PETROBRAS	TECHNICAL SPECIFICATION	Nº: I-ET-0000.00-0000-24A-P9U-001	
	CLIENT: --		SHEET: 1 of 14
	JOB: --		--
	AREA: --		--
-	TITLE: RIGID SPOOL STRUCTURAL DESIGN		EDD/EDR
			-

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	General revision.
B	General revision.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	06/12/2017	23/11/2020	02/09/2022						
EXECUTION	UT6L	UT6L	UT6L						
CHECK	CTWI	CTWI	CTWI						
APPROVAL	CLZ2	CLZ2	CLZ2						

TABLE OF CONTENTS

1 INTRODUCTION

1.1 OBJECTIVE

The present document presents the minimum scope and deliverables of subsea Rigid Spool (here referred to as Spool) structural design (here referred to as design).

1.2 SCOPE

This document addresses:

- The design of the Spool with respect to mechanical and fatigue resistance, comprising of all straight pipes, pipe bends, reductions and welds (including the welds with the connectors);
- The loads acting on all spool connections (mechanical connectors, flanges etc).

The following items may need to be properly accounted for in the Spool design activities, but their design is out of scope of this document:

- Connectors (mechanical connectors, flanges etc), connector pup-pieces, valves etc;
- Strakes, buoyancy modules, insulation, coating, anodes and any sort of accessory attached to the linepipes and pipe bends;

Concerning all aspects not specifically covered in the present document (e.g.: corrosion, corrosion protection, material choice, fragilization etc), CONTRACTOR must comply with the Master Project Specifications and contractual requirements.

This document does not address the Spool installation, which is covered in ref. [7].

1.3 DEFINITIONS AND ABREVIATIONS

CF	Cross-Flow
FSHR	Free Standing Hybrid Riser
IL	In-Line
LRTA	Lower Riser Termination Assembly
Master Project Specification	Document which contains the Project basic technical specifications
MEG	Mono-Ethilene Glicol
OD	Outside diameter
PLET	Pipeline End Termination
PLEM	Pipeline End Manifold
Project	Project addressed by the Master Project Specification
Rigid Spool	Assembly of rigid pipes and rigid pipe bends used to connect a subse pipeline to another subsea structure
SCF	Stress Concentration Factor

Spool configuration	Spool geometric shape
Spool connection	Connection component welded to the spool end (Mechanical connectors, flanges etc)
System Pressure Test	Pressure test executed on the subsea pipeline system after the spool is connected.
Target Box	Area of uncertainty for the hub position prior to the structure installation
VIV	Vortex Induced Vibration

2 PREMISSES

2.1 MASTER PROJECT COMPLIANCE

The Spool design must comply with the Master Project Specification in every aspect.

2.2 SCENARIOS

The Spool design must address at least the Project applicable scenarios specified below. It is worth noting that these scenarios may occur in a different order than presented here, and that the spool extremities displacement range considered for each must cover all possibilities throughout design life.

- As-Landed
- Empty
- System Pressure Test (see NOTE below)
- Operation scenarios (including the full range of steady flow conditions, transient conditions, shut-down, packing, shut-in, cleaning and maintenance operations and incidental operation)
- Accidental

Additional scenarios may be required (e.g. innertization, hibernation…), depending on the project installation procedure, operational characteristics, interface loads requirements, chosen design code or other reasons. It is CONTRACTOR's responsibility to identify all additional relevant scenarios for dimensioning and design verifications.

NOTE: Within this document, System Pressure Test comprises any kind of pressure test executed with the spool in-place. Such tests may be referred to as “Leak Test”, “System Test” or similar terminology throughout the Project documentation. Such test conditions shall be included in the design scenarious even when the test execution is out of CONTRACTOR's scope of service. If there is any doubt concerning the System Pressure Test scenario, a Technical Query must be sent to PETROBRAS for clarification.

2.3 SPOOL CONFIGURATIONS

At least 3 configurations (Near-Near, Nominal and Far-Far) must be considered to cover Target Box uncertainties.

If fundamental changes in spool configuration and/or boundary conditions are expected in order to cover the Target Box uncertainties (e.g. soil contact or buoyance modules up from a certain hub-hub distance), more configurations may be required.

2.4 LOADS

CONTRACTOR must consider all applicable loads in design verifications for each scenario. The list below anticipates commonly expected loads to be accounted for, although it may not cover all possible loads. It is CONTRACTOR's responsibility to identify all applicable loads for each scenario.

2.4.1 Weight and buoyancy of spool and all its components (connectors included).

2.4.2 Misalignments: The Spool is expected to experience pre-stress from misalignments (linear and angular) due to fabrication and metrology tolerances / uncertainties. CONTRACTOR must encompass all possible combinations of misalignments and other loads.

2.4.3 Internal and External Pressure

2.4.4 Temperature (including the difference of temperature between fabrication, installation and operation)

2.4.5 Currents and Waves (Meteocean), including drag coefficient amplification due to VIV (DNV-RP-F105 [6] item 5.4)

2.4.6 End connections displacements:

2.4.6.1 Pipeline axial displacements[1], see Figure 1;

2.4.6.2 Structure settlements[2];

2.4.7 Riser movements: spools connected to the base of a FSHR, riser tower or similar must consider the envelope of movements of these structures.

2.4.8 Dynamic and Inertia loads: There are cases in which Dynamic and Inertia effects may be significant, and Spool design must properly account for them by means of non-linear dynamic analyses. It is CONTRACTOR's responsibility to identify such cases, analyse and document accordingly. Special attention is brought to Spools connected to FSHR, which may experience dynamic coupling from LRTA movements.

2.4.9 VIV: the Spool design must consider VIV according to DNV-RP-F105 [6], with special attention to Appendix A, with the following amends:

2.4.9.1 The Fatigue damage calculation must account for the cyclic Axial, Bending and Torsional loads acting on the spool sections. Cyclic Principal Stresses must be considered (see DNV-RP-F105 Appendix A item A.8.5).

2.4.9.2 The partial safety factors associated to natural frequencies must be those associated with "Not Well Defined" classification (ref. [6] Table 2-3).

2.4.9.3 Sreening fatigue criteria (DNV-RP-F105 [6] item 2.4) is not accepted.

---

[1] Lower Bound to Upper Bound soil conditions shall be considered to determine maximum and minimum pipeline displacements. Cyclic effects (e.g.: walking) must also be taken into account.

[2] Lower Bound to Upper Bound soil conditions shall be considered to determine maximum and minimum differential settlements. If structures tilt is foreseen after spool connections the corresponding connector rotation and displacements must also be considered in the Spool design.

2.4.9.4 Extreme load analyses must consider drag coefficient amplification described in DNV-RP-F105 [6] item 5.4 and VIV induced loads.

2.4.9.5 The current and wave induced particle velocity must be taken at a height from seabed coherent or conservative with respect to the point of the spool under evaluation.

2.4.9.6 If any spool section's gap with the seabed is shorter than 0.8OD, the gap effect must be accounted for on added mass of this section (see DNV-RP-F105 [6] item 6.6.7).

2.4.10 Internal flow associated loads: the Spool design must consider loads associated with internal flow whenever applicable. Examples are slugs, hammering forces, etc.

2.4.11 Spool-soil interaction: if the spool is expected to touch the seabed in normal or ab-normal conditions, the Spool design must consider loads associated with soil interaction (e.g.: normal reaction, friction etc).

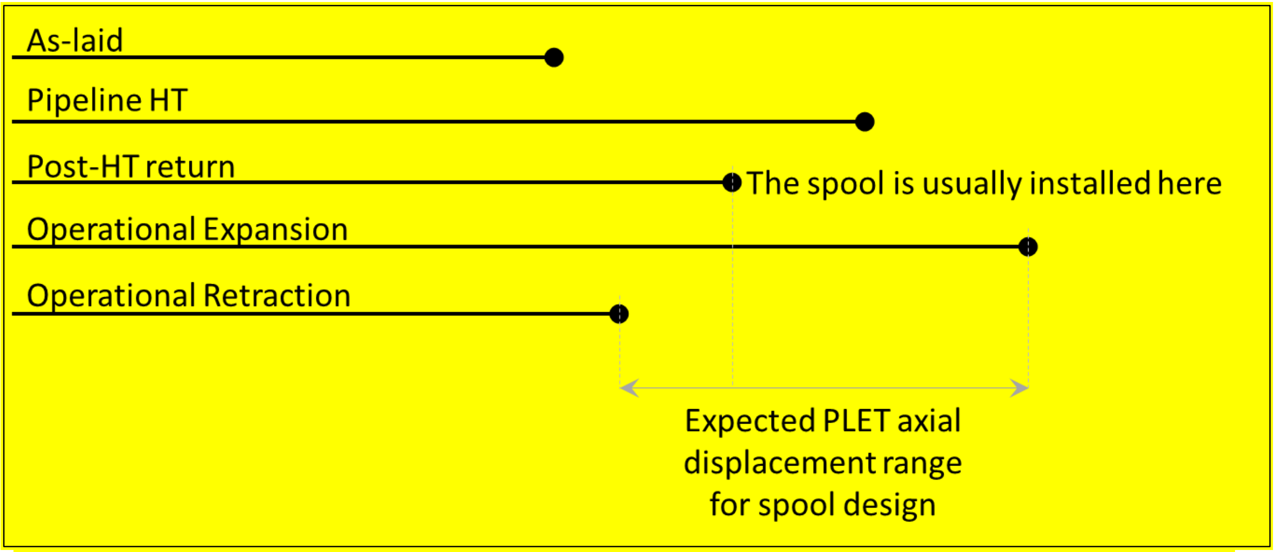

Figure 1 – Expected range of PLET axial displacement for spool design in typical installation sequence, where the spool is installed after the pipeline Hydrostatic Test (HT). The displacements are purely illustrative with respect to the proportion of displacements. Please note that Operational Expansion and Retraction must incorporate full range of operational conditions (shut-down, incidental, etc) and cyclic effects (e.g. Pipeline Walking).

3 ANALYSES

3.1 GLOBAL FINITE ELEMENT MODEL

The Spool configurations must be analysed through Finite Element (FE) models. The FE models must attend the following requirements:

3.1.1 The mesh must be sufficiently refined for the analyses purposes.

3.1.2 The load application steps must be coherent with the expected installation/operation sequence.

3.1.3 The model characteristics must be conservative with respect to the calculation of loads along the Spool and interface loads.

3.1.4 Fabrication/metrology misalignments must be applied as prescribed displacements/rotations on the connectors.

3.1.5 The connectors must be modelled as rigid components with due dimensions and mass. The connector pip-piece must be modeled as a pipe with its own characterisitics.

3.2 LOAD CASE MATRIX

The following load case matrix must be applied to every Spool configuration. This load case matrix constitutes a minimum scope; additional cases may be necessary depending on the Project particularities.

3.3 INDUCTION BEND FINITE ELEMENT MODEL

The 3D FE model for induction bends assessment described in item 4.3 must attend the following requirements:

3.3.1 The geometry must consider the post-bending extrados bend thinning and section ovality;

3.3.2 The geometry must not consider the post-bending intrados bend thickening unless the induction bends MPQT and ITP control this parameter;

3.3.3 The mesh must be built with 3D solid elements;

3.3.4 The model must consider geometric non-linearities (large displacements and rotations);

3.3.5 The mesh must consider elasto-plastic material behavior with lower bound resistance.

3.3.6 The bend 3D model extension (e.g. tangent length) must be coherent with where the loads from the global model will be extracted.

Table 1 – Load Case Matrix

Scenario	Parameters (Notes 1, 2)					
	Internal Pressure	**Internal Fluid Weight**	**Temperature**	**Differential Pipeline End Displacement (Note 3)**	**Differential Settlement Between Structures**	**Fabrication & Metrology tolerances / uncertainties (Note 7)**
As-Landed	Applicable	Applicable	ambient	zero	min./max.	all combinations
Empty	zero	zero	ambient	zero/max. **(Note 4)**	min./max.	all combinations
Flooded	Column	water filled	ambient	zero/max. **(Note 4)**	min./max.	all combinations
System Pressure Test	Test Pressure	water filled	ambient	zero/max.	min./max.	all combinations
Operation (Notes 5, 6)	min./max.	Associated to pressure and temperature	min./max.	min./max.	min./max.	all combinations
Incidental (Note 6)	incidental	Associated to pressure and temperature	Zero/design	min./max.	min./max.	all combinations
Accidental	min./max.	Associated to pressure and temperature	min./max.	min./max.	min./max.	all combinations

Notes:

1) All combinations of the applicable environmental loads (Hydrodinamic loads and Riser movements) shall be included in the load case matrix.
2) All columns shall be considered as independent parameters unless it is explicitly defined here as associated. E.g.: For Flooded Scenarion, the following combinations of Structures displacement Range and Differential Settlement Range must be considered: (zero; min.), (zero; max.), (max.; min.), (max; max).
3) Minimum diferential end displacements must be the minimum of all calculated values and zero. Maximum differential end displacements must be the maximum of all calculated values and zero.
4) Unless residual differential pipeline end displacements are calculated for the post System Pressure Test Empty and Flooded conditions, the maximum value adopted shall be the same one from System Pressure Test condition.
5) Min./max. values shall consider all operational profiles, including transients, Shut-down, Shut-in, packing, cleaning and maintenance operations etc.
6) For pipelines that operate with different fluids, different sets of operation load cases shall be define for each fluid.
7) The linear and angular misalignments to be considered must cover at least the interval defined by the acceptance interval for deviation of a dimensional control measurement from the corresponding field measurement plus the interval defined by ± 3 times the Combined Standard Uncertainty (defined in [8]) of the measurements (field and dimensional control).

4 DESIGN CRITERIA

4.1 DESIGN CODES

Table 2 specifies the codes that must be used for the Spool design. The most recent issues of each code must be used.

Table 2 – Design Codes

Component	Code	
	Mechanical Resistance	**Fatigue**
Straight Pipes	DNV-ST-F101	DNV-ST-F101 + DNV-RP-C203
Induction Bends	(either one of the following) • DNV-ST-F101 (Section for Alternative Allowable Stress Design for Induction Bends)* • ASME VIII Div. 2 • ASME B31.8 / ASME B31.4, as applicable, plus section 4.3 below.	
Diameter reduction	To be agreed with COMPANY	To be agreed with COMPANY
*All checks with DNV-ST-F101 section 5.6.2 criterion must consider wall thickness thinning.		

4.2 ALLOWABLE INTERFACE LOADS

The Spool design must meet the restrictions on the connection loads (allowable loads on the connectors, flanges, structures etc).

4.3 INDUCTION BENDS COMBINED LOADS ASSESSMENT UNDER EXTERNAL OVERPRESSURE

As an alternative to DNV-ST-F101 item 5.6.2 criteria validity limitations or ASME VIII Div. 2, 3D FE analysis may be used to assess the bend resistance to combined loads, verifying if it withstands the design loads This is considered fulfilled if the FE bend model does not fail (i.e. no excessive section deformation and loads can be further increased) under the load combination described as follows.

The external pressure $p_{ext,FE}$ must be applied so that the difference between external and internal pressure $(p_{ext} - p_{int})$ is multiplied by a safety factor of $\gamma_m \cdot \gamma_{SC,LB}$:

$$p_{ext,FE} - p_{int,FE} = \gamma_m \cdot \gamma_{SC,LB} \cdot (p_{ext} - p_{int})$$

$p_{ext,FE}$= external pressure applied in the FE model

$p_{int,FE}$= internal pressure applied in the FE model

p_{int}= actual internal pressure

p_{ext}= actual external pressure

$\gamma_m, \gamma_{SC,LB}$: defined in DNV-ST-F101 section 5

The design forces and moments at bend ends, generically referred to as $P_{Sd,i}$, must be applied on the FE model multiplied by the equivalent safety factor $\gamma_m \cdot \gamma_{SC,LB}$ as follows:

$$P_{EF,i} = \gamma_m \cdot \gamma_{SC,LB} \cdot P_{Sd,i}$$

Where:

$P_{Sd,i}$= design force or moment component, calculated as per DNV-ST-F101 item 4.7.3 Design Load Effect.

$P_{EF,i}$= force or moment component applied on the FE model, $i = 1,2,3$

$\gamma_m, \gamma_{SC,LB}$: defined in DNV-ST-F101 section 5

The $P_{Sd,i}$ load components picked for 3D FE analyses must cover all loads from the spool global analyses. This must be clearly demonstrated in graphs and/or tables.

FE model requirements for this analysis are given in section 3.3.

5 DELIVERABLES

5.1 DESIGN PREMISES

CONTRACTOR must provide a Spool Design Premisses Report for previous approval, containing all premises and criteria for Spool design, adequately referenced.

The Spool Design Premisses Report must contain a detailed load case matrix clearly showing the applied loads for each scenario.

5.2 FLEXIBILITY REPORT

CONTRACTOR must provide a Flexibility Report demonstrating that the Spool design complies with contractual, code and interface loads requirements.

The Design Report minimum content comprises:

5.2.1 Spool sketch(es) / drawing(s) showing all coordinate systems used in the analyses and report of results (specially interface loads);

5.2.2 Reference to issued drawing(s) of the considered Spool configurations showing all relevant design data;

5.2.3 Detailed input and output file(s) in editable format (.csv, .txt, .xls, .xlsx or equivalent) containing complete lists of input parameters and analysis outputs for each Spool Configuration and evaluated Scenario. The files must follow the template provided in Annex 1. Inputs and outputs provided only in image or pdf format will not be accepted;

5.2.4 Tables with resumed outputs (maximum criteria checks, maximum loads etc) identifying which cases are being informed, and graphs containing unity check distribution for most relevant cases (also identified).

5.2.5 End connector load coordinate systems and convention: The connector loads must be informed at the Hub faces/Flange faces. The coordinate system and sign convention for load report (loads acting on the structure or acting on the spool) must also be clearly reported.

5.2.6 Other auxiliary calculation spreadsheets.

5.3 OPERATIONAL CYCLING FATIGUE REPORT

CONTRACTOR must provide an Operational Cycling Fatigue Report demonstrating that the Spool design complies with contractual and code fatigue requirements.

The Design Report minimum content comprises:

5.3.1 Spool sketch(es) / drawing(s) showing all coordinate systems used in the analyses and report of results (specially interface loads);

5.3.2 Reference to issued drawing(s) of the considered Spool configurations showing all relevant design data;

5.3.3 Fatigue stress histograms and damage at each weld;

5.3.4 End connection cyclic loads;

5.3.5 SCF calculations;

5.3.6 Other auxiliary calculation spreadsheets.

5.4 VIV REPORT

CONTRACTOR must provide a VIV Report demonstrating that the Spool design complies with contractual and code requirements concerning VIV.

The VIV Report minimum content comprises:

5.4.1 Spool sketch(es) / drawing(s) showing all coordinate systems used in the analyses and report of results;

5.4.2 Reference to issued drawing(s) of the considered Spool configurations showing all relevant design data;

5.4.3 Vibration mode classification as IL/CF/both depending on the the spool “leg” and flow direction (see DNV-RP-F105 Appendix A item A.4);

5.4.4 VIV fatigue damage per mode and total for all contributing modes. For modes that can be considered as both IL and CF, it must be evident that the highest damage was considered;

5.4.5 VIV Fatigue stress histograms and damage at each weld;

5.4.6 Other auxiliary calculation spreadsheets.

6 ANNEX

Annex 1 Input_Output_Template=B.xlsx	CONTRACTOR must include one file per Spool configuration / scenario following this template. Columns may be added in order to adapt the template to specific project particularities.

7 REFERENCES

[1] DNV-ST-F101, Submarine Pipeline Systems

[2] ASME Boiler and Pressure Vessel Code VIII - Division 2

[3] DNV-RP-C203, Fatigue Design of Offshore Steel Structures

[4] ASME B31.8, Gas Transmission and Distribution Piping Systems

[5] ASME B31.4, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

[6] DNV-RP-F105, Free Spanning Pipelines

[7] I-ET-0000.00-0000-966-P9U-001, Installation Analysis

[8] ISO/IEC Guide 98-3:2008, Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)