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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL – THIS DOCUMENT REPLACES I-ET-0000.00-6500-966-P9U-001

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1 INTRODUCTION

1.1 SCOPE

This Technical Specification has the objective to establish the minimum scope of work, technical requirements and deliverables related to the installation analyses of rigid subsea pipelines, risers and spools.

The contents of this Technical Specification is limited to the installation operations described on section 3. Other installation operations not addressed on this document, e.g. towing and above water tie-in, shall performed according to the codes, standards and other technical specifications adopted for the pipeline design.

1.2 GENERAL REQUIREMENTS

The requirements of this specification are supplemental to the requirements of ref. [A 1].

In addition to the required analyses and premises 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.

1.3 DEFINITIONS

Equipment settings	Installation parameters that may be adjusted for pipe laying (for example ramp and stinger radius, tower angle, nominal tension and dead band)
Project specifications	The set of documents (e.g. technical specifications, material requisitions, standards, descriptive memorials) provided by PETROBRAS to the CONTACTOR for the detailed design and construction of the pipeline
Installation accessories	Any installation accessories that must be considered in the analysis model to represent the pipeline configuration and behavior (for example cables, padeyes, A&R heads, buoys, yokes, swivel).
Fatigue damage, Laying	Accumulated fatigue damage on a single weld from the tensioner/clamp to the seabed during the continuous laying operation
Fatigue damage, Stand-by	Fatigue damage accumulated along the pipeline overbend and sagbend sections when the laying operation is interrupted
Fatigue damage, Installation	Laying fatigue damage plus maximum stand-by fatigue damage.
Overbend	Pipeline section over the vessel and stinger excluding the stinger tip section
Sagbend	Pipeline section from the stinger tip (included) to the seabed.
Stinger Tip Section	Pipeline section on the stinger last roller box where there is no physical restriction to limit further curvature.

1.4 ABBREVIATIONS

A&R	Abandonment and Recovery
BE	Best Estimate (most likely)
FEA	Finite Elements Analysis
HOC	Hang-Off Clamp
ILA	In-line Assembly
LB	Lower Bound
LCC	Load Controlled Condition
MIF	Moment Intensification Factor
PLEM	Pipeline End Manifold
PLET	Pipeline End Terminator
RAO	Response Amplitude Operator
TDP	Touchdown Point
WD	Water Depth

1.5 SYMBOLS

H_s	Significant wave height
H_w	Regular wave height
T_p	Wave spectrum Peak period
T_w	Regular wave period

1.6 SYSTEM OF UNITS

International System of Units shall be used on the installation analyses reports.

2 REFERENCES

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

[A 2] DNV-OS-F201 Riser Systems.

[A 3] DNVGL-RP-C203 Fatigue Strength Analysis of Offshore Steel Structures.

[A 4] DNVGL-RP-C205 Environmental Conditions and Environmental Loads.

[A 5] DNVGL-RP-F109 On-bottom Stability Design of Submarine Pipelines.

[A 6] DNVGL-RP-N103 Modelling and analysis of marine operations.

[A 7] DNV-OS-H205 Lifting Operations (VMO Standard - Part 2-5)

[A 8] Guideline for Installation of Rigid pipelines – Limit State Criteria, Report No.: 2014-0185, DNVGL.

[A 9] Guideline for Installation of Rigid and Flexible Pipelines, Umbilicals and Subsea Power Cables – Analyses, Report No.: 2014-0183, DNVGL.

[A 10] DNV JIP Lined and Clad Pipelines, Phase 3 – Guideline for Design and Construction of Lined and Clad Pipelines – Report NO.: 2011-3167 – Rev. 02, 2013-08-20.

[B 1] Ness O. B. and Verley R. “Strain Concentrations in Pipelines with Concrete Coating: An Analytical Model”, Proceedings of OMAE, volume V, Pipeline Technology, 1995.

[B 2] Bruschi R., et al. “Concrete Coated Submarine Pipelines: Further Advances in Strain Concentration at Field Joints and Relevant Implications on Strain Based Design”, Proceedings of OTC, 1995, OTC 7858.

[C 1] I-ET-0000.00-0000-940-P9U-004 ON-BOTTOM STABILITY ANALYSIS.

[C 2] I-ET-0000.00-0000-24A-P9U-001 RIGID SPOOL STRUCTURAL DESIGN

3 SCOPE OF WORK

3.1 GENERAL

The following operations shall be analyzed:

- Pipe Lay, platform transfer and related operations
  - Initiation;
  - Normal pipe lay operations;
  - Lay-down;
  - Abandonment and recovery;
  - In-line assemblies installation;
  - Buoyancy modules installation;
  - Platform transfer and pull-in;
  - Contingency Operations (other operations identified through HAZID/HAZOP).
- Reeling;
- Spool Installation;

Additional operations required to perform all pipeline construction phases shall be analyzed as required by Project specifications and ref. [A 1].

The analyses shall be performed according to the requirements of sections 4, 5 and 5.3.

The analyses and results shall be documented according to section 7.

Normal pipe lay and A&R analyses shall be performed for different locations along the pipeline route. The analysis performed shall be sufficient to define the equipment settings and limiting environmental conditions along the route.

Initiation, lay down, A&R, ILA installation, buoyancy modules installation platform transfer, platform pull-in and spool installation analyses shall consider all operation steps and results shall be presented step by step.

A&R scenarios must include both planned and unplanned (A&R due environmental or accidental conditions).

Accidental flooding shall be assessed for all operations planned to be performed with empty pipeline to verify the capacity of the installation vessel and equipment to sustain the loads as well as to verify pipeline, ILA and components integrity.

For platform transfer and pull-in operations, planned to be perform with empty pipeline, the flooded condition with the riser full of sea water shall also be analyzed as a normal operation condition (not accidental).

4 ANALYSIS AND RESULTS

4.1 PIPE LAY, PLATFORM TRANSFER AND RELATED OPERATIONS

4.1.1 Static Analysis

Static analysis shall be performed to establish the equipment settings, cable length and to determine the functional loads.

For operations with continuous configuration changes[1], the complete sequence of operations shall be simulated in order to verify the proposed procedure and to check the pipeline, riser, equipment and accessories limits for all steps. In addition, for such operations the static analysis may be used to determine the critical steps for establishment of operational environmental limits.

The following information/results shall be presented:

- Equipment settings, water depth, seabed slope, maximum admissible static offsets;
- Pipeline top tension, bottom tension, tip separation, departure angle, suspended length, horizontal projection;
- Bending moments/strains
- Roller and clamp reaction load.
- Cable loads
- Cable suspended lengths
- Vessel offsets/position.
- Anchor loads.
- Loads at structures and accessories connections (flanges, swivels, and/or welds)
- ILA vertical and horizontal distance to TDP
- Riser top connection loads
- Riser top connection position
- Clearance between Riser and vessel hull
- Clearance between cables and vessel hull
- Clearance of other already installed risers
- Pull-in loads

4.1.2 Dynamic Analysis

Dynamic analysis shall be performed to determine the limiting environmental conditions for operations and to provide loads for the design of components[2].

Limiting environmental conditions shall be based on both extreme loads and fatigue loads.

The analyses shall consider at least sixteen wave directions equally spaced with respect to vessel axis. The full range of wave periods, as specified in the metocean report (e.g. scatter diagram), shall be considered.

[1] For example platform transfer and pull-in, initiation and laydown, ILA installation.
[2] For example buoyancy module clamping system

4.1.2.1 Extreme Load Analyses

Dynamic analyses shall be representative of the analyzed seastates (Hs, Tp) with at least three hours duration. The following options are accepted:

- 3 h irregular wave simulation
- Regular wave simulation with $H_w = 2 \times H_s$ and $T_w = T_p$

In case irregular wave simulation is performed, the time series of the results (loads, LCC criteria, tip separation, etc.) shall be processed to determine the most probable maximum/minimum values. This process includes a suitable distribution fitting and extreme value estimation.

In case regular wave simulation is performed, irregular wave analyses shall be performed to validate the results of the regular wave approach for the worst cases.

Extreme load analysis shall be performed with and without extreme current profiles (1-year return period) and vessels offsets. Conservative combinations of current profiles and wave directions shall be considered.

The maximum/minimum dynamic values for the following results shall be presented:

- Pipeline top tension, bottom tension, tip separation, departure angle;
- Bending moments/strains
- Roller and clamp reaction load.
- Cable loads
- Anchor loads.
- Loads at structures and accessories connections (flanges, swivels, buoyancy modules)
- Riser top connection loads
- Clearance between Riser and vessel hull
- Clearance between cables and vessel hull
- Clearance of other already installed risers
- Pull-in loads
- Other limiting criteria (see section 5)

4.1.2.2 Fatigue and ECA Fatigue

Dynamic analysis shall be performed to estimate the maximum accumulated installation fatigue damage as well as to generate input data for ECA.

For each incidence direction the stress/strain blocks and the corresponding fatigue damage shall be presented.

Contractor shall evaluate stress ranges at several locations to determine the maximum damages for base metal and welds.

To determine the stress or strain histogram at least 1 hour sea-state duration shall be simulated for each analyzed condition and the rainflow-counting algorithm shall be used.

Contractor shall present damage per hour rates for each condition analyzed.

4.2 REELING

4.2.1 General requirements

Reeling cycle analyses shall be performed to verify maximum strains and residual ovality, to check liner/clad integrity and to determine stress and strain cycles for ECA. Both regular pipe joints (same nominal thickness) and transition joints shall be analyzed.

For thermally insulated pipes, the effect of different mechanical properties for mother pipe coating and field joint coating shall be considered.

The following information/results shall be presented:

- Back tension and minimum reeling radius;
- Pipeline stress and strains cycles and maximum/minimum values;
- Limiting criteria check (refer to sec. 5);

4.3 RIGID SPOOL INSTALLATION

4.3.1 General requirements

The installation analyses shall meet the requirements of DNVGL-RP-N103 and DNV-OS-H205, ref. [A 6] and [A 7].

The following information/results shall be presented:

- Cable lengths and static and dynamic loads
- Spool components loads and stress;
- Limiting criteria check (refer to sec. 5);

5 LIMITING CRITERIAS

5.1 GENERAL

Integrity of lined and clad pipelines and risers shall be assessed according to the project specifications for cladded pipelines design.

Fracture shall be assessed according to the project specifications.

5.2 PIPE LAY, PLATFORM TRANSFER AND RELATED OPERATIONS

5.2.1 General

The section below presents the limiting criteria to be adopted for definition of equipment settings and limiting environmental conditions.

The LCC local buckling criteria, ref. [A 1], shall be verified along all pipeline and riser sections. The minimum γ_{sc} adopted shall correspond to the safety class low.

Stand-by fatigue damage rate shall be small enough to accommodate the maximum expected operations interruptions but shall not be less than 12 hours.

The total installation fatigue shall account for the stand-by periods plus the fatigue damage during installation operations.

For riser installation the maximum loads and fatigue damage on the flexible joint/stress joint shall be verified.

The contact between the riser (or its attachments) and the platform (or any other riser, umbilical, etc.) is not acceptable.

5.2.2 Pipeline and Riser

The following criteria shall be verified on the overbend section:

- LCC local buckling
- Concrete crushing
- Pipeline Rotation
- Fatigue
- Fracture
- Residual ovality
- Cladded pipe specific criteria

The following criteria shall be verified on the sagbend (including the stinger tip):

- LCC local buckling
- Tip separation
- Positive effective tension
- Fatigue
- Fracture
- Cladded pipe specific criteria

Pipeline rotation is not acceptable when half shell anodes are used, unless the possibility of anodes buried with the pipeline exposed has been considered in the cathodic protection design.

5.2.3 Station-keeping

For all scenarios, limiting weather conditions shall be defined such that the laying vessel shall be able to keep position while sustaining the required horizontal tension

For dynamically positioned vessels this capability shall be verified by the presentation of capacity plots for both intact and failure conditions defined in ref. [A 1] and Project specifications.

For anchored vessels this capability shall be verified by the comparison of the required tension with the one used for mooring system analysis.

5.2.4 Laying Equipment and Accessories

The following criteria shall be verified for all analyzed conditions:

- Tensioner/HOC static and dynamic tension capacity
- Installation accessories and initiation anchor allowable loads

5.2.5 In-Line Assemblies

The following criteria shall be verified for ILA installations:

- Allowable loads on the assembly
- Pipeline Rotation

5.2.6 Curved Laying

Curved laying stability shall be verified according to ref. [A 5] using maximum expected dynamic bottom tension and LB lateral soil resistance.

5.2.7 On Bottom Stability

Pipeline stability during installation phases shall be verified according to ref. [C 1].

For temporary abandonment conditions the riser sections shall meet the stability criteria for pipelines during installation phases according to ref. [C 1].

5.2.8 Platform Pull-in System

The capacity of the platform pull-in system shall be verified during all steps of the analyses.

5.3 REELING

The DCC local buckling criteria, ref. [A 1], shall be verified for reeling of regular pipe joints.

Reeling of transition joints shall be verified using FEA. The analysis shall demonstrate the same failure probability of regular pipe joints.

5.4 RIGID SPOOL INSTALLATION

In addition to criteria of ref. [A 6] and [A 7], the spool components shall met the criteria of the design code adopted for the spool components (ref. [C 2]).

6 MODELLING CONSIDERATIONS

6.1 GENERAL

FEA model to access Integrity of lined and clad pipelines and risers shall be assessed according to the project specifications for cladded pipelines design

The effect of stiffness discontinuities (e.g. field joints, buckle arrestors, J-collars, etc.) shall be considered. For concrete coated pipelines the methodology proposed on ref. [B 1] and [B 2] may be applied to determine the bending moment acting on field joints. Other discontinuities shall be assessed through FEA.

6.2 PIPELAY, PLATFORM TRANSFER AND RELATED OPERATIONS

6.2.1 General

The minimum pipeline length in contact with seabed to avoid boundary conditions influence shall be determined based on the modeled parameters.

The element length shall be refined to produce accurate results for the analysis scenarios.

Tensioners dead band and clamp stiffness modeling shall be supported by documentation, otherwise a conservative rigid behavior shall be adopted.

The model of the riser in the top region shall not be pinned. The stresses induced by motion on the riser top region during installation shall be properly represented.

6.2.2 Pipeline Properties

The steel pipe shall be modelled with nominal dimensions and a Ramberg-Osgood stress-strain relationship based on specified minimum yield and tensile strength. Typical values may be used for other steel properties as needed.

Anti-corrosion coatings and thermal insulation coatings shall be modelled with nominal densities and with a thickness equal to the nominal one plus one half the positive thickness tolerance.

Concrete coatings shall be modelled considering an increase of at least 3% on the nominal density, to account for water absorption, and with a thickness equal to the nominal one plus one half the positive thickness tolerance.

Concrete coated pipelines shall be modelled by means of an equivalent moment-curvature relationship calculated according to ref. [B 1] and [B 2].

6.2.3 In-line Assemblies

The assemble model shall consider the following parameters calculated based on nominal dimensions and properties:

- Hidrodynamic areas and volumes.
- Mass
- Buoyancy
- Length
- Axial and bending stiffness.

6.2.4 Contact Iterations

Pipe-soil interaction shall consider axial and lateral friction and vertical stiffness. Unless otherwise noted the BE pipe-soil properties values shall be used.

Soil profile/slope influence on results shall be verified. If there is a risk of axial instability the soil profile shall be modeled and LB axial soil resistance.

If there is a risk of pipeline lateral instability during installation, the pipe-soil interaction model shall consider the lateral slope and LB lateral soil resistance.

Pipe-rollers interaction shall consider axial and lateral friction coefficients and vertical stiffness.

6.2.5 Environmental Loads

Hydrodynamic coefficients for pipeline and riser sections with no attachments shall be calculated according to ref. [A 4], with conservative considerations about the range of KC numbers. Otherwise, a drag coefficient of 1.2 and an inertia coefficient of 2 may be used. Hydrodynamic coefficients for strakes and buoyancy modules shall be selected according to manufactors/designers specifications and ref. [A 4]. Hydrodynamic coefficients for other components shall be calculated according to ref. [A 4].

Wave spectrum shall be defined according to the environmental technical specifications applicable to the Project.

Effects of wave spreading to model short crested seas may be considered if specified in the metocean specification for the applicable location.

6.2.6 Softwares and Spreadsheets

The following computer programs are accepted for the installation analyses on regions without risk of lateral instability during installation:

- PipeLay
- Orcaflex
- Flexcom

For pipe laying analysis on regions with risk of lateral instability, Contractor shall propose the analysis software to Petrobras approval prior to executing the work.

Spreadsheets used for computations shall be verified and validated.

6.3 REELING

The FE model for reeling analyses shall:

- have adequate element size refinement to capture the results;
- adopt adequate material models to represent the behavior evaluated (local buckling, ovalization);
- be long enough to avoid influence of boundary effects on the studied region;
- have appropriate boundary conditions to represent the expected loading.

The strength mismatch shall be select based on statistical properties for the weaker and the stronger pipes.

The following computer programs are accepted for reeling FEA:

- Abaqus
- Ansys

6.4 RIGID SPOOL INSTALLATION

Rigid spool stress/loads during installation shall be determined with FEA.

The FE model may be constructed with pipe and elbow elements.

Connectors, flanges and other items that may contribute to spool loading shall be must be considered.

Hydrodynamic loads shall be selected according to ref. [A 6], [A 7] and manufactors/designers specifications for strakes and buoyancy modules.

7 DELIVERABLES

7.1 GENERAL

Input and output analyses electronic files shall be sent to Petrobras verification along with the analysis reports.

7.2 REPORTS

An installation analyses design basis and premises report shall be submitted for Petrobras evaluation and approval prior to starting the analyses. This report shall contain all information required to build the models and to perform the analyses including:

- Design Premises
  - Environmental data
  - In-line Assemblies data
  - Pipeline specification and properties (Diameter, thickness, coatings, materials)
  - Buoyancy modules data
  - Flexible joint/stress joint data
  - Vessels data (Basic dimensions, operational draft and trim, RAOs, DP capability plots, mooring system allowable loads)
  - Ramp/Tower data (tensioners, clamp, supports, rollers)
  - Stinger data (roller type and description, positions)
  - Reeling equipment information (aligner radius, drum radius, layout drawings)
  - Installation accessories included in the model
  - Equipment characteristics and limits (tensioners, A&R winches, pull-in system, etc.)
  - Other information required to build the models and evaluate limiting criteria
- Input data for analysis
  - Pipeline model parameters
  - Assemblies model parameters
  - Installation accessories modeling parameters
  - Contact modeling properties
  - Tensioner/Clamp modeling
- Software
- Drawings.
- DP capability plots

Drawings section shall present vessel and stinger views indicating: RAOs reference point and directions, rollers locations and dimensions, tensioners and clamp locations and dimensions.

RAOs shall be provided for all directions to be analyzed in a tabular form, in .txt, .csv or .xls format file, along with a description of the RAOs sign and direction conventions adopted.

Tensioners, clamps, supports and rollers positions and dimensions shall be provided in tabular form.

After approval of the design basis and premises and completion of the analyses, the analyses reports shall be issue for Petrobras comments.

The analyses reports shall present all information and results to conclude that limiting criteria are met including:

- Equipment settings
- Limiting environmental conditions (wave, current and wind)
- Results (section 4)
- Limiting criteria check (section 5)
- References