven design method validated by small scale or full scale testing on similar *Bellows* geometry, as per [10].

Installation and fabrication (FAT) loads shall be accounted on the design.

6.3 DIMENSION

The *Flexible Joints* shall match with the dimensions of the Project selected Receptacle(s). Fabrication tolerances of the external FXJ profile and Receptacles shall be considered and interference/assembly study shall be performed.

NOTE 1: in case where the Project specified Receptacle is greater than the SUPPLIER designed FXJ Body size (leading to a big lateral gap and reduced base contact area between FXJ and Receptacle), a centralizer piece to interface the FXJ base to the Receptacle should be provided. In such case, this device shall be already delivered attached to the FXJ Body.

NOTE 2: minimum lateral (annular) gap between Body and Receptacle base shall be as indicated in ref. [22]. Maximum gap shall be defined by SUPPLYER, but limited to 10 mm.

NOTE 3: the minimum lateral (annular) gap abovementioned shall either be extended up to the top lateral contacting area between Body and Receptacle or disregarded, based on the result of the overturning analysis of sec. 6.4.1.5.1.

[1] *A table with the set of load cases considered in the design shall be provided. This set of load cases shall conservatively cover the expected angular rotations, axial loads, pressures and temperatures for the required service life, as per [1] to [4]. More than one combination should apply and SUPPLIER shall evaluate the most relevant combinations according to its design methodology.*

The design of the *Flexible Joint* shall assure free rotation of the *Extension* (without contact with the *Body* or the Receptacle) over the maximum Project specified angular deflection. Receptacle mounting angle tolerance shall be taken into account.

Riser and FPU rigid spool dimension and tolerances shall be considered to design appropriate *Flexible Joint*'s ends (*Extension* and flange neck if any), in view of welding requirements (Hi-Lo), and coating requirements (coating cut-back characteristic).

In case standard flange is specified, the flange elevation "A" above Receptacle bottom to the top connection (along FXJ centerline), and the minimum required clearance "B" beneath the flange, for subsea flange assembly, are given in [2] or [5] for each FXJ type, See Figure 6.1. SUPPLIER/ CONTRACTOR shall consider these values on the FXJ design, and inform PETROBRAS, during clarifications on BID phase, if this requirement cannot be fulfilled.

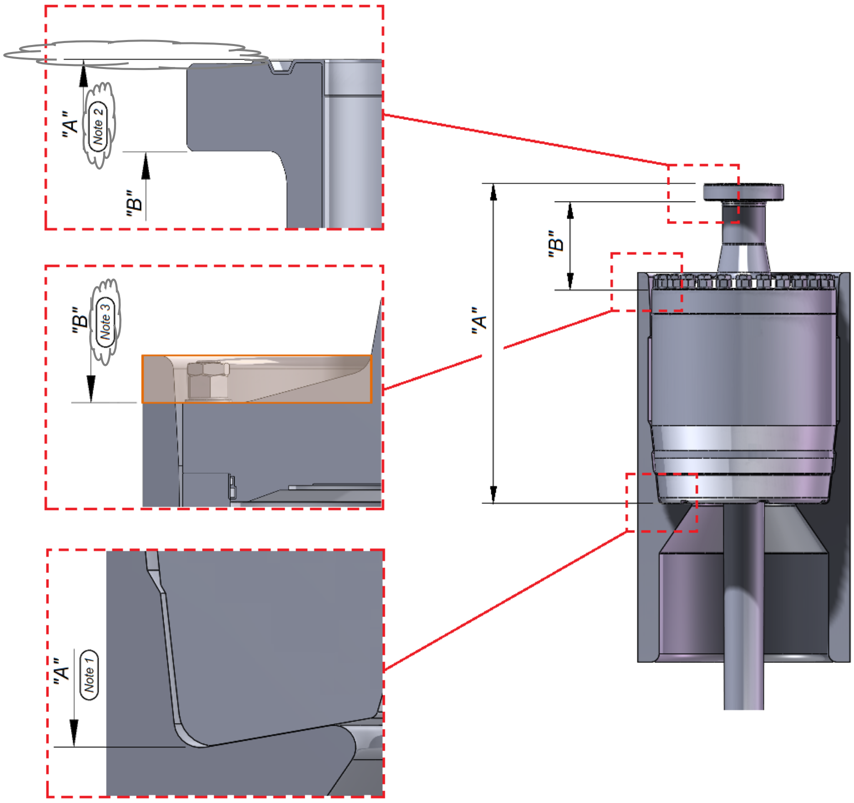

Figure 6.1 – Flange elevation "A" above Receptacle/ FXJ Body bottom, and minimum clearance "B" for subsea flange assembly/ disassembly.

NOTE 1: [Figure 6.1] the reference bottom edge for elevation "A" is the Receptacle lowest edge. The actual height of the FXJ shall take into account the height of centralizer piece assembled on FXJ bottom, if any, and the lateral gaps between *Body/* centralizer piece and the Receptacle.

NOTE 2: [Figure 6.1] the top reference for elevation "A" is the raised face of the *Standard Flange*.

NOTE 3: [Figure 6.1] the reference bottom level for minimum clearance "B" shall take into account the nearest obstruction below the bolt hole, considering a region within 3 times the flange bolt diameter about hole centerline.

For weld neck or connector, elevation to neck end or to the conector sealing face is defined in [2] or [5].

In case a mock–up for Receptacle (optative item) is required for the Project, then CONTRACTOR shall consider the drawing of [22], with mock–up reference geometry to guide its construction. Especially the specified gaps between the mock-up and the Receptacle shall be considered, to avoid any displacement of the mock-up inside the receptacle during the fit-up test and spool adjustment.

In case different internal diameters are specified for the bore (riser) and for the top connection (FPU interface) in [2] or [5], a smooth 1 : 5 slope diameter transition may be provided, either along the *Spherical Thrust* or the *Attached Flange*, if needed .

6.4 LOADS AND LOAD CONDITIONS

6.4.1 FLEXIBLE JOINT

As a minimum, the following loading parameters/conditions shall be considered and documented by SUPPLIER when designing the *Flexible Joint*:

- Internal and external pressure, including test pressure;
- External loads (e.g. cocking rotations and riser tension, installation loads, platform spool reactions, torsion);
- Cyclic (fatigue) loading;
- Thermal load effects and thermal transients.

6.4.1.1 Loading Cases

Table 6.1 indicates the minimum set of design cases to be considered in the structural design of metal and elastomeric parts of each *Flexible Joint* type for the Project. Reference [5] summarizes all these load cases. The responsebilities about the emission of the final data set for FXJ design is presented on section 1.2.

Table 6.1 – Design Loading Case Matrix for *Flexible Joint*.

Design Case	Load Category	Description	Load Combination from Riser Global Analysis, [18]	Design Loads	Cf (1) [30]
1	Temporary 1	Hydrotest	ULS1	[2], [5], [9]	1.35
2	Maximum Operating	10 years-RP(2) environmental condition	ULS3		1.0
3	Extreme 1	100 years-RP(2) environmental condition	ULS2		1.2
4	Extreme 2	Incidental pressure	ULS4		1.2
5	Extreme 3	10 years-RP(2), one mooring line broken	ALS2		1.2
6	Survival 1	100 years-RP(2), one mooring line broken	ALS1		1.5
7	Survival 2	Max. free rotation angle (FPSO heeled)	ALS3		1.5
8	Temporary 2	Installation(3)	-		1.2
9	Abnormal 1	10 years-RP(2), with loss of buoyance modules	ALS5		1.2
10	Abnormal 2	100 years-RP(2), with loss of buoyance modules	ALS4		1.2
11	Fatigue (Sec. 6.4.1.3)	Fatigue conditions (wave with associated annual current distribution)	-		N/A

(1) The Cf factor is the design case factor used to calculate allowable stresses, as per [30]. Load categorization may vary depending on choosen design code. The use of different design code and safety factors shall be approved by PETROBRAS.
(2) Return period (RP) of wind–wave occurence.
(3) Installation case to be defined by CONTRACTOR. Max. allowed installation water depth according to [5]. See also sec. 6.11.

6.4.1.2 Strength Analysis (Design Cases #1 to #10)

The selection of load cases to be analysed shall be performed in accordance with section 7.1 of [18]. One plot of “Tension x Angle” shall be presented for each load category of Table 6.1 and shall include all results from global analysis and the selected load cases in order to demonstrate that the selected ones are representative of the whole set of results. SUPPLIER should preferably combine the maximum overall tension with the maximum overall angle per load category (one case). Alternatively, if conservatism reduction is deemed necessary, several tension with associated angles covering the periphery of the plot of “Tension x Angle” may be selected, and submitted to PETROBRAS approval. Among the selected pairs, at least the load cases with the maximum angle and the maximum tension values shall be included (with the respectives associated tension and angle values).

NOTE: for load combination ALS3, the plot of “Tension x Angle” shall include the load case with maximum angle reassessed with zero offse, if this new condition brings higher top riser rotation angle, with the associated tension, as per section 5.3 of [18].

Envelope of all internal fluid combination (maximum overall pressure at maximum overall temperature) associated with each load category of Table 6.1, as informed in the blocks *“Conector de Topo”* of [9] shall be considered for strength analysis. Internal fluid condition per load category shall follow the prescribed in Table 3 of ref. [18] (i.e., hydrotest, design or incidental).

Transient (temporary) scenarios with extreme flow conditions possibly beyond normal operating condition – events generating cryogenic temperature, or higher temperature or pressure than those listed in operating conditions – shall be included in the elastomer structural verification.

The mounting angle tolerance of the Receptacle at the FPU, defined in [5], shall be considered as an additional permanent deflection of the FXJ.

De-rated material properties at design temperatures shall be established as input to the design.

6.4.1.2.1 Allowed Load Case Reductions and Modifications for Strength Analysis

In case all the loads (i.e., BOTH tension and angle) among the Load Categories "Extreme 1", "Extreme 3", "Abnormal 1" or "Abnormal 2", or between the Load Categories "Survival 1" and "Survival 2", are covered by those of any of the other case(s) associated with the same Cf, the covered Load Category(ies) may be disregarded in the analyses.

The load combination ULS1 (Temporary 1, hydrotest) and ULS3 (Maximum Operating), from riser global analysis specification [18], may be modified for the purpose of Flexible Joint design, if needed during FXJ calculation cycles to overcome potential design issues.

- For the *ad hoc* ULS1 case, sea state may be reduced considering operation metocean specification [8], or by limiting the significant wave height of annual wave set or by another procedure in line with CONTRACTOR's pre-commissioning philosophy (seastate limits). The so defined operation seastate window limit (Hs & Tp) shall naturally not be exceeded during hydrotest operation execution.
- For the *ad hoc* ULS3 case, the return period of the current load may be reduced to 1-year (i.e., wave/ wind 10yr–RP associated with 1 yr–RP current), instead of the prescribed 100yr–RP in the riser global analysis specification [18] that follows the adopted riser design code (DNV–ST–F201), closer to the expected day-to-day operating condition. Only the critical load case of the ULS3 for angle and for tension (and associated) may be re-ran, with the annual current at the same level and direction and with the same offset of the critical original cases.

6.4.1.2.2 *Bellows* Analysis

Especially for *Bellows* strength analysis, the combination of maximum pressure (design) and minimum temperature[2] and vice versa, both with the maximum cocking angle per load category shall be checked in addition to the nominal cases of Table 6.1 (normally associated with design pressure and maximum temperature). Such combinations tend to be critical for the Bellows given that they may lead to maximum axial displacement of the intermediate flange/ "Z-plate" of the *Bellows*. The choice of design pressure and temperature for each combination shall be as per the value ranges presented in design and operating fluid profiles [9].

2 Referring to the lowest operating temperature within the normal operating range, not the L.A.S.T.

6.4.1.3 Fatigue Analysis

Accepted criteria for fatigue analysis (fatigue curves) for metal parts are given in [5], and reproduced in Appendix B. Different curves shall be present to PETROBRAS approval.

The fatigue parcels for FXJ design are detailed in the following sub-sections.

6.4.1.3.1 Motion and Loading Fatigue Parcels

Fatigue damage on metal and elastomeric parts due to FPU motions and riser loads shall be calculated from time series of tension and angle at CoR for several sea states (with the associated probability of occurrence), as provided in [5]. SUPPLIER shall present and perform a procedure to count the cycles of tension and angle and to combine the resulting stresses appropriately for each *Flexible Joint* type, keeping the simultaneity of the response.

NOTE 1: During bidding phase of EPCI contracts, PETROBRAS may provide fatigue loading based on Basic Design analysis, considering wave-wind-current combination at Project location, and already include “storm conditions” and extreme current events with the probability of occurrence, to subsidize preliminarly. The responsibility for the emission of final fatigue data is according section 1.2.

NOTE 2: The data sheet issued by PETROBRAS presents, for each riser type and position, a list of all fatigue load cases sorted by most damaging contribution, as well as the number of LCs representing 99% of the damage, within [5]. CONTRACTOR should issue a similar list on its input datasheets for FXJ design. SUPPLIER may choose to perform the damage calculations with the reduced set of LCs, based on SUPPLIER own technical judgement, especially for elastomeric part.

For *Body*, *Extension* and centralizer piece fatigue damage calculation, the cyclic stress range due to the alternating rotation shall account for the increased angular stiffness of the *Flexible Element* at small angular variation.

Installation and FAT loads shall be included in *Flexible Element* (both elastomer and reinforcements), *Extension* and *Bellows* strength and fatigue damage calculation.

6.4.1.3.2 Steady State Flow Fatigue Loading Parcel

The maximum operating pressure (*“máxima pressão operacional”*) and the associated temperature (*“temperatura associada à máxima pressão operacional”*) are informed in the blocks *“Conector de Topo”* of [9] and shall be considered for fatigue analysis of the elastomer. These are tipicaly the crossed pair of maximum operating parametes for all fluid combinations.

NOTE: For certain Projects, refined stead state flow operating envelope for Production/ Service FXJ, consisting of several points (pairs) of maximum operating pressure and associated temperature, may also be informed in [2] and [9], in addition to the crossed pair. SUPPLIER may also request this data to PETROBRAS, if necessary for design. In this case, all the points informed for the operating envelope shall be analysed.

Resulting stiffness from the stead flow pressure and temperature shall be considered on the loading definition for metallic parts of sec 6.4.1.3.1.

6.4.1.3.3 Transient Flow Cycling Fatigue Loading Parcel

For elastomeric compound and *Bellows*, in addition to the riser tension and angle, installation and FAT fatigue loading, SUPPLIER shall include the damage contribution from pressure cycles for all the operational and transient flow condition detailed in [2], [5] or [9]. Schematic representations of the transient flow phases per riser function are detailed in Appendix C.

6.4.1.4 Thermal Analysis

The thermal analysis to determine the temperature on each FXJ component shall take into account the appropriate fluid combination (pressure and temperature), as per flow profiles informed within [2] and [9], per each Load Category of Table 6.1.

The seawater temperature shall be given by [7], considering i) for extreme analyses, the maximum seawater temperature (Tmax) at the level corresponding to the minimum water depth at FXJ position and ii) for fatigue analyses, the average seawater temperature (Tavg) at the level corresponding to the mean water depth at FXJ position. Linear interpolation may be used.

Thermal properties of the conveyed fluid is not informed when more than one flow condition is present, due to the many combination of the thermal parameters involved. Instead, SUPPLIER shall conservatively consider the flow velocity and maximum temperature informed in [9].

For the *Flexible Element*, at least the overall minimum and maximum temperatures (operating and transient conditions) and the temperature at the the most loaded elastomer layer per Load Category shall be reported.

6.4.1.5 Complementary Analyzes

Additional load case(s) other than those cases listed in Table 6.1 may be included, to account for any specifities of a given Project (e.g., pre–deployment on seabed/ WETS/ recovery).

The below listed complementary analyses shall be executed and reported when applicable. Other Project specific extra load case condition will also be clearly defined within Project documentation in [2] or [5].

6.4.1.5.1 Body Overturning

The stability of the Body supported on the Receptacle base for a critical loading combination shall be checked and reported. Normally, the load combination with the least riser tension associated with the maximum moment at CoR may in principle cause a tilt movement of the Body, and shall be checked. No influence of the spool shall be considered in this assessment. If any overturn tendency is confirmed, a contact with the limited gap, as per sec. 6.3 extending up to the top of the Receptacle shall be required. Preliminary overtuning assessment should be performed prior to the purchase of the forgings, to confirm the dimension.

6.4.1.5.2 Hybernation

Normally, the riser is installed into the FPU, but do not start immediately, occasionally staying idle for long period. Strength and fatigue assessments of the unpressurized *Flexible Element* shall be executed and reported, observing the adequate load category relative with the expected duration of the hybernation phase, as per sec. 4.2.1.3 of [27].

6.4.1.5.3 Pre–deployment/ WETS/ Recovery

When full pre–deployment on seabed of the riser is foreseen for the Project, the *Flexible Element* strength and fatigue resistances assessments shall be executed and reported. This assessment shall take into account the possible external overpressure associated with the very small mean temperature (sea bottom) and the loads to which the uncompressed elastomeric pads would be subjected to during the process of deployment on seabed, WETS and recovery.

6.4.1.5.4 Bolting

Specific strength analysis for the bolts of the Attached Flange and HOA (installation only) shall be executed and reported. Reference is made also to the FEA consideration of sec. 6.4.4.2. No dynamically loaded studs/ bolts in operation are allowed.

6.4.2 INTERFACE LOADS

SUPPLIER shall evaluate and report if any riser load is transmitted to the FPU spool through the Flexible Joint, and if any movement of the Top Connection is expected due to extreme load cases, especially the load cases which induce the highest cocking angle and the lowest riser tension at CoR (with associated tension and angle respectively).

Any relevant interface loads due to top flange connection (FPU spool or attached equipment if any), provided by PETROBRAS in [2] or [5], shall be used as input data for structural design of *Flexible Joint*.

6.4.3 FAILURE MODES

It shall be shown by SUPPLIER that the FXJ have the required structural safety against all predicted failure modes. A FMECA report shall be produced and included within the documentation for this purpose. As a minimum, the components shall be designed against the following possible failure modes, as appropriate:

- Plastic collapse;
- Buckling;
- Fatigue failure (high and low cycle);
- Brittle fracture;
- Excessive deflections;
- Leak-tightness;
- Corrosion and wear;
- Deformations and sudden disengagement;
- Accumulated plastic strains;
- Galling;
- Functionality;
- Rapid gas decompression (elastomer);
- Hydrogen induced stress cracking;
- Other types of environmental assisted cracking;
- Cyclic load;
- Elastomer degradation by continuous exposure to ozon and UV ray (for emerged *Flexible Joint* only).
- Elastomer degradation by continuous exposure to conveyed fluid, when applicable.

6.4.3.1 Fail–safe Design

Flexible Joint design shall be inherently fail-safe. In the event that a complete fail of the *Flexible Element* occur (i.e. disintegration of the elastomer pads), the *Extension* shall not detach from the nested steel reinforcements on the *Body*, preventing the loss of the riser.

6.4.4 FINITE ELEMENT ANALYSIS

Finite element analysis shall be used to establish structural, buckling, leak-tightness, and fatigue performance of the FXJ.

All relevant pressure, temperature and external loading conditions, including cyclic pressure, temperature and external loading where relevant, shall be considered.

Finite element analysis, or other CFD technique, may be used to estimate critical convection film boundary conditions along the interior and exterior *Flexible Joint* surfaces.

Care shall be exercised in the finite element analysis to ensure that appropriate element types, mesh refinement, element aspect ratio/distortion and boundary conditions are used.

Applied boundary conditions shall be clearly indicated in model sketches and/or in finite element plots.

Mesh sensitivity analysis shall be performed to ensure that accurate results are predicted. Mesh density convergence checks shall be presented in the reports.

The sensitivity of the calculation model and the parameters utilized in the model shall be examined.

6.4.4.1 FEA methods to evaluate plastic collapse capacity

Strength verification of the FXJ carried out by SUPPLIER shall include the evaluation of plastic collapse capacity. This check shall be aligned with the rules and procedures of selected internationally accepted codes.

There are different ways of estimating the plastic collapse capacity of a component using FEA:

- elastic analysis;
- limit analysis;
- elastic-plastic analysis.

The criteria used to determine limit or plastic loads assume defect-free, tough and ductile material behavior in addition to weld overmatch if applicable. Fracture mechanics should be considered if the above conditions are not fulfilled.

6.4.4.2 Elastic analysis

The principle used in some design codes when verifying a component by linear elastic FEA is that critical sections shall be identified and verified by linearizing the stresses across the sections. Stresses are in general decomposed into membrane, bending and peak stresses as well as categorized as primary or secondary stresses. Several FEA programs include modules that perform stress linearization which may be used by SUPPLIER.

For the FE models where the analysis is nonlinear because contact behavior is essential to simulate the interaction between different components, the method of code compliance check for linear elastic FEA may be used provided that the material model is linear elastic. In such cases, the code compliance check must be carried out at critical load steps in the non-linear analysis.

Bolt stresses shall be verified against the allowable stresses defined on the selected codes.

Primary average shear and average bearing stresses shall be calculated and compared to allowable limits. In case where the selected code does not address the shear primary average shear and average bearing stress checks, PETROBRAS shall be consulted on which methodology to be used.

In using elastic finite element analysis to calculate the FXJ plastic collapse capacities, SUPPLIER shall be aware of the following limitations of this approach:

- For components with a complex geometry and/or complex loading, the categorization of stresses as primary or secondary in the elastic analysis requires significant knowledge and judgment on the part of the analyst. Application of elastic-plastic analysis methods is recommended for cases where the categorization process can produce ambiguous results;

- The use of elastic stress analysis and stress categorization to demonstrate structural integrity for heavy thickness components (e.g. pipes with diameter to wall thickness ratio less than 10), especially around structural discontinuities, can produce non-conservative results and is not recommended;

- In cases where calculated peak stresses are above yield over a through-thickness dimension which is more than 5% of the wall thickness, linear elastic analysis can give a non-conservative result;

The structural evaluation procedures based on elastic stress analysis provide only an approximation of the protection against plastic collapse.

For the reasons listed above, the decision to perform elastic finite element analysis to calculate the FXJ plastic collapse capacities shall be reported and justified at the beginning of the Project, on the first revision of Design Premises document. Supplier shall also consider that, due to the aforementioned limitations of the elastic analysis technique, PETROBRAS may require additional limit analyses or elastic-plastic analyses of the FXJ, as per sections 6.4.4.3 and 6.4.4.4 of this Technical Specification.

6.4.4.3 Limit analysis

Limit analysis is based on elastic-perfectly plastic material model and small deformation theory. The objective of a limit analysis is to guarantee that the relevant loading is below the load that produces overall structural instability.

The limit analysis shall be carried out following the guidelines of the respective codes selected for the verification of the FXJ.

PETROBRAS may require the performance of limit analysis in addition to the elastic one when the presented results of elastic analysis were not conclusive.

6.4.4.4 Elastic-plastic analysis

Elastic-plastic analysis is generally based on material model which considers true strain hardening and large deformation theory. Some codes recommend the use of idealized stress-strain curves based on the material properties.

Elastic-plastic finite element analysis gives more realistic and accurate simulation of the stresses, strains and displacements than elastic finite element analysis and limit analysis, including local load redistribution due to yielding up to maximum load carrying capacity or resistance.

The objective of an elastic-plastic analysis is to guarantee that the relevant loading is below the load that produces overall structural instability.

The elastic-plastic analysis shall be carried out following the guidelines of the respective selected codes for the verification of the FXJ.

PETROBRAS may require the performance of elastic-plastic analysis in addition to the elastic one when the presented results of elastic analysis were not conclusive.

6.4.4.5 FEA Methods to Evaluate Protection Against Local Failure

Strength verification of the FXJ carried out by SUPPLIER shall include the evaluation of protection against local failure. This check shall be aligned with the rules and procedures of selected internationally accepted codes.

SUPPLIER is not waived to check protection against local failure if, for any reason, the selected codes do not contemplate checking this failure mode. For this case PETROBRAS shall be consulted about the acceptance criteria to be used. See, for instance, the methods given in section 5.3 of [43].

Design codes usually recommend a simplified local stress check procedure to be carried out as part of a linear elastic FEA. For some codes the protection against local failure is guaranteed by limiting the sum of the principal components at any point in the structure. For other codes the limit is imposed on the maximum principal stress component at any point in the structure.

For FEA involving plasticity, plastic collapse load analysis via the elastic-plastic method is preferable for checking local failure because it closely represents the actual structural response in comparison with a limit analysis. The local geometry of the structure shall be correctly represented in the FE-model to allow an accurate estimate of local strains that will be used in the code compliance verification.

6.4.4.6 FEA Methods to Evaluate Protection Against Progressive Collapse

Methods for protection against progressive collapse from repeated loading are found on internationally recognized design codes. SUPPLIER shall follow the recommended procedure of the respective selected codes for the verification of the FXJ.

For a FE elastic analysis, the sum of primary plus secondary stresses shall be less than the respective allowable value defined on the selected code. Note that if all requirements for protection against plastic collapse are met in an elastic FE analysis with all stresses categorized as primary then the load is safe regarding progressive collapse. In the context of verification of protection against progressive collapse by means of elastic analysis, it is considered acceptable the use of stress linearization as per section 5.5.6 of [43].

However, if elastic-plastic analysis results are used, then an assessment method compatible with such type of analysis shall be employed instead (e.g. see section 5.5.7 of [43]).

6.4.4.7 FEA Methods to Evaluate Functionality

Finite element analysis may be used to demonstrate functionality of the FXJ as a complement to tests required by PETROBRAS and/or when deemed necessary by SUPPLIER. In general, a proper numerical evaluation of functionality (e.g. check of leakage due to contact separation) requires the use of non-linear elastic-plastic FE-models.

Temperature effect on material properties shall be considered whenever relevant.

For pre-loaded structures (e.g. FXJ Flanges), sensitivity in pre-load should be estimated based on the difference in thermal expansion between materials and any uncertainty in the pre-loading application method. Any long term relaxation effect should be accounted for.

6.4.4.8 FEA for Fatigue

Fatigue life evaluation of the FXJ carried out by SUPPLIER shall include the assessment of both welds and plain material following the rules and procedures of a selected internationally accepted code.

When creating FE models for the purpose of calculating stresses for subsequent fatigue analysis, care must be taken to ensure that the mesh density and level of detail modeled are in accordance with the assumptions in the chosen S-N curve.

FE meshes for the calculation of stress ranges in plain material (e.g. forged components far from any weld) should be extra fine in areas where stresses are determined (notch stress method). The geometry of the elements should be carefully evaluated in order to avoid errors due to deformed elements. The size of the model shall be sufficiently large so that the calculated results are not significantly affected by assumptions made for boundary conditions and application of loads (e.g. [47]).

6.4.4.9 FEA documentation

The analysis report shall be sufficiently detailed to allow for independent verification by a third party, approved by the PARTIES, either based on review of the documentation, or using independent analyses (sensible data may be provided under a non-disclosure agreement and provisions of sec. 5.4). The documentation should include at least description of:

- Purpose of the analysis;
- Failure criteria;
- Geometry model and reference to drawings used to create the model;
- Boundary conditions;
- Element types;
- Element mesh;
- Material models and properties;
- Loads and load sequence;
- Analysis approach;
- Application of safety factors;
- Mesh convergency study results;
- Analysis results;
- Sensitivity analysis;

- Discussion of results;
- Conclusions;
- Any other performed verification.

6.5 PREVENTION OF BRITTLE FRACTURE

Materials for *Flexible Joint* components shall be selected to prevent brittle fracture. Lowest Anticipated Service Temperature due to operational riser depressurization shall be considered for selecting and testing metallic material to prevent brittle fracture on *Body* and *Extension*.

Material selection for elastomer, *Reinforcements* and *Attached Flange* shall consider Lowest Anticipated Service Temperature (L.A.S.T.), as per [5].

6.6 MAXIMUM ANGULAR ROTATION

The maximum riser top rotation angle will be informed within contract documentation, [5].

Flexible Joint shall be tested for the maximum designed cocking angle, as per Section 9.2.

SUPPLIER shall take into account the limitation of the Hang–off system selected for the Project, as per Project documentation. Contact of the *Extension* with the Receptacle and box structure, considering also the difference (if any) between Receptacle built angle and riser top angle as well as the angular mounting tolerance of the Receptacle, as per [5], shall be avoided.

6.7 ROTATIONAL STIFFNESS

SUPPLIER shall provide table and graphic representation of the rotational stiffness values in the form of rotational stiffness versus angle variation, for each *Flexible Joint* design under the full range of design conditions and upper limit values defined in Project documentation.

Thus, rotational stiffness table/ graphics for FAT, operationals (fatigue), extremes, incidental, hydrotest, installation and Hi-Sep conditions, shall be reported in a Stiffness Summary Specification, containing also Excel spreadsheet or other ASCII writable file format of the curves.

The input conditions (temperature, pressure and tension) employed to compute the stiffness curves shall be informed.

The stiffness tables shall contain rotational stiffness values from 0.01° up to at least the overall maximum calculated riser angle for the Project, or the maximum physical angle for the Flexible Joint before contact with the FPU structure or with its own metallic parts (whichever is greater).

Information on any adjustment of the nominal stiffness curve (software predicted) to a design stiffness curve (e.g. nominal plus 2 std) shall be clearly stated. Reference temperature for predicted rotational stiffness curve shall be informed.

NOTE 1: Stiffness curve at intended FAT conditions (temperature and pressure) shall also be informed. This design curve is intended to be the maximum value (criterion) for stiffness measurement during FAT.

The stiffness values measured during the FAT shall not exceed the limits presented by SUPPLIER as per [5], or the values considered to perform the riser global analysis.

NOTE 2: CONTRACTOR may propose optimized *Flexible Joint* stiffness values, based on preliminary riser global and fatigue analysis with sufficient sea state simulations, as per [18], to improve design margins for riser fatigue analysis and *Extension* sizing. Subsequent modification of the design rotational stiffness values shall be approved by PETROBRAS.

SUPPLIER shall characterize the stiffening effect of each Flexible Joint design as a function of the basic rotational stiffness and of the cocking rotation angle amplitude, for alternating angle as low as 0.01deg. More refined angle bins shall be provided at the beginning of the tables. The following discretization shall be observed: {[0.01°: 0.01°: 0.1°] ; [0.1°: 0.1°: 1.0°]; ; [1.0°: 1.0°: “max angle”]}, being [“initial value”: “step”: “final value”].

The “not to exceed” rotational stiffness values and the stiffening curves shall be confirmed for each *Flexible Joint* type in accordance with the FAT requirements described in Section 9.

If a measured stiffness higher than the corresponding stiffness in the design curve (criteria) occur, conclusive assessment for the nonconformity shall be presented to PETROBRAS.

Computed design stiffness curves for each Load Category conditions of Table 6.1 shall be informed, to be adequately used in riser global analyses. These stiffness curves are usually more related with the temperature, and in lesser ways with the pressure and tension associated with the Load Categories. Thus, fewer design curves adjusted only for temperature, that serve several cases, may be generated.

6.8 MAINTENANCE

The *Flexible Joint* shall not require any intervention for maintenance or repair during the specified service life. However, the riser shall be removable and re-installable. The *Flexible Joint* shall meet this requirement and and PARTIES shall work together to generate a procedure for such operation, per sec. 10.5.

Flexible Joint shall be provided with adequate access for inspection and maintenance. SUPPLIER shall provide a periodic inspection procedure for integrity and ageing checking of the *Flexible Joint*, specialy the elastomeric element. The inspection will be limited to indications of cracks, tears or unexplained bulges, i.e. surface breaking.

If there is a possibility to replace any part at any moment, SUPPLIER shall provide a procedure for such operation.

The *Flexible Joint* shall be capable of passing inspection pig as per Section 6.10.

Failure of the *Flexible Element* within the *Flexible Joint* assembly shall not result in the loss of the riser, i.e. shall be fail-safe. The line shall remain attached to the *Flexible Joint* and supported by the FPU hang–off system.

The application of a protective painting over the exposed surface of the rubber shall be executed whenever storage period equal or longer than 06 months before the offshore installation campaign is foreseen (first application to be executed in SUPPLIER factory, before installation of the locking system). Periodic renewal of the rubber protectant application shall be scheduled each 6 months. Application control, with the date of application, place, date fot the next application and applicator identification/ signature, shall be kept. The comencial product “Age Master® No. 1” or similar are acceptable.

6.9 IN-SERVICE INSPECTION

SUPPLIER shall generate an Inspection and Maintenance Manual (sec. 10.5) for the periodic inspection confirming the integrity of the *Flexible Joint* and the related components during the service life of the field.

SUPPLIER shall also supply the procedure for removing marine growth on the *Flexible Joint* and the related components prior to the inspection.

For HPHT *Flexible Joints* with *Bellows*, SUPPLIER may optionally provide means to inspect for eventual leak of produced fluid into the annular fluid (glycol or other inert fluid) without interruption to the operation.

6.10 PIGGING REQUIREMENTS

Flexible Joint design shall consider following requirements related to pigging:

- Enable riser cleaning with foam-pigs, brush pigs and magnet-pigs in order to remove residues, according to pre-commissioning procedure;

- Enable riser gauging, consisting of the passage of a bi-directional caliper or pig with gauging plate, as defined in design;

- Enable pigging operations in two directions;

- Internal diameter transitions may be required by PETROBRAS and will be defined in Contractual Documents. In this case, the provisions of section 6.3 shall be considered. Otherwise, if SUPPLIER design requires internal diameter transitions, the required diameter variation and slope shall be presented to PETROBRAS for approval;

- The cone angle to be considered for pigging shall be 3.0 deg minimum. If greater angle is expected to occur (as per Load Category "Temporary 1" result), SUPPLIER shall be consulted and shall take actions, regarding the FXJ design, to allow pig passages in the most critical scenario foreseen for the actual operation. Pig passage test to the calculated angle shall be performed, as per sec. 9.2.2;

- The sealing length of the pig (length between the first and the last sealing discs of the pig, NOT its total length) shall be verified geometicaly (CAD), and by testing (sec. 9.2.2), to be adequate for the FXJ design and possible by-passes of flow at the Spherical Thrust.

- The flexible joint system shall neither be damaged nor loose its sealing properties because of the pigs passage (integrity of the *Thermal Barrier*, *Spherical Thrust*, etc.).

- An uninterrupted bore passage for pig shall be ensured throught all FXJ length during all service life (specially for the *Spherical Thrust*, which shall remain integrated).

6.10.1 CONVENTIONAL PIG

The *Flexible Joint* shall be capable of passing disc-type (Mandrel / Solid-cast) pigs equipped with wire brushes. SUPPLIER shall review the Flexible Joint design based on the overall design criteria and demonstrate to PETROBRAS's satisfaction that this can be achieved.

SUPPLIER's evaluation shall consider the dimension and operation of typical disc-type pigs and in particular the minimum pig length required for the pig to pass through the *Flexible Joint* without losing its seal.

6.10.2 INSPECTION PIG

The *Flexible Joint* shall be capable of passing an ultrasonic or magnetic type inspection pig in both directions at a 3.0deg maximum misalignment angle.

SUPPLIER shall provide to the manufacturer of the inspection pigs all information required to perform a simulation of the inspection pig passing through the *Flexible Joint*.

6.11 INSTALLATION

SUPPLIER shall provide assistance on request to PETROBRAS and CONTRACTOR during preparation of the *Flexible Joint*, installation onto the Hang–off system and handling procedure. SUPPLIER shall review the riser installation and comissioning procedures to confirm that the FXJ design suits the installation induced loads.

NOTE: The design characteristics of the *Flexible Joint* system shall accommodate the installation motions and loading conditions without detrimental effects (in particular excessive rotation or deflection). All components of FXJ shall be checked for load envelop related to each of the installation phases (deployment on seabed, recovery, riser transfer, pull–in, etc. according to CONTRACTOR procedure).

SUPPLIER shall also provide a detailed (step by step) procedure for the handling, storage, transportation and preservation of the *Flexible Joint* system, and submit to CONTRACTOR and PETROBRAS for review. In case of the acquisition of spare FXJs, the preservation procedure shall consider long periods of storage.

An anti-impact coating applied on the *Extension* may be required, if stated in [2] or [5], to mitigate the risk of indentation on the steel surface during pull-in, if large amplitude of movement is foreseen. In this case, the requirements for this anti-impact coating is found in [6].

In cases where full pre-deployment on seabed is required in the Project, *Flexible Joint* protective kit design (bipartite shroud) and *Extension* locking system lay down tool shall be provided (to prevent damage to the *Flexible Element)*. In both cases, summary procedures for remote (ROV or automatic) disconnection of these protective tools shall be supplied. Track record of supply or qualifications of the lay down tool, considering predicted loads and field water depth, shall be presented in technical proposal at BID stage. Detailed procedure of disconnection and locking system (lay down tool) inspection shall be included within FXJ handling and inspection manual.

6.12 CONNECTION AND WELDING

The Project specified top connection of the *Flexible Joints* (as per, [2] or [5]) shall be supplied forged as an integral unit with the attached flange, separate from the body.

The attachment of the riser to the *Extension* (riser pup piece) shall be a butt weld connection. SUPPLIER shall assure the pipe *Extension* material, riser pup piece and dimensions are compatible with each riser pipe type/size in accordance with PETROBRAS's Specification for the Project.

SUPPLIER shall perform the welding in accordance with PETROBRAS's Specification for Flowline and Riser Welding and NDE [20], or supply test rings when welding will be performed by CONTRACTOR.

6.13 CORROSION PROTECTION

Corrosion protection of the *Flexible Joint* and the riser shall be accomplished with a combination of protective coating and cathodic protection.

The *Extensions* shall be coated with a corrosion protection coating compatible with the corresponding riser coating.

If *Bellows* is not required (e.g. water injection riser), SUPPLIER shall assess the possibility of galvanic corrosion due to contact between dissimilar material on wetted surfaces. A study of galvanic corrosion shall be presented, balancing the proportion of anodic/ cathodic areas. The employment of sacrificial anodes is permited, following the recommendations of [28]. Painting or TSA coating is not permited on internal surface. Other form of coating, if required, may be submitted for PETROBRAS to approval.

At least, the outer surface of the *Body*, including all flanges and openly exposed surfaces (excluding face of flange), shall be coated with TSA in accordance with [6] – Additional coating layer, if any, is informed in [6]. The effectiveness of the proposed system shall be well documented and tests shall demonstrate the efficiency of the system. Before installation, all non coated (TSA or epoxy) external surfaces shall be protected with a single coat of primer or corrosion inhibiting material during pre-installation phase (storage and transport\ handling).

CRA alloy UNS N06625 weld overlay shall be applied on the sealing surfaces of the *Attached Flange*, *Extension* and *Body* (metallic ring sealing areas), on the *Standard Flange* groove and raised face (entirety) or connector sealing face (when specified) as well as on all surface wetted by work fluid in the *Flexible Joints* with *Bellows*. No other permanent coating but the CRA overlay shall be applied over these surfaces.

The *Standard Flange* nut bearing areas (on the neck side of the flange tab) shall not be coated, to allow the electrical contact with the *Flexible Joint*.

All coatings and coating procedures used by SUPPLIER or SUB–SUPPLIERs are subject to the PETROBRAS's review and approval. Qualification of personnel as per section 8.10.

SUPPLIER shall assure electrical continuity between the *Body* and the *Extension*, and between the bolts and *Attached Flange*, otherwise written within Project specification [2] or [5].

Internal surfaces weld overlay shall be applied according to Section 7.4.3, when demanded per [5] or [3].

6.14 ECA EVALUATION REPORT

CONTRACTOR or SUPPLIER shall produce an ECA report, [4], for the detailed design phase to stablish the acceptance criteria for *Extension* CRA layer (dynamic), in adherence with the provisions of [25].

The exposure of the base metal (steel) to the conveyed fluid due to a full-crack throught the clad layer shall be considered as a fail. SUPPLIER shall consider a initial flaw size equivalent to an undetected defect throughout the circumference with a height equal to the PoD 90%|95% of the AUT system used in the volumetric inspection of the weld–overlay.

7 MANUFACTURING REQUIREMENTS

7.1 GENERAL

SUPPLIER shall review riser and top connection material selection and confirm compatibility with SUPPLIER's Flexible Joint design. SUPPLIER is responsible for ensuring the overall metallurgical compatibility of the *Flexible Joint* components, including compatibility with the pipe sections to be welded to the *Extension*. SUPPLIER shall summarize the material selected for all *Flexible Joint* component for PETROBRAS review within the BID submission.

7.2 MATERIAL COMPONENTS

Copies of material specifications, results of all mechanical properties tests, and mill test certificates shall be provided to PETROBRAS.

7.3 MATERIAL SELECTION

PETROBRAS acknowledges the use of ASTM A694 ([35]) or ASTM A707 L3 ([36]) forging for bodies and attach flanges, and ASTM A707 L5 ([36]) for the *Extension* with internal clad layer where applicable. Additional, Project related metallic material requirements may by also presented in [3].

The compatibility between all materials shall be checked. Materials shall not be affected by galvanic reactions and can be welded to other where necessary. In particular, the adequacy between the *Extension* and the riser materials is critical.

NOTE: compatibility of the internal parts shall also be checked. Design shall avoid any harmful contact between dissimilar material (including *Bellows*, bolts, studs and nuts).

7.3.1 BOLTS AND NUTS

Bolts and Nuts shall comply with [21] ~~and 0~~. For bolts and nuts for Gas Injection, Service and Gas Export risers reference is made to [26], section.6.2.6.

7.3.2 STEEL REINFORCEMENTS

Steel material of reinforcements used in the manufacturing of the *Flexible Joints* shall be low alloy carbon steel with enhanced properties for fatigue purposes or other adequate material. Material shall be acceptable to [31], [48] or [49] . Selection shall be based on SUPPLIER experience for similar design conditions.

7.4 MANUFACTURING PROCEDURES

A manufacturing Quality Control Plan shall be prepared by SUPPLIER and reviewed by PETROBRAS prior to commencing manufacture. Witness, Inspection and Hold points shall be identified in the plan along with a description of the nonconformance review process.

7.4.1 WELDING PROCEDURES

Prior to commencing manufacture, it shall be demonstrated that all proposed welding procedures for each type of welding operation to be utilized during manufacture will produce properties in the heat affected zone which meet the requirements of Section 8.3 herein. Reference shall be made to [20].

Personnel shall comply with the requirements of [19].

Welding and NDT of pressure containment components shall be performed according to [26].

Weld overlay shall comply with section 7.4.3.

If pup piece is included within scope of supply, the weld of pup piece to the Extension shall be qualified, in addition to the pup piece to riser weld. The ground-flush to remove the weld reinforcement shall be performed in girth welds if necessary to achieve the required fatigue design curve (CONTRACTOR defined curve). DPI shall be carried out in the outer girth weld surface in accordance with [26]. In addition, UT shall be performed in order to check minimum design thickness.

SUPPLIER shall provide NDT calibration blocks for AUT examination of the weld between the Extension and the riser pipe joint for the same heat material.

Weld test rings of the forged materials for each of the Extensions shall be provided by SUPPLIER for weld qualifications of the *Extension* to the riser pipe. Quantity, dimensions and delivery time of the test rings are defined on contractual documents.

7.4.2 FORGINGS

7.4.2.1 Material

Forging materials shall comply to section 8 of [26] with additional or modified requirements below:

- Test Temperature for Charpy Impact Testing shall comply with Table 8.2;
- Requirements from [33] shall be fulfilled considering de class indicated on Project Data Sheet [5] for each *Flexible Joint* type. The hardness after all fabrication steps shall not exceed 230HV10 for Class 3 *Flexible Joints* and 250HV10 for other cases;
- SSC Testing shall be executed in accordance with general instructions declared in section 8 of [26], if exposed to the predicted fluid;
- Gas Injection *Flexible Joints*, Sulphur content shall not exceed 0.003%. For other CS lines, section 8.3.6.2 of [26] shall be fulfilled;
- In cases where weld overlay shall be applied, the requirements stated in section 7.4.3 shall be complied with;
- For forging with weld overlay, no SSC and HIC tests are required to be done, provided that the provisions of section 7.4.3 are fulfilled.

7.4.2.2 Qualification Test Sample (QTS)

Quality test Samples shall be used to qualify the mechanical properties of all forgings on a lot basis. QTS shall comply with section 8 of [26] and Appendix A of this Specification.

QTS configuration and dimensions shall be in accordance with Appendix A and fully described in the documentation package.

QTS shall have a suitable hot work ratio to qualify all parts represented.

QTS shall accompany the forging they represent through all heat treatment cycles.

7.4.3 WELD OVERLAY

7.4.3.1 Static Loaded Components

Attached Flange, *Body* and other static loaded components shall be qualified according to [32] and [44]. The maximum iron content in internal surface shall not exceed 5%wt. Corrosion tests according to section 6.3 of [24] shall be executed. If only some parts of a certain component are static loaded (e.g. *Extension* top), then the provisions of this section are limited to the static regions of component.

7.4.3.2 Dynamic Loaded Components

Weld overlay procedure used to deposit the clad weld shall be qualified in accordance with section 6.2 of [24]. If the strengthening effect of clad weld is demanded, the provision of section 5.2 shall be observed.

Weld overlay shall be executed in several welding passes in order to limit the maximum height of welding passes. At least, two welding passes are required. After each pass, a machining and a LP shall be executed. The maximum height of each machined pass shall not be higher than the maximum height of a full circumferential flaw calculated by ECA according to section 6.14.

NOTE 1: Interpass machining is required because conventional volumetric NDT is not able to reliable detect and size (height, length and depth) flaws on weld overlay layers. In this case, several welding passes with interpass machining and LP will limit the maximum height of a non-detected full circumferential flaw in the weld overlay.

NOTE 2: Alternatively to multiple welding passes with interpass machining, a single pass, multiple torch application, with at least two welding layers, may be performed. In this case weld overlay shall be fully inspected by pAUT system qualified according to section 8.8.2. In any case, a final machining of the entire length of the CRA ovelaid ID shal be performed.

Acceptables CRA layer thickness measurement techniques, equipments and measurement tolerances according to [41] and [42]. For the *Extension*, a minimum of 06 (six) equally spaced thickness measurements along the circumference, every 0.400m in the length of the forging shall be taken. CRA layer thickness shall be determined by the difference of the pre- and pos-overlaid measurements done in the same zone.

Each machining step shall be executed with a CNC machine. The CNC machine shall be calibrated every shift.

The inner surface to be in contact with the conveyed fluid shall have Ra roughness lower than 3.2 µm and a maximum rt of 40 µm. The acceptance criteria for roughness are requested to be fulfilled in overall surface condition. After final machining, the weld profile (weld bead) shall not be visible and the surface shall be free from any kind of grooves or any other stress concentration areas, as steps due to start / stop and repairs.

Pickling shall be performed. The pickling solution to be applied shall fulfill the requirements of Item C.6.1, Table A1.1 of [40]. Subsequent rinsing shall be performed using water with low chloride content.

7.4.3.3 Corrosion Tests

Corrosion tests according to section 6.3 of [24] shall be executed.

7.4.4 TOLERANCES

Extension and pup piece ends:

- ID tolerance (including OoR): ±0.25 mm (up to 150 mm from end).
- OD tolerance: ±0.5 mm (max.).
- Clad layer thickness tolerances: +2.0/-0 mm (overall).

NOTE: in case a pup piece is supplied, the pup piece to Extension internal hi-lo shall not exceed 0.5 mm as well as the riser first weld (riser pipe end dimension and tolerances in [5] and [3]).

7.4.5 BI-DIAMETER BELLOWS

SUPPLIER shall submit the detailed MPS of the *Bellows* and the detailed drawings or procedures of the connection to the *Body* and insert. The MPS shall include the heat treatment details if such is required as to guarantee the material performance for the complete service life. MPS shall be subjected to CONTRACTOR approval and shall cover all metallurgical aspects, fabrication tolerances, weld and NDT requirements, dimensional control before and after the forming of the corrugations and FAT.

8 INSPECTION AND MATERIAL TESTING

8.1 WITNESS/ MONITORING POINTS AND TESTS

The manufacturing quality, Inspection and Test Plan (ITP) shall include proposals for PETROBRAS Witness, Hold, Review and Monitor points. The ITP for SUPPLIER and its SUBCONTRACTORS shall be submitted for PETROBRAS review and approval prior to the start of production operations. The testing program shall include appropriate tests to assure qualification of the materials, processes, and the completed *Flexible Joint*. As a minimum, the mechanical properties testing program shall include the types defined in Section 8.3. All testing procedures are subject to both internal and external QC oversight and verification.

8.2 MILL TEST CERTIFICATES

Mill Test Certificates shall be supplied for metallic materials, which include the following information:

- Steel making process;
- Yield and ultimate tensile strength and % elongation;
- Chemical analysis including carbon equivalent;
- Impact Charpy V-notch, hardness test results and percentage shear;
- CTOD test results for *Extension* and *Attach Flange*.

8.3 MINIMUM INSPECTION AND TESTING REQUIREMENTS FOR *EXTENSION*

Extension Mechanical and corrosion testing shall comply, at least, to [26], sections 8.4 and 0, amended with information of APPENDIX A. Exceptions to requirements stated may be provided on Project Specific Data Sheet [5] or [3]. All testing shall be performed in the final heat treated conditions.

8.4 CHARPY V-NOTCH IMPACT TEST

Materials shall be selected to prevent brittle fracture. Charpy impact testing shall be performed in accordance with component specifications to verify material and weld toughness in the final delivery condition. The test temperature for Charpy impact testing of forgings shall be in accordance with Table 8.2 considering minimum temperature defined within this same table below. ~~Exceptions to requirements stated may be provided on Project Specific Data Sheet [5]~~.[EXCLUDED]

Additionally for *Extensions* (all services) and all FXJ components from Gas Injection, Export, and Service, Charpy V-notch testing shall exhibit a minimum mean value of 50% (minimum individual value of 40%) shear fracture appearance at the specified temperature.

Table 8.2 – CVN Testing Requirement for All Riser Function

CVN energy absorption avg., [J]	Table 7–5 of [26]	
CVN energy absorption min., [J]		
Tmin	L.A.S.T. ([2] or [5])	
CVN Test Temperature	t ≤ 20mm	L.A.S.T.
	20 < t ≤ 40mm	L.A.S.T. minus 10°C
	t > 40mm	L.A.S.T. minus 20°C
Shear Area (Mean/ Individual) [%]	50/40	

8.5 CTOD FRACTURE TOUGHNESS TESTING

CTOD fracture toughness testing shall be performed on the *Extension*. A set of 3 longitudinal specimens shall be extracted from the QTS and tested to evaluate the fracture toughness of each forging heat treatment lot. Specimens shall be taken at equal distances around the circumference of the forging (i.e. every 120 degrees) CTOD specimen dimensions, fatigue pre-cracking, and testing shall be in accordance with [37].

Either SE(B) or C(T) type specimens may be utilized. SE(B) specimens shall be Bx2B for thicknesses (B - full thickness) less than 63.5 mm (2.5-inch) but may be BxB for thicknesses greater than or equal to 63.5 mm (2.5-inch).

CTOD specimen orientation shall be such that the long axis of SE(B) specimens is oriented parallel to the tubular axis and the machined notch is oriented perpendicular to tubular external and internal surfaces.

The test temperature shall be the minimum design temperature. The CTOD value shall be greater than or equal to 0.38mm.

After testing, all specimens shall be subjected to the validity checks of [37]. Significance of pop-ins shall be assesses as described in [37], Paragraph 9.1.3.

If a test fails to meet the requirements, two re-tests shall be performed (for the failed test only) on samples taken from same QTS. Both re-tests shall meet the specified requirements. Forging shall be rejected if one or both of the re-tests do not meet the specified requirements.

8.6 ULTRASONIC EXAMINATION

Each forging shall be ultrasonically examined in accordance with [34] and the supplementary requirements of [26], App D sect D.4 or D.5.

8.7 MAGNETIC PARTICLE INSPECTION

All forgings, for which finish machining has been specified, shall be examined by wet magnetic particle Testing (MT) in accordance with [38]. DC magnetizing prods shall not be allowed. Examination shall be performed after final heat treatment final and machining processes.

Surface coverage shall be 100 percent of finish-machined surfaces with magnetization in at least two mutually perpendicular directions (circumferential and longitudinal for hollow cylinders or tubulars).

Examination shall be conducted after all heat treatment operations (excluding stress relief) have been completed. MT procedures and magnetization plans shall be approved by PETROBRAS.

Remnant magnetic field strength (residual magnetism) shall not exceed 800A/m subsequent to MT.

8.8 WELD OVERLAY

8.8.1 NDT

Weld overlay shall be inspected as [26], Appendix D, section D.3 where applicable.
Acceptance criteria as per [26] Appendix D, section D.3.6.

8.8.2 AUT QUALIFICATION TESTING (WHEN REQUIRED IN SECTION 7.4.3.2)

SUPPLIER shall adopt a suitable Phased Array Ultrasonic system (pAUT) in order to detect lack of fusion and other planar/volumetric flaws within weld overlay.

pAUT qualification requirements shall comply with sections 6.5.2, 6.5.5 and 6.5.6 of [24].

8.9 INSPECTION AND TEST REPORTS

Each test performed shall result in a test report and a quality assurance inspection report, which shall be issued to PETROBRAS within two weeks of test completion.

8.10 QUALIFICATION AND CERTIFICATION OF INSPECTORS

Personnel qualification of Weld, NDT and dimensional inspectors shall comply with [26], and the modifications detailed in [19].

Personal qualification for painting operator and inspector shall comply with sections 10.2.2 and 10.2.5 of [50], and the modifications detailed in the section on the “Requirements for Painting Systems”, of the Coating Assessement for the Project [6].

Qualification of metal spray operators shall be in accordance with item 10.2.3 of [50].

9 FACTORY ACCEPTANCE TESTS (FAT)

9.1 GENERAL

SUPPLIER shall propose, for PETROBRAS review, a Factory Acceptance Test procedure to be carried out on each manufactured *Flexible Joint* except for test indicated below with different frequency. The FAT procedure shall ensure that all relevant aspects of the design and fabrication of the *Flexible Joint* are in compliance with the relevant codes and PETROBRAS specifications and ensure the resistance adequacy of the *Flexible Joint* to the maximum Project loads.

After FAT sequence is complete, the test fluid shall be drained and the interior surfaces dried.

The tests shall not initiate any permanent anomaly on the rubber or metallic parts, and the service life of the Flexible Joint shall not be significantly affected by the FAT.

9.2 MINIMUM SET OF FACTORY ACCEPTANCE TEST ON FLEXIBLE JOINTS

The FAT procedure shall include as a minimum requirement the steps detailed in the following sub-sections.

9.2.1 ROTATIONAL STIFFNESS MEASUREMENT

Table 9.1 – Rotational Stiffness Requirements

PURPOSE:	To confirm rotational stiffness of the design, and the 'not to exceed' rotational stiffness criteria used in the riser analysis, as per sec. 6.7 and Project references [2] or [5].	
TEST CONDITIONS		**NOTES**
Pressure:	Design pressure(1)	(1) value as per [2] or [5].
Temperature:(2) (3)	Ambient	(2) Reference temperature considered for the reported rotational stiffness values (criterion) shall be informed. (3) Test–to–reference–temperature correction methodology shall be presented and agreed upon before the beginning of FAT as per [10].
Axial tension:(5)	Mean operation riser tension(4)	(4) value as per [2] or [5]. (5) Axial tension can be achieved both by direct tension application on the Extension or by an increase of internal (test) pressure to simulate the effect of riser tension load. The amount of added pressure being proportional to the axial tension divided by the effective pressure area over the Flexible Element geometry. Pressure equivalent tension calculation shall be reported.
Testing Angles:	0.3°, 0.5°, 1.0°, 2.0°, 3.0°, 4.0°, 6.0°, 15°(6) (7)	(6) One-plane measurement of rotational stiffness for each testing angle shall be performed. At least 05 complete cycles per angle amplitude shall be performed, with stiffness measurement during the last cycle. (7) Stiffness measurement at the design maximum angle, instead of 15°, is accepted. If measurement up to maximum Project angle (maximum free rotation angle, as per [5]) is not feasible in the FAT test bench, an angular capacity test shall be performed as per [10], and rotational stiffness shall be measured up to 6.0° at least.
Frequency of Test:	FoaK	
Acceptance Criteria:	• Each measurement shall be below the design stiffness curve.(8) • No flaws or blisters can be seen on elastomer cover surface after the test.	(8) If this criterion is not met at any measured stiffness, but conclusive cause for deviation is identified as not related with FXJ design and can be corrected, the stiffness measurement test shall be sucessfuly executed again on the first and on all subsequent constructed FXJ of the kind. Deviations without conclusive cause established, or that can reasonably be related to FXJ flawed design shall be cause for rejection.
Records and Report:	• Test Date/Time • P/N and S/N • Ambient Temperature • Internal Fluid Temperature • Elastomer Temperature(9) • Internal Pressure • Elapsed Time • Rotational Force • Rotational Displacement • Actuator Position (10) • Bending Moment (11) • Calculated angular stiffness (12) • Suface condition inspection and evaluation(13)	(9) Thermal Couple distribution on testing flexible joint shall be informed. (10) Measure and record the "moment arm" with respect to the CoR to the location of the applied load for tested Flexible Joint. (11) Record load and calculate moment. (12) Information on any correction of the nominal stiffness curve (software predicted) to a design stiffness curve (e.g. nominal minus 2std.) shall be clearly stated. (13) Perform post–test inspection of the suface condition, reporting and evaluating any anomalous indications if any appear.
GENERAL NOTES:		
• In case any test parameter does not conform with the procedure, a NCR shall be issued with conclusive cause for the deviation. For nonconformities related with stiffness measurement acceptance criterion, see note (8). • The elastomer cover plate surface shall be inspected for any kind of flaws or blister. • This tests (rotational stiffness measurement and maximum angle test) may be performed without *Bellows*. A mock–up (temporary) Extension may also be used, provided that the tested *Flexible Element* remains intact and undamaged due to the disassemble/ assemble of the Extensions (temporary/ definitive). • Test equipment calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder, pressure recorder, inclinometer and linear displacement tranducer (LVDT).		

9.2.2 PIGGING PASSAGE TEST

Table 9.2 – Pigging Passage Test Requirements.

PURPOSE:	To test the ability of the system to enable the free passage of the very pig type (CONTRACTOR supplied) to be used in the riser commissioning, in a fully assembled FXJ, and ensure that eventual bypasses of fluid at the Spherical Thrust and top of the Extension do not hinder the passage of the pig.	
TEST CONDITIONS		**NOTES**
Pressure:	(1)	(1) The pressure necessary to move the pig all the way through the FXJ shall be compatible with the operation procedure (after adjusted to compatibilize for the water column and pig weights).
Temperature:	Ambient	
Axial tension:	N/A	
Testing Angle:	(2)(3)	(2) Test angle shall be based on the most critical scenario foreseen for the actual operation (Temporary 1 result and CONTRACTOR's commissioning procedure), including support mounting tolerance. (3) At least a 3 degrees rotation of the Extension shall be kept during pig passage (if calculated angle is lower).
Frequency of Test:	FoaK(4)	(4) One complete passage of commissioning pig per FXJ type.
Acceptance Criterion:	• Pig to reach the opposite end of the *Flexible Joint*	
Records and Report:	• Test Date/Time • P/N and S/N • Ambient Temperature • Applied Pressure • Elapsed Time • Inclination of the Extension • Pig general condition(5)	(5) Perform post–test inspection of the pig condition (discs or plates), reporting and evaluating any damage if any appear.
GENERAL NOTES:		

- In case acceptance criterion does not conform, a NCR shall be issued with conclusive cause for the deviation.
- Passage of the CONTRACTOR provided commissioning pig shall be performed after the welded test cap at Extension end is removed. The same pig type shall be used in the actual operation.
- The test rig may be either in horizontal or vertical orientation. If verticaly oriented, the pig shall initiate in the bottom end and terminate at the top end of the FXJ.
- The fluid media shall be city tap water (fresh water). Proper corrosion inhibitor shall be added, in case of non-CRA FXJ.
- Test equipment calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder, pressure recorder and inclinometer.

9.2.3 HYDROSTATIC TEST

Table 9.3 – Hydrostatic Test Requirements

PURPOSE:	Pressure integrity test at *Extension* deflected position, to detect possible leaks and to ensure the structural integrity.	
TEST CONDITIONS		**NOTES**
Pressure:	Hydrostatic pressure(1)	(1) Value as per [2] or [5].
Temperature:	Ambient	
Axial tension:	None	
Mean Angle:	4°(2)	(2) The Extension inclination may be applied only for the FoaK tested FXJ, with ZERO mean angle for the remaining unities.
Test Duration:	At least 4 hours after pressure stabilization.	
Frequency of Test:	All units	
Acceptance Criteria:	• Pressure variation lower than 5% of test pressure, or 3.45MPa (whichever is less), after pressure stabilization. (3) • No flaws or blisters can be seen on elastomer cover surface after the test.	(3) If this test criterion is not met, but conclusive cause for deviation is identified and can be corrected, the stiffness measurement test shall be sucessfuly executed again on the failed tested FXJ. Deviations without conclusive cause established, or that cannot be correted (FXJ flawed design) shall be cause for rejection.
Records and Report:	• Test Date/Time • P/N and S/N • Ambient Temperature • Internal Fluid Temperature • Elastomer Temperature(4) • Internal Pressure • Graph of internal pressure vs. elapsed time • Graph of Temperatures vs. elapsed time	(4) Thermal Couple distribution on testing flexible joint shall be informed.
GENERAL NOTES:		

- In case any test conditions do not conform with the procedure, a NCR shall be issued with conclusive cause for the deviation. For nonconformities related with pressure drop acceptance criterion, see note (3).
- Internal hydrostatic tests pressure shall not be lower than the riser hydrostatic test pressure, as specified in [2] or [5].
- Agreement shall be obtained with PETROBRAS representative witnessing the test that pressure stabilization has occurred before proceeding with the hold period of the pressure test.
- All components shall be visually inspected for leakages throughout the test period. The test shall be performed in air to allow visual inspection.
- Tests shall be performed with end caps installed on both ends of the Flexible Joints. Pressure recorders and charts shall be utilized. Following the completion of the test, SUPPLIER shall be responsible for removing the end cap and the associated heat-affected zone (HAZ) from the lower end of the *Extension*, leaving a clean straight edge ready for beveling, or the condition stated in [2] or [5]. An extra length of at least 100mm, in addition to the defined Extension length, shall be provided and remain after cutting of the test end cap.
- The fluid media shall be city tap water (fresh water). Proper corrosion inhibitor shall be added, in case of non-CRA ID FXJ.
- Test equipment calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder, pressure recorder, inclinometer and linear displacement tranducer (LVDT).

9.2.4 AXIAL STIFFNESS

Table 9.4 – Axial Stiffness Test Requirements

PURPOSE:	Verify the integrity of the *Flexible Element*.	
TEST CONDITIONS		**NOTES**
Pressure:	Hydrostatic pressure(1)	(1) values as per [2] or [5]. This test may be performed during the hydrostatic test.
Temperature:	Ambient	
Axial tension:	None	
Mean Angle:	Zero	
Frequency of Test:	All units	
Acceptance Criterion:	Measured axial stiffness higher than minimum predicted.	
Records and Report:	• Test Date/Time • P/N and S/N • Ambient Temperature • Internal Fluid Temperature • Elastomer Temperature(2) • Internal Pressure • Rotational displacement • Axial displacement • Angle vs. elapsed time • Axial displacement vs. elapsed time • Calculated Axial Stiffness vs Predicted Stiffness	(2) Thermal Couple distribution on testing flexible joint shall be informed.
GENERAL NOTES:		
• In case test conditions do not conform with the procedure, or the measured axial stiffness deviates from the acceptance criterion, a NCR shall be issued with conclusive cause for the deviation. • Axial stiffness test may be waived if the assessment of the integrity of the *Flexible Element*, according to SUPPLIER design methodology, is not related to this property. If axial deflection of the Flexible Element is used to lock the *Extension* and compress the *Flexible Element* during pre-deployment on seabed (when applicable), the measure of the axial stiffness shall be performed. • Test equipment calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder, pressure recorder, inclinometer and linear displacement tranducer (LVDT).		

9.2.5 *BELLOWS* TIGHTNESS TEST

Table 9.5 – *Bellows* Tightness Test Requirements

PURPOSE:	To demonstrate that the *Bellows* operates properly (no through thickness crack or damage on sealing connections) at conclusion of FAT and prior to the final assembly of the Flexible Joint.	
TEST CONDITIONS		**NOTES**
Pressure (abs.):	5×10^4 Pa(1)	(1) refers to the test on rigid, nonporous packagen of [39]. Pressure inside assembled *Bellows* chamber.
Temperature:	Ambient	
Axial tension:	None	
Mean Angle:	None	
Test Duration:	At least 1 hour after pressure stabilization/ test valve closure.	
Frequency of Test:	All units	
Acceptance Criterion:	Leakage rate below 4.35×10^{-4} Pa m^3 s^{-1}	
Records and Report:	• Test Date/Time • P/N and S/N • Ambient Temperature • Internal Fluid Temperature • Internal Pressure • Graph of internal pressure vs. elapsed time • Graph of Temperatures vs. elapsed time • Name and stamp/ signature of the operator(2)	(2) register this data in case manual measurement is performed (not automatized/ mechanized).
GENERAL NOTES:		

- In case test conditions do not conform with the procedure, or the acceptance criterion is not met, a NCR shall be issued with conclusive cause for the deviation.
- This test shall be executed after all other FAT tests, aiming to check the gas-tightness of the internal assembly (e.g. seals between the *Bellows* and the flange and between the *Bellows* and the riser Extension), and to verify *Bellows* integrity.
- Either vacuum test or helium leak test of the assembled *Flexible Joint* (*Bellows* seals) are acceptable.
- Test equipment calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder and pressure/ vacuum recorder or helium detector.

9.2.6 ELECTRICAL CONTINUITY TEST.

Table 9.6 – Electrical Continuity Test Requirements

PURPOSE:	Check the electrical continuity between top flange, Extension and Bolts. See the Project requirement for electrical continuity/ discontinuity in [2] or [5].	
TEST CONDITIONS		**NOTES**
Pressure:	N/A	(1) The resistance measumentents shall be the following: Attached Flange to Extension, Bolts (all) to Attached Flange and Bolts (all) to Body.
Temperature:	Ambient	
Axial tension:	N/A	
Mean Angle:	N/A	
Frequency of Test:	All units	
Acceptance Criteria:	Measured resistances < 0.01 Ω[(2)]	(2) milliohmmeter with minimum resolution of 5 mOhms.
Records and Report:	• Test Date/Time • P/N and S/N • Electrical resistances[(1)] • Name and stamp/ signature of the operator[(3)]	(3) Register this data in case manual measurement is performed (not automatized/ mechanized).
GENERAL NOTES:		
• In case the acceptance criterion is not met, a NCR shall be issued with conclusive cause for the deviation. • The measurement shall be restricted to the Flexible Joint parts. The support frame of the FXJ for the test shall have a minimum of 100Ω to prevent short cuts to occur. • Resistance meter calibration certificates and characteristics (reference, accuracy, range) shall be included in the report. Calibration certificates (valid within the previous 6 months) shall be supplied for the milliohmmeter.		

9.3 COMPLEMENTARY TESTS ON *FLEXIBLE JOINTS* ASSEMBLY AND PARTS

SUPPLIER may be requested to perform some complementary test, in order to verify certain design paramethers, a per the provisions stated in [10].

9.4 CALIBRATION CERTIFICATES

All calibration certificates must be available to PETROBRAS representatives at the start of FAT activities, and all Serial Numbers shall be checked on site before start of tests. Any calibration reports presented must have the standards used to calibrate, calibration and expiry dates, errors found (average and each level tested), signature and identification of professional in charge. Any changes of instruments, software or channels used during tests must be preceded by an additional calibration report to be presented to PETROBRAS, showing that everything is within acceptance criteria by approved procedures.

10 QUALITY CONTROL AND REPORTING

10.1 QUALITY MANAGEMENT SYSTEM

Each element of the work shall be executed in accordance with quality management systems that comply with the requirements of CONTRACTOR and PETROBRAS project requirements.

SUB-SUPPLIER shall refer to document “Project Quality Management Plan”.

10.2 QUALITY PLAN AND QUALITY CONTROL PLAN

SUB-SUPPLIER shall produce for SUPPLIER review and approval a project quality plan and a project quality control plan:

Project quality plan	Detail the organization, responsibilities, activities, and an index of referenced and applicable procedures to complete the Work, including that of SUB-SUPPLIERS and SUPPLIER.
Project quality control plan (ITP)	Detail quality control plan and control monitoring to be employed during mobilization, acquisition and reporting phases.

All SUB-SUPPLIERs shall address and resolve any audit reports, recommendations and / or corrective action requests issued by the CONTRACTOR to the satisfaction of the CONTRACTOR and of the PETROBRAS.

SUB-SUPPLIERs shall also refer to document “QHSE Management for Suppliers / Subcontractors”.

10.3 MOBILISATION AND CALIBRATION

All equipment used for calibration purposes will be provided with recent bench calibration.

10.4 DESIGN, PROCUREMENT AND FABRICATION PROCEDURES REPORTS AND RECORDS

The following procedures, reports and records shall be provided to PETROBRAS for review:

- QA/QC procedures, to be submitted to PETROBRAS for review prior to start of design and production work. The plans and procedures shall include, as a minimum, the following elements:

  - Manufacturing ITPs for PETROBRAS to comment (assign inspectioin points);
  - Material and Process Qualification Plan;
  - Inspection and Test Reports to be provided including all reports defined in this Specification;
  - NDT Procedures;
  - FAT Procedures;
  - Document Control Procedures;
  - Traceability Plan;
  - Nonconformance Procedure including examples of a report form to be utilized.

- Design Basis and Methodology (DBM) to be submitted to PETROBRAS for review prior to start of design and production work, as a minimum, includes the following:
  - Design Parameters;
  - Design methodology including FEA tools to be used as agreed by PETROBRAS;
  - Proposed material specifications;
  - Chemical composition and mechanical properties of steel components (yield strength, tensile strength, percent elongation, area reduction and other required properties);
  - Component material lists and descriptions, including designation of any Proprietary material, whose technical specification may be revised by PETROBRAS in SUPPLIER premises;
  - List of Design Drawing to be provided;
  - Design calculations and reports for each element to be provided.

In bidding phase, In case of direct purchase by PETROBRAS, the following documentation\ informations are requested to be issued (Technical Proposal):

- Technical Review, comprised by:
  - Preliminary GA drawings, with the following minimum information: main dimensions, view showing the assembly to the receptacle with any centralizer piece (if required) and the maximum free angle, and confirming elevation "A" of Figure 6.1, as per [2] or [5];
  - A summary list of material selection of main metallic and non-metallic parts (forgings, *Reinforcement* and elastomeric compound);

  - *Bellows* description, or justification for the nonuse of *Bellows* barrier for the cases listed in sec. 6.2.2;
  - Cladding and NDT Procedure Proposal;
  - Detail for the *Extension* locking system, and if WETS is required, also provide a brief description of the remote disconnection tool and disconnection procedure, adherent with the provisions of sec. 5.2.8, and relevant track record of supply and tests;
  - External coating specification (preliminary);
  - Rotational stiffness curves, for each FXJ type, with temperature correction factors, if applicable, observing the "not to exceed" stiffness values according to section 6.7;
  - FXJ testing and test bench description, in line with the provisions of section 9;
  - Technical notes of previous design and material qualification tests, as per [10];
  - Any technical clarification and alleged exceptions or request for requirement deviation from Project Specifications (this included);
  - Mock–up drawing (preliminary), indicating the typical tolerances (gaps) between FXJ and Receptacle in accordance with [22] (optional, see Table 5.1);
  - *Bellows* Leak detection Device Proposal (optional, see Table 5.1);
  - Pull-in head description (optional, see Table 5.1).
- Typical Manufacturing Plan/ Procedure;
- Typical Quality Control\ Management Plan;
- HSE
- Typical ITP;
- Typical NCR form;
- SUB–SUPPLIERs list;

The final documentation of the detailed Project shall include:

- Design Basis and Methodology;
- Design Report;
- FMECA report of operational phase (and of the installation phase, in case of PETROBRAS direct purchase);

- Final stiffness curves and temperature correction factors, if applicable.
- Manufacturing Procedure Specification (MPS) to be submitted to PETROBRAS for review prior to start of design and production work, as a minimum, includes the following:
  - Procedures including process control plans;
  - Testing and Inspection Plan with monitoring points identified;
  - Factory Acceptance Testing.
- Inspection and test reports;
- As-built drawings or as-built dimensional reports;
- Inspection and test records, and procedures as defined by this Specification.

The QA/QC, DBM and MPS shall be written specifically for the PURCHASE ORDER and shall be approved by PETROBRAS prior to commencement of manufacturing operations.

SUPPLIER shall notify PETROBRAS of any changes in these practices for PETROBRAS review/approval prior to implementation.

Design calculations and reports of the Flexible Joint shall be issued to PETROBRAS for review prior to the manufacturing.

Nonconformity reports shall be issued to PETROBRAS within the contractual deadline.

All nonconformity reports, including concession requests, shall be submitted to PETROBRAS for review.

10.5 INPECTION AND MAINTENANCE MANUAL

SUPPLIER shall present an inspection and maintenance manual for the *Flexible Joints*.

This manual shall present, at least, any inspection necessary to avoid the *Flexible Joint* failure during the whole specified project operational life.

All necessary tools, inspection methodology, acceptance criteria and inspection interval shall be present in this manual, for each necessary inspection.

10.6 *FLEXIBLE JOINT* AND MOCK–UP DRAWINGS

Prior to start of manufacture, General Assembly drawings shall be supplied to PETROBRAS for review. Subsequent revisions to drawings shall also be issued to PETROBRAS for review, as they are prepared. GA drawings shall include the following as a minimum:

For Mock–ups:

- Mock up as per ref. [22] (for Receptacle) and/ or ref. [23] (for HOA), and:
- Elevation A of Figure 6.1;
- Position of the CoG (in air);
- Total weight;
- Material identification;
- Details of handling attachments;
- Dimensional details of the standard flange and test port (if required), or the top interface system selected for the Project;
- Assembly between the Mock–up and the Project specified Receptacle or Tubular Support, showing the nominal gaps values and tolerances at the lateral contact region(s), in case of Receptacle assembly.

For Flexible Joints:

- Interface, overall dimensions and tolerances (including total length, distance from CoR to *Extension* end, elevation “A” of Figure 6.1, *Body* diameter and *Body*’s external profile);
  - Presented dimensions and tolerances shall be sufficient to FPU constructor to design the topside hard pipe spool.
- Position of the CoR and CoG (in air and water);
- Total weights;
- Product tag positioning and identification pattern (see sec. 10.7.1);
- Material identification ~~and source part number~~;
- Details of handling attachments.

- Dimensional details of the standard flange and test port (if required), or the top interface system selected for the Project;

- Extension profile detail scheme, showing the sectional variation along the inner and outer sides of the extension: lengths, positions of each taper start and end along the Extension, each outer diameter at geometric transition sections, and inner diameter variations (steps) if any.

- Dimension and dimensional tolerance of diameters and thickness (including CRA layer if required) at the *Extension* or pup piece end;

- Detail of the external coating coverage and “cut–back”.

- Assembly between FXJ and the Project specified Receptacle, showing any auxiliary device (such as centralizer piece), the *Extension* at the normial and at the maximum free angle positions, and nominal gaps values and tolerances of the *Body*/ centrelizer piece at the lateral contact region(s) with the Receptacle.

- Temporary devices views (when applicable): locking system for handling assembled in the FXJ. Lay down tool views on the “compressed” (assembled) and on the released configurations in the FXJ. View of the protective bipartite shroud assembled onto the FXJ.

10.7 TRACEABILITY AND MARKING

- Raw material traceability of components shall be established during fabrication, verified at receiving inspection, and shall be fully documented throughout the entire manufacturing process;

- Product tagging, per sec. 10.7.1;

- SUPPLIER shall use an individual mark (P\N) for each fabricated part;

    - SUPPLIER shall provide a list of the parts P\N per FXJ tag, as per sec. 10.8.

- This mark, transferred on the associated documentation, shall allow a proper traceability;

- Manufacturing operator and Inspector mark;

- On all kind of documents (Manufacturing or test router, report or ITP), the person who shall handle the task will affix his own mark and signature.

10.7.1 FLEXIBLE JOINT ASSEMBLY TAGGING

The identification tagging of the Flexible Joints of the Project shall be marked as indicated in Table 10.1 and Figure 10.1, on the top of the Extension, and on two diametrically opposed sides.

Stencil mark caracters of the FXJ tagging shall be approx. 70mm high and shall be in black.

The tag is to be used for identification purpose during manufacture, installation and facilitate the identification in periodic inspection during service life.

Table 10.1 – Tagging Formation for Flexible Joint.

FXJ–	Condensed Project/ Field Name or acronym –	PO (for Oil Production) (1)	ID”(2)	–X(3)
		PG (for Gas Production) (1)		
		WI (for Water Injection) (1)		
		GI (for Gas Injection) (1)		
		WAG (for Water Alternating Gas Injection) (1)		
		GE (for Gas Export) (1)		
		OE (for Oil Export) (1)		
		GL (for Gas Lift/ Service) (1)		

(1) If one FXJ is designed to performs two functions, both tags shall be written (separated or not by bar “/”).
(2) Inner diameter in inches. It may be omitted if only one ID for a specific function (or both functions, in case of convertible FXJ) is present.
(3) Alphabetic sequential by order of fabrication (i.e., moulding/ assembling of the Extension to the Body) per function, per ID. It may be omitted if only one FXJ of a kind is present.

Examples of possible tags: FXJ–MERO4–PO8”–A; FXJ–BUZ9–GL5.13”–A; FXJ–BUZ6–GE; FXJ–SEP2–PWAG8”–C.

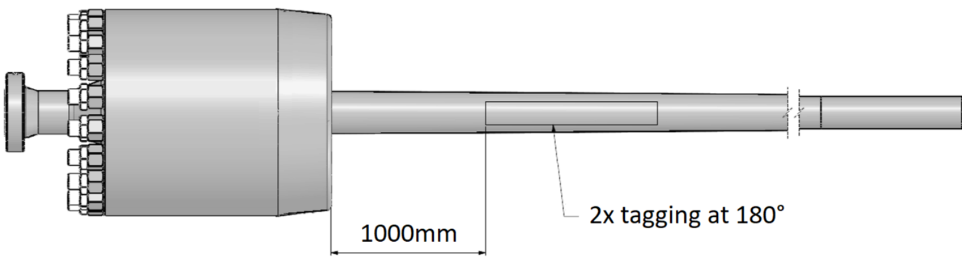

Figure 10.1 – Flexible Joint Tagging.

10.8 DOCUMENTATION REQUIREMENTS (DATA BOOK)

Copy of a final report for each manufactured FXJ shall be submitted to PETROBRAS for review and approval prior to final acceptance. This report shall contain Purchase Order number, part number, dash number, serial number, actual weight, all material certifications, dimensional verification, test results and on-site verification of current visual examination compliance by site inspectors and surveyors, and shall certify that the product was manufactured and inspected in accordance with the requirements of applicable drawing(s) and this Specification.

Additional documentation shall be submitted in accordance with PETROBRAS’s Requisition.

SUPPLIER shall submit a detailed description of the manufacturing process.

SUPPLIER shall document the design with drawings and calculations.

All tests and clarifications required for the design acceptance and the evaluation of the Flexible Joint shall be submitted.

SUPPLIER shall submit the quality control procedures for PETROBRAS review and approval.

SUPPLIER shall submit document stating all deviations to this Specification.

SUPPLIER shall include a traceability list for each fabricated parts per P\N, at least for the main parts highlighted in bold in System Description of sec. 1.3, associated with each assembled FXJ by their tags.

10.9 INSPECTION AND TEST PLAN

This section concerns the product fabricated by SUPPLIER as well as the product purchased by SUPPLIER.

At the beginning of the Project, within the contractual deadlines, the Inspection and Test Plans (ITP) for all stablished items shall be issued for PETROBRAS comments. SUPPLIER shall obtain with PETROBRAS all self assigned Inspection points (mainly Hold and Witness points) before the start of the manufactures.

The same document shall be used by the SUPPLIER and its SUB–SUPPLIER.

The following ITP shall be produced:

- *Flexible Element* ITP;
- *Steel Reinforcements* (Interleaves spun plates) ITP;
- Forgings ITP(s);
- Machining ITP(s);
- Coating/ painting ITP;
- Cladding ITPs (structural clad and sealing surfaces);
- *Flexible Joint* ITP (assembly, moulding, final painting, tests, etc.).

The ITP sums up the inspection points, applied by:

- SUB-SUPPLIER;
- SUPPLIER;
- PETROBRAS and CONTRACTOR;
- 3rd Party Inspection.

The ITP shall be submitted for PETROBRAS review. All PETROBRAS holding and witnessing points shall be confirmed prior to start of manufacturing.

The inspection points are defined hereafter:

Table 10.2 – Inspections Points and Definitions

Inspection Level	Definition
H: Hold Point	A point at wich work cannot progress beyond, until the activity has been witnessed or written approval has been given by the parties who have designated the hold point.
W: Witness Point	A point where the opportunity to witness shall be given to the parties who have designated the witness.
W1: FoaK	A Witness Point limited to the First of a Kind event.
M: Monitor Point	Activity surveillance on a random basis to verify compliance with contract specifications and procedures.
R: Review Point	Evaluation of Project generated documentation.

Contractual aspects of the inspections (including notification for inspection issual deadline and notification date revision) shall adhere to the Contractual Guidance for Quality Management, as per [1].

APPENDIX A – FORGING QUALITY TEST SAMPLE – DNVGL-ST-F101

A.1 – Extension

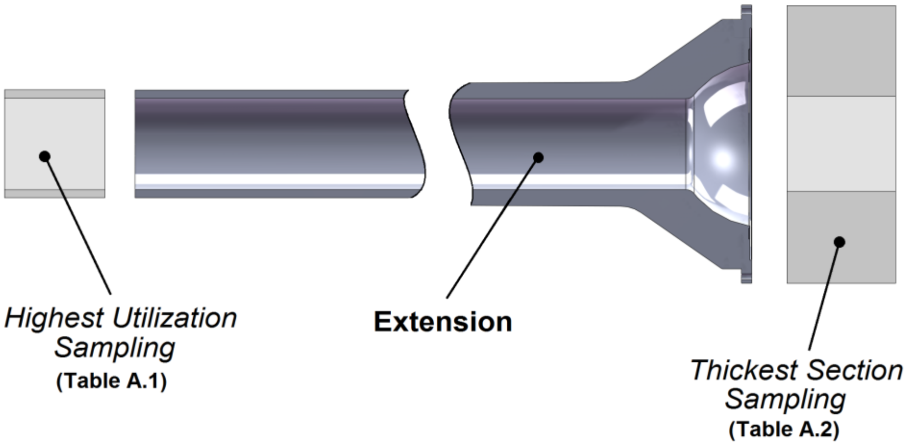

Figure A.1 – Riser Extension and Test Samples Locations

Note: Quality test Samples shall meet DNVGL–ST–F101 ([26]), sec.8 requirements. Prolongations or rings with same material, thickness, forging reduction, from each heat and heat treatment batch are acceptable.

Table A.1 – *Extension* Highest Usage Factor Section Testing

Tensile	2	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Charpy	2 sets	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets
CTOD	3	Longitudinal specimens

Table A.2 – *Extension* Thickest Section Testing

Tensile	1	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One set in the tangential direction 2 mm below the internal surface
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets

A.2 – Body

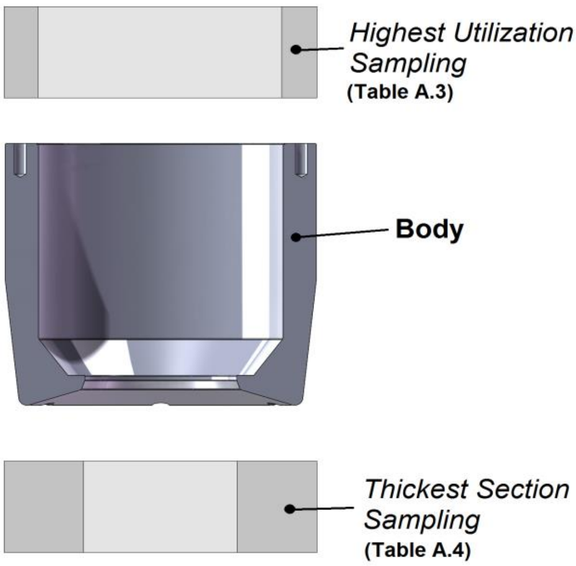

Figure A-2 – Flexible Joint Body and Test Samples locations

Note: Quality test Samples shall meet DNVGL–ST–F101 ([26]), sec. 8 requirements. Prolongations or rings with same material, thickness, forging reduction, from each heat and heat treatment batch are acceptable.

Table A.3 – *Body* Highest Usage Factor Section Testing

Tensile	2	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Charpy	2 sets	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets

Table A.4 – *Body* Thickest Section Testing

Tensile	1	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One set in the tangential direction 2 mm below the internal surface
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets

A.3 – Attached Flange

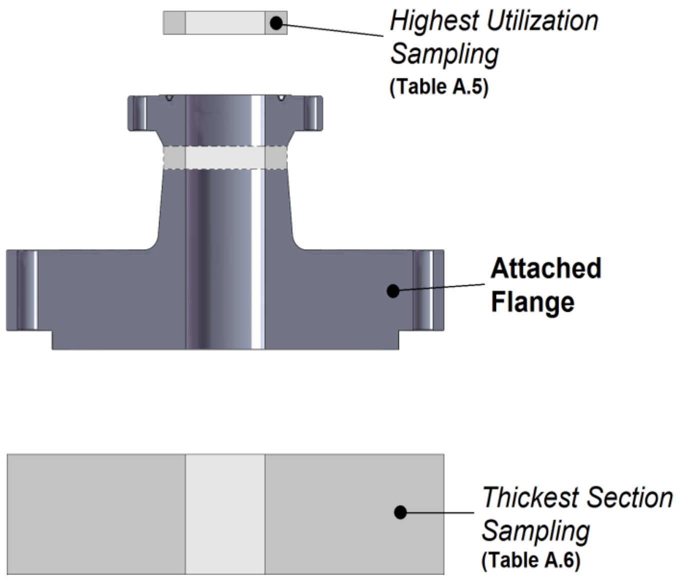

Figure A.3 – Attached Flange and Test Samples locations

Note: Quality test Samples shall meet DNVGL–ST–F101 ([26]), sec. 8 requirements. Prolongations or rings with same material, thickness, forging reduction, from each heat and heat treatment batch are acceptable.

Table A.5 – *Attached Flange* Highest Usage Factor Section Testing

Tensile	2	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Charpy	2 sets	One mid thickness specimen in both tangential and axial direction from the area with highest utilisation (after final machining)
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets

Table A.6 – *Attached Flange* Thickest Section Testing

Tensile	1	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One specimen in tangential direction from the thickest section 1/4WT below the internal surface and at least T or 100 mm, whichever is less, from any second surface.
Charpy	1 set	One set in the tangential direction 2 mm below the internal surface
Metallographic	2 sets	As for the CVN impact testing sets
Hardness	2 sets	As for the CVN impact testing sets
Corrosion Test		Sour

APPENDIX B – STANDARD INPUT DATA SHEET FOR *FLEXIBLE JOINT* DESIGN

Attached to this document it is presented an Excel file with a model of PETROBRAS standard input data sheet for Flexible Joint design, constructed in accordance with main FXJ SUPPLIERS. A PETROBRAS filled version of this standard data sheet, with Project data, will be issued to CONTRACTOR or SUPPLIER during the BID phase (depending on the chosen purchasing strategy, as per sec. 1.2).

When FXJ supply is within a EPCI contract, the definitive inputs for component design is a CONTRACTOR responsibility. CONTRACTOR is free to include or exclude items in the datasheet according to it’s own understanding.

APPENDIX C – TYPICAL TRANSIENT FLOW CONTIDITONS

The typical transient flow sequences according to the riser fuction, which normally occur during Project service life, are outlined in this appendix. These informations complement the “Pressure Cycles” section of Project Data Sheet for Flexible Joint design, [5]. Some riser, events or operations may be disregarded depending of Project scope of work and operational philosophy, and thus may not be informed in the Project Data sheet. The following events\ operations are outlined below.

PETROBRAS may present, in contractual documents ([2]), a detailed profile of pressure and temperature variation along the time for some of all of these operations. In these cases, it is preferred to consider the detailed profile to datasheet values.

- Short / Partial Shutdown: event characterized by the shutdown of the system and subsequent restart of the operation.
- Long / Full Shutdown: event usually characterized by the shutdown of the system, riser depressurization, diesel (or dead oil) circulation and restart of operation.
- Diesel or dead oil circulation: operation consists in circulate diesel (or dead oil) thru the service line ir order to remove the operational fluid from the pipeline and fill it with diesel or dead oil. It may be performed also for pigging operations.
- Bullheading: operation performed in order to remove the operational fluid from the pipeline, injecting it into the reservoir.
- WAG Cycle: In WAG injection lines, operation performed during the change of operation mode (water to gas or gas to water). Consists in system shutdown, diesel or dead oil circulation and restart of operation.