PETROBRAS	**TECHNICAL SPECIFICATION**	N°: **I-ET-0000.00-0000-940-P9U-002**	
	CLIENT:		SHEET: 1 of 15
	JOB:		CC:
	AREA:		PROJECT:
DDP	TITLE: **RIGID PIPELINE ON-BOTTOM ROUGHNESS AND FREE SPAN DESIGN**		I EDD/EDR

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	GENERAL REVISION

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DATE	06/12/2017	23/12/2020							
PROJECT	EDD/EDR	EDD/EDR							
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1 INTRODUCTION

1.1 OBJECTIVES

This Technical Specification establishes the minimum scope of work, minimum technical requirements and minimum deliverables related to the On-Bottom Roughness (OBR) analysis and Free Span (FS) design of rigid subsea pipelines.

The main objective of OBR analysis and FS design is to document that the expected pipeline configurations satisfy the combined load local buckling and the fatigue limit states criteria for all conditions (from as-laid to the end of design life).

1.2 SCOPE OF WORK

The scope of OBR analysis and FS design activities comprises:

- To determine the pipeline deformed configuration due to the seabed bathymetry and associated section loads, stresses, strains, etc.
- To predict the FS locations and characteristics
- To design against FLS and ULS
- To provide stress histograms and static stresses for ECA
- To define of the mitigations required to satisfy the limit state criteria and to estimate loads for mitigations design
- To calibrate the FE models against surveys after pipeline construction and re-evaluate the results from design phase.

1.3 SCENARIOS

The OBR and FS design activities must cover all scenarios from as-laid to end of operation, including permanent, transient and temporary conditions. Specific scenarios are detailed in sections 3 and 4.

In addition to the scenarios established in this Technical Specification, CONTRACTOR shall perform and include on the deliverables, all analyses judged necessary, based on its previous experience, particularities of the project and good engineering practice, to assure safe operations and pipeline integrity.

1.4 APPLICATION

This technical specification applies to all pipeline sections excluded dynamic riser sections[1].

1.5 GENERAL REQUIREMENTS

The OBR and FS assessments shall fulfill the requirements of DNVGL-ST-F101 (ref. [1]) and DNVGL-RP-F105 (ref. [2]) and the supplemental requirements defined on this technical specification.

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[1] Only riser sections between the floating production unit and the riser/flowline transition, as defined on ref. [7], are out of the scope of this technical specification.

1.6 ABBREVIATIONS AND DEFINITIONS

PLET	Pipeline End Termination
ECA	Engineering Critical Assessment
EAF	Effective Axial Force
FE	Finite Element
SCF	Stress Concentration Factor
ARQ	Approximate Response Quantities
ULS	Ultimate Limit State
FLS	Fatigue Limit State
FS	Free Span
OBR	On-Bottom Roughness
Pcr	Free span critical buckling load as defined on DNVGL-RP-F105
Master Project Specification	Document containing main project specifications

2 REFERENCES

[1] DNVGL-ST-F101, Submarine Pipeline Systems.

[2] DNVGL-RP-F105, Free Spanning Pipelines.

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

[4] DNVGL-RP-F114, Pipe-soil interaction of submarine pipelines.

[5] DNVGL-RP-F110, Global buckling of submarine pipelines.

[6] I-ET-0000.00-0000-940-P9U-003, Thermomechanical Design of Subsea Pipelines.

[7] I-ET-0000.00-0000-274-P9U-001, SLWR Detailed Structural Design Requirements.

3 ON-BOTTOM ROUGHNESS ANALYSIS

3.1 GENERAL

Pipeline configuration on the seabed shall be evaluated through FE analysis with the following objectives:

- To predict the location and characteristics of FS along the pipeline route for all scenarios
- To evaluate the effectivity of the proposed mitigations
- To provide functional loads for ULS check along the route
- To provide stress blocks, associated to operational cycles, for FLS check.
- To provide stress blocks, associated to operational cycles, and static stresses for ECA.

For pipelines susceptible to global buckling the results of the buckle interaction and walking analysis, ref. [6], shall also be used to confirm/complement the results obtained from the models and scenarios defined on sections 3.2 and 3.3.

The behavior of uplifted spans must be verified according to ref. [5] item 6.3.2. It shall be verified for each analysis scenario whether the uplifted span fulfils the criterion to buckle laterally or not. For scenarios where this criterion is not fulfilled the uplifted span shall be considered in the vertical plane and addressed for all failure modes as any other FS within the scope of this Technical Specification.

3.2 MODELLING

3.2.1 General

The following items need to be properly accounted for in the models:

- Equipment[2] (PLET's, in-line assemblies, etc.)
- Flexibility spools
- Strakes, coating, and any sort of accessory attached to the pipeline
- Mattresses, grout bags, mechanical supports
- Buckle initiators (sleepers, buoyancy sections, residual curvatures, etc.)
- Anchoring[3].

For pipelines with buckle initiators, the OBR assessment must consistently consider the locations and characteristics of the buckles with special attention to their influence on the free spans along the route.

In general, the model must consider the entire pipeline length. For very long pipelines, CONTRACTOR may adopt overlapping sections with appropriate boundary conditions. The overlap length must be long enough to prevent boundary effects on each pipeline section.

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[2] At least, the height of the pipe-equipment connection point and the equipment-soil resistance shall be considered.

[3] The force/displacement behavior of anchors may be dependent on a number of factors like pre-stress, the direction of the pipeline axial movement, soil parameters, gaps, etc.. A non-linear best estimate force/displacement response curve shall be used to account for anchors behavior.

3.2.2 Dimensionality

The FE models must meet the following requirements:

- Pipelines not susceptible to global buckling: 2D, 2½D or 3D.
- Pipelines susceptible to global buckling: 2½D or 3D.

3.2.3 Loads

CONTRACTOR must consider all applicable loads in design verifications for each scenario. At least the following loads shall be accounted for:

- Weight and buoyancy
- Internal and external pressure
- Temperature
- Residual lay tension
- Static riser bottom tension at TDP associated to each scenario.

The above list anticipates commonly expected loads. It is CONTRACTOR's responsibility to identify additional loads and sensitivity analyses applicable for each scenario[4].

3.2.4 Softwares

The FE model must be performed in one of the following softwares:

- ANSYS
- ABAQUS
- SAGE 3D (only for pipelines not susceptible to global buckling).

3.2.5 Pipe-soil interaction

Best estimate soil properties should be considered for definition of vertical, lateral, and axial pipe-soil interaction.

Static vertical reaction curves must be calculated according to DNVGL-RP-F114 (ref. [4]).

In design stage, the OBR model should reproduce the anticipated embedment predicted in Pipe-Soil Interaction far from free span shoulders at each load scenarios. In survey calibration stage, the OBR model shall reproduce the field measured embedment. To achieve these objectives the static vertical reaction curves as calculated in ref. [4] may require some adaptation depending on the FE modelling strategy.

Static lateral and axial pipe-soil interaction should be determined according to DNVGL-RP-F114 (ref. [4]). As alternative, CONTRACTOR may adopt the best estimate lateral and axial pipe-soil interaction resistance determined for the Pipeline Thermomechanical Design (ref. [6]).

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[4] CONTRACTOR should evaluate the relevance of static current loads and perform additional/sensitivity analyses including it if necessary.

Rock and carbonate outcrop locations shall be considered for definition of specific pipe-soil interaction properties.

3.2.6 Pipeline Section Properties

Unless specifically required in project documentation, the pipeline must be modeled with nominal properties, with no wall thickness loss due to corrosion. Exception is made to concrete weight coating thickness, which shall be modeled using the nominal value plus half the tolerance range.

3.3 SCENARIOS

Referring to DNVGL-RP-F105 item 6.5.1, Table 1 and Table 2 show the sequence of scenarios that must be considered for ULS check and FS occurrence prediction.

Table 1 – Load step sequence for single fluid operation pipeline

Step	**Scenario**
1	As-laid
2	Flooded
3	Pressure-test (Hydrotest)
4	Flooded
5	Empty (if applicable)
6	Operation min.
7	Operation med.
8	Operation max.
9	Incidental
10	Shut-down

Table 2 – Load step sequence for pipeline operating with multiple fluids

Step	**Operation fluid**	**Scenario**
1	Project dependent	As-laid
2	Water	Flooded
3	Water	Pressure-test (Hydrotest)
4	Water	Flooded
5	-	Empty (if applicable)
6	1	Operation min.
7		Operation med.
8		Operation max.
9		Incidental
10		Shut-down
11	2	Operation min.
12		Operation med.
13		Operation max.
14		Incidental
15		Shut-down
(…)	(…)	(…)

For each analysis step, boundary conditions must reflect the actual situation of the pipeline.

Proposed mitigations shall be included on all applicable analysis scenarios. This may require design loops.

Table 3 shows how the pressure, temperature and density profiles must be determined for Operation min., Operation med., Operation max., Incidental and Shutdown scenarios.

Table 3 - Operational, Incidental and Shutdown profile choices

Fluid	**Gas**			**Other**		
	Pressure	**Temperature**	**Density**	**Pressure**	**Temperature**	**Density**
Operation min.	0.0	ambient	0	0.0 at riser top	ambient	Minimum density
Operation med.	Intermediate pressure profile (Note 1)	Assoc. with chosen pressure profile (Note 1)	Assoc. with pressure profile (Note 1)	Intermediate pressure profile (Note 1)	Assoc. with chosen pressure profile (Note 1)	Assoc. with pressure profile (Note 1)
Operation max.	Maximal operational pressure profile (Note 2)	Associated with Maximal operational pressure profile (Note 2)	Associated with Maximal operational pressure profile (Note 2)	Maximal operational pressure profile (Note 2)	Associated with Maximal operational pressure profile (Note 2)	Associated with Maximal operational pressure profile (Note 2)
Incidental	Incidental pressure profile	Design Temperature	Associated with Incidental pressure profile	Incidental pressure profile	Design Temperature	Associated with Incidental pressure profile
Shutdown	Shutdown profile (steady state) (Note 3)	Shutdown profile (steady state) (Note 3)	Shutdown profile (steady state) (Note 3)	Shutdown profile (steady state) (Note 4)	Shutdown profile (steady state) (Note 4)	Shutdown profile (steady state) (Note 4)

Notes:

1) This table assumes that the Master Project Specification will provide Pressure, Temperature and Density profile sets for several flow condition, and Operation med. profiles can be easily selected among them. If this is not the case, Operation med. profiles must be obtained by interpolating between Operation max. and Operation min.

2) This table assumes that the Master Project Specification will provide Pressure, Temperature and Density profile sets for several flow condition, and a Maximum operational pressure profile can be easily selected among them. If this is not the case, Operation max. profiles must be: MAOP, Design Temperature and maximum density available.

3) Shutdown scenario for gas: This table assumes that the Master Project Specification will provide Pressure, Temperature and Density steady state profiles or that they can be obtained from shutdown Transient profiles. If this is not the case, Shutdown scenario must consider zero pressure, ambient temperature and zero density.

4) Shutdown scenario for other fluids: This table assumes that the Master Project Specification will provide Pressure, Temperature and Density steady state profiles or that they can be obtained from shutdown Transient profiles. If this is not the case, Shutdown scenario must consider zero pressure at riser top, ambient temperature and minimum density profile.

3.4 ULS CHECK

ULS check shall be performed along all pipeline and for all scenarios. The combined loading criteria for load controlled condition in DNVGL-ST-F101, ref. [1], shall be applied.

For lateral global buckling locations the ULS check defined above may be limited to the bending moment component on the vertical plane, provided the resultant bending moments or strains are check for ULS on thermomechanical analysis documents (ref. [6])

3.5 OPERATIONAL CYCLES FATIGUE

The fatigue damage due operational cycles must be evaluated considering the cycles informed in Master Project Specification. If necessary, extra scenarios must be simulated in addition to scenarios in item 3.3 to obtain the stress ranges.

4 FREE SPAN ASSESSMENT

4.1 GENERAL

FS response to VIV and direct wave action shall be evaluated to provide environmental loads and stress blocks for ULS and FLS check and ECA.

CONTRACTOR has many possible ways to perform the assessment of the Free Spans, both in terms of model type, design criteria and analysis coverage:
Model type:

- Realistic seabed (FE).
- Flat seabed (FE).
- Approximate response quantities - single span[5].
- Approximate response quantities - pinned-pinned [6] (Only accepted for approximation of 1st natural frequency for VIV avoidance.).

Design criteria[7]:

- VIV avoidance (DNVGL-RP-F105 item 2.3)
- Fatigue and ULS criteria (DNVGL-RP-F105 items 2.5 and 2.6).

Analysis coverage:

- Pipeline section or group of spans
- Individualized span or multi-span.

The assessment of FS on sleepers or crossings shall be performed with realistic seabed model.

4.2 SCENARIOS, EXPOSURE TIME AND ENVIRONAMENTAL CONDITIONS

Free span assessment must consider all scenarios in item 3.3 with the exposure period defined on Table 4.

Table 4 – Scenarios and exposure period

Scenario	Exposure Period
All scenarios prior to operation, excluding Pressure-test.	For ULS check, FLS check and ECA the exposure period of each scenario shall be conservatively estimated by CONTACTOR from installation/construction schedule, but not smaller than one month.
Operational min., Operational med., Operational max., and Shutdown.	For ULS check all scenarios shall be considered as permanent operational conditions. For FLS check and ECA the worst scenario shall be considered during the entire service life[8].
Pressure-test	For ULS check this scenario may be considered as temporary condition.
Incidental condition	For ULS check this scenario may be considered as temporary condition.

[5] Refer to DNVGL-RP-F105 item 6.8.1 for validity conditions.
[6] Refer to DNVGL-RP-F105 item 6.8.1 for validity conditions.
[7] Screening Fatigue Criterion (DNVGL-RP-F105 item 2.4) is not accepted.
[8] Unless the COMPANY Design Basis explicitly specifies their duration.

In addition to the scenarios above, CONTRACTOR shall verify on the buckle interaction and walking analyses results whether the FS during shutdown and during normal operational conditions remain stable on the same location and within the range of characteristics predicted by OBR analyses, or not. FS whose location or characteristics differ from those predicted on OBR analyses shall be evaluated considering the exposure period defined on Table 4 for operational conditions and shutdown.

The characteristic environmental conditions for ULS check shall be selected according to the exposure period defined on Table 4 and DNVGL-RP-F105 (ref. [2]). However, for temporary conditions less than three days the 1-year return period shall be used instead of weather forecasts.

4.3 FREE SPAN INTERACTION

A set of two or more spans must be preliminarily considered as Interacting multi-spans when at least one of the following characteristics is observed:

- The minimum distance between two adjacent spans is shorter than the longer span, or
- One of the spans in the set does not meet the VIV avoidance criterion with pinned-pinned boundary condition.

Multi-span assessment must be performed according to DNVGL-RP-F105 item 6.10.

If a large number of multi-spans is observed, CONTRACTOR may choose to build a project-specific set of Interaction diagrams/tables (DNVGL-RP-F105 item 1.6.4) with multi-span flat-seabed FE. In this case, one diagram is required for each Scenario (empty, flooded, Operation…) for each pipeline section, and the EAF and gap used for this assessment must be coherent with OBR analysis results.

4.4 FREE SPAN FINITE ELEMENT MODELLING

4.4.1 validation

If CONTRACTOR uses FE for Free Span modal quantities extraction, the FE modelling must be validated against DNVGL-RP-F105 item 6.7.4. In addition to zero EAF, as requested in DNVGL-RP-F105 item 6.7.4, validation must be performed up to EAF = -0.5*Pcr.

4.4.2 Pipe-Soil Interaction

For natural frequencies evaluation and mode shape extraction the dynamic soil stiffness shall be calculated according to DNVGL-RP-F114 (ref. [4]) using best estimate properties.

4.5 FREE SPAN VIV EVALUATION SOFTWARE

DNVGL’s FatFree may be used for free span VIV and direct wave action response evaluation. The use of other software shall require PETROBRAS approval prior to the issue of the Free Span Design Report.

4.6 ULS CHECK

This section applies for FS locations and scenarios where the VIV avoidance criteria are not fulfilled or are subject to direct wave action.

ULS check shall be performed, for all FS and scenarios considering the loads from OBR analyses and the environmental bending moments associated to VIV and direct wave action. The combined loading criteria for load controlled condition in DNVGL-ST-F101, ref. [1], shall be applied.

For lateral global buckling locations nearby or coincident to FS locations, e.g. sleepers as initiator, the ULS check defined above may be limited to the bending moment component on the vertical plane, provided the local buckling checks from thermomechanical analysis documents (ref. [6]) are reassessed taking account the environmental bending moments/strains. For this reassessment, the functional and environmental loads shall be combined according to DNVGL-ST-F101, ref. [1].

4.7 FREE SPAN FATIGUE

Fatigue damage due VIV and direct wave action shall be calculated for all scenarios and exposure times presented on section 3.3.

5 DELIVERABLES

5.1 DESIGN PREMISES

CONTRACTOR must provide an OBR and FS Design Premises Report for previous approval, containing all premises and criteria for OBR and FS design, adequately referenced.

The OBR & FS Design Premises Report must contain:

- Detailed division of the pipeline in sections for analyses
- SCF calculations
- Summary of all relevant inputs for OBR and FS design
- Exposure time and Fatigue S-N curve(s) for each scenario
- Detailed load case matrix clearly showing the applied loads for each scenario
- Static soil reaction curve and dynamic soil stiffness
- Soil resistance curves.

5.2 DESIGN REPORT

CONTRACTOR must provide an OBR and FS Design Report demonstrating that the pipeline complies with the present specification requirements.

The Design Report minimum content comprises:

- OBR model output lists in editable format according to Table 5
- Buckle interaction and walking analysis model output lists in editable format according to Table 5 (if applicable)
- Operational Fatigue Damage
- ULS check for OBR analysis loads along the pipeline
- List of predicted FS containing Interaction classification, EAF, gap (average of central 1/3 of the span length), FLS and ULS check
- Loads for mitigation design
- All stress histograms and static stresses used for ECA analyses inputs
- Other auxiliary calculation spreadsheets.

Table 5 – Output file format.

Software	Description
Sage 3D	Input summary file (.doc) and complete outputs for every phase in .csv format.
Ansys	one .txt file per step, containing Node coordinates, Effective Axial Force, Temperature, Mises Stress, Stress Components, Strain Components, Moments, Shear Forces and Normal forces, Contact Opening, Contact Reactions, Contact slippage.
Abaqus	one .txt file per step, containing the following variables: ESF1, COORD1, COORD2, COORD3, Temp (nodal or element), MISES (maximal among all section points), S11, S22, S12, LE11 (minimum and maximum among all section points), SM1, SM2, SM3, SF1, SF3, SF3, RF1, RF2, RF3, RM1, RM2, RM3, CF1, CF2, CF3, CM1, CM2, CM3, COPEN, CPRESS, CSLIP1, CSLIP2, CSHEAR1, CSHEAR2.

5.3 AS-BUILT ANALYSIS

When as-laid and as-built survey results are available, CONTRACTOR must provide a comparison between survey and OBR results as well as a comparison between the exposure periods assumed for fatigue calculations and the actual ones.

Additional analysis with a calibrated model is mandatory for pipelines susceptible to global buckling or whenever survey results identify free spans that differs from OBR predictions. Survey tolerances should be considered for comparison.

In OBR model calibration against survey, the most common parameters to be adjusted are the residual lay tension and the soil resistance parameters. The parameters shall be adjusted such that the free spans configurations and lateral displacements meets the survey data for both as-laid and as-built. The as-laid survey lateral imperfections should be considered.