PETROBRAS	TECHNICAL SPECIFICATION	Nº:	I-ET-3010.00-1500-274-P56-001	
	CLIENT:	E&P	SHEET:	1 of 16
	JOB:	OFFSHORE PRODUCTION UNITS		-
	AREA:	SUBSEA FACILITIES		
-	TITLE:	RISER INTERFERENCE ANALYSIS		SUB/ES
				-

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL – THIS SPECIFICATION REPLACES I-ET-3010.00-1519-274-PPC-001 - RISER INTERFERENCE ANALYSIS.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E
DATE	13/10/2022					
EXECUTION	CSOE					
CHECK	BXT4/BX54/BXQ9					
APPROVAL	CWFB					

CONTENTS

1. PURPOSE

The riser system should be designed to avoid interferences. The design shall include evaluation or analysis of any potential riser interference (including hydrodynamic interaction if relevant) with other risers and between risers and mooring lines, tendons, vessel hull, seabed, or any other obstruction (Ref. [A1]). Abnormal service conditions, including the case of one mooring line damaged (Ref. [A1]) and loss of buoyance module (Ref. [A4]) shall also be considered. Interference should be considered during all phases of the riser design life, including installation, in-place, and unusual events (Ref. [A1]). The accuracy and suitability of the selected analytical technique should be assessed when determining the probability and severity of contact.

This Technical Specification is applicable for Fixed or Floating Production Units (FPU) and has the purpose of providing minimum requirements for in-place interference analysis of risers with neighboring flexible risers, umbilicals, rigid risers (e.g., SCRs-Steel Catenary Risers, and SLWRs-Steel Lazy Wave Risers), mooring lines, UNIT hull or structure or any other obstruction.

2. ABBREVIATIONS AND DEFINITIONS

- BM — Buoyancy module
- Cd — Drag Coefficient
- CONTRACTOR — Company responsible for the interference analysis
- DAF — Drag Amplification Factor
- FH — Free Hang or free catenary.
- FPU — Floating Production Unit (SS, FPSO in Turret or SM)
- FSHR — Free Standing Hybrid Riser.
- Hmax — Maximum wave height
- may — Is used where alternatives are equally acceptable
- Metocean — Meteorologic & Oceanographic
- MHR — Multiple Hybrid Risers
- N.E. — non-exceedance
- Project — Scope of activities performed by the CONTRACTOR to design, construct and install the riser system for a specific field and host FPU.
- RAO — Response Amplitude Operator
- RHAS — Hybrid Riser
- SAG — Riser section bend downward or riser deepest section between the unit and buoyancy section.
- SCR — Steel Catenary Riser
- shall — Indicates a mandatory requirement
- should — Indicates a preferred course of action
- SLWR — Steel Lazy Wave Riser
- SM — Spread Mooring
- SS — Semi-submersible
- SSWR — Steel Steep Wave Riser
- TDP — Touchdown Point
- TDZ — Touchdown Zone
- UNIT — Fixed or Floating Platform
- VIV — Vortex-Induced Vibration
- HOG — Riser section bend upward or top of the buoyancy section.

3. APPLIED DOCUMENTS

[A1] API RP 17B, Recommended Practice for Flexible Pipe, Fifth Edition.

[A2] DNV-RP-F203, Riser Interference.

[A3] DNV-RP-C205, Environmental Conditions and Environmental Loads.

[A4] API RP 17L2, Recommended Practice for Flexible Pipe Ancillary Equipment.

[B1] I-ET-3010.00-1500-960-PPC-006 – Structural Analysis of Flexible Pipes, latest revision.

[B2] I-ET-0000.00-0000-274-P9U-001 - SLWR Detailed Structural Design Requirements, latest revision.

[B3] I-ET-0000.00-0000-274-P9U-006 - Riser Configuration Data Sheet, latest revision.

[B4] Project Metocean Data (1)

[B5] Project Duration of extreme current profiles and Clusters of simultaneous metocean conditions(1)

[A5] Project "Caracterização dos Fluidos Deslocados" (1)

[C1] Eassom, Adrian, Marcollo, Hayden, Potts, Andrew E., Boustead, Nicholas, and Andrew Kilner. "Umbilical VIV Fatigue with Mode Number and Mode Amplitude Dependent Structural Damping." ISOPE-I-16-477, Paper presented at The 26th International Ocean and Polar Engineering Conference, Rhodes, Greece, June 2016.

[C2] Riveros, C.A., Utsunomiya, T., Maeda, K. et al. Response prediction of long flexible risers subject to forced harmonic vibration. J Mar Sci Technol 15, 44–53 (2010). https://doi.org/10.1007/s00773-009-0070-5.

[C3] Bech, Arild, and Bjorn Skallerud. "Structural Damping In Flexible Pipes: Comparisons Between Dynamic Tests And Numerical Simulations." ISOPE-I-92-125, Paper presented at the The Second International Offshore and Polar Engineering Conference, San Francisco, California, USA, June 1992.

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

4. GENERAL REQUIREMENTS

Only time-domain analyses are allowed. The linearization of the hydrodynamic loading required by frequency-domain techniques does not apply to hydrodynamic models incorporating interaction effects from adjacent risers.

Interference analysis shall be performed considering the transient (period from the application of loads to steady state is achieved) and the steady state conditions. Care shall be taken to evaluate the duration of the transient period for each application. In compliant configurations (such as lazy-wave) in deep waters, the time to achieve the steady state may be relatively long.

Wave data and Current profiles shall be obtained from the applicable Metocean Data [B4] and [B5] (provided by PETROBRAS). All reference levels of current profiles provided shall be used for interference analysis, with extreme currents and also operational currents usually adopted for fatigue evaluation, which shall be used to find the 98% Non-Exceedance current profile.

In case of interference is identified, its progression shall be evaluated considering contact (the interference, which may start in an allowed position of the riser, e.g. bare riser, and evolve to a not allowed position, e.g., intermediate connector or buoyance section); the sliding length and path shall be reported. The time step, riser segment discretization, and pipe stiffness shall be adequately considered to ensure the correct model of the phenomenon. The progression of the contact point with the sliding of one riser over the other shall not, in any condition, extend to a region where interference is not allowed. The CONTRACTOR shall document that structural integrity will not be jeopardized and the fatigue life will not be affected, and wear resistance shall be ensured. If deemed necessary by the CONTRACTOR, the contact energy, peak force, and velocities at collision time and location may also be evaluated.

The premises for the interference analysis shall be submitted by the CONTRACTOR to PETROBRAS approval, presenting all the assumptions and methodology to be used. The CONTRACTOR shall clearly explain the alternative methods, additional loading cases, or any deviation from this specification on the Riser Design Premise and Methodology as per [B1] and [B2] for PETROBRAS evaluation and approval.

As the interference phenomena depend on the configuration of neighbors' risers and is an interactive phenomenon, it is recommended that CONTRACTOR promotes design review meetings to update PETROBRAS about the evolution of the design and harmonize different risers' configurations from other CONTRACTORs. These meetings may occur between the Phases described in Table 2.

Configuration staggering (top angle, SAG & HOG height, and position, etc) is the preferable solution for interference mitigation and shall consider riser fluid content, vessel offset, hydrodynamic coefficients, and soil friction.

4.1. Hydrodynamic Coefficients

The selection of hydrodynamic coefficients tends to introduce a source of uncertainty in the accuracy of the analysis results. In riser analyses, Cm is usually taken to be 2.0, while Cd varies between 0.7 and 1.2 as per equation (1).

$$\begin{cases} Re < 2\,x10^5 \;\rightarrow\; Cd = 1.20 \\ 2\,x10^5 \;\leq 5\,x10^5 \;\rightarrow\; Cd = 1.2 + \varphi[5 - \log_{10}(0.5Re)] \qquad \varphi = \frac{0,5}{\log_{10} 2.5} \\ Re \;\geq 5\,x10^5 \;\rightarrow\; Cd = 0.70 \end{cases} \tag{1}$$

Any cylindrical body in a current flow will be subjected to vortex shedding for some sea current velocities. Therefore, a VIV analysis shall be conducted to evaluate the correct drag amplification factor (DAF) along all riser lengths and determine the final amplified Cd as per equation (2).

$$Cd_{amplified} = DAF * Cd_{original} \tag{1}$$

The original Cd shall consider Reynolds Number variation and surface roughness. Guidance on the selection of original Cd for buoyancy modules and other accessories is given in DNV-RP-C205 Ref. [A3]. Original Cd shall be used for straked sections according to manufacturer laboratory tests.

For DAF calculation, CONTRACTOR shall adopt Shear7 software. Care shall be taken on the definition of the procedure of VIV analysis to not over-predict or under-predict the DAF values. CONTRACTOR shall justify the adopted parameters, such as stiffness and damping, the method, and parameters used to define vibration modes and curvatures.

Any simplification, like a 1.2 constant original Cd value and/or fixed DAF by riser segments, may be accepted if fully justified in the design premise document before analysis execution and submitted to PETROBRAS for approval. However, it is always recommended to perform sensitivity studies to investigate the effect of the selected coefficients on the final lateral riser displacements and define how the DAF values will be applied in the model (i.e. DAF weighted average per segments length, based on the original DAF calculated in Shear7).

Structural damping might reduce the VIV and shall consider up to: 0.3% for Rigid Risers and 5% for Flexible Risers and Umbilicals see ref [C1], [C2] and [C3], any other value shall be duly justified for Petrobras approval.

For a conservative approach, the upper bound value for DAF is required for the upstream riser ($DAF_{(Upper)}$) and the lower bound value or no DAF for the downstream ($DAF_{(Lower)}$). This will tend to bring the mean position of the risers closer to each other as per Ref. [A2]. Using no DAF on the downstream riser is recommended as a first estimation as per Ref. [A2]. No wake effect is foreseen for catenary risers due to the angular separation.

5. INTERFERENCE CRITERIA

The interference of risers with the following structures is not acceptable in any circumstances:

- Flexible/umbilical or rigid risers in the buoyance sections of compliant configurations such as lazy-wave, pliant-wave, or steep-wave);
- Mooring lines;
- Subsea arch and its tethers;
- UNIT hull or structures of Fixed Platforms;
- Unprotected accessories (such as unprotected intermediate end fitting of neighboring risers).
- Riser Touchdown zone

The interference of risers with the following structures/sections is acceptable if provided a comprehensive evaluation of the consequences in both structures for Petrobras approval:

- Straked sections;
- Protected elements (i.e., flexible connectors with polymeric protective cover)

Depending on the environmental loading case (according to Table 1), clashing between risers in the bare section (i.e. without any ancillary components) is allowed. Table 1 presents the acceptance criteria considering the riser interference and riser crossing below mooring lines.

TABLE 1 - ACCEPTANCE CRITERIA FOR INTERFERENCE ANALYSIS

Environmental Loading Case (Current Return period)²	Interference Criteria
98% non-exceedance	No clashing¹ No umbilical riser crossing below any mooring line¹
1-year	No flexible or rigid riser crossing below any mooring line¹
100-year	No clashing on the buoyancy modules section³ No clashing on Riser Touchdown zone⁴

1: Unless otherwise specified by PETROBRAS.
2: Compass directions shall be considered for all referenced current profile levels.
3: Consider BM section as the arclength between the first and the last BM plus additional length 2xL (L for each side) see Table 4.
4: Consider Riser TDZ with additional length 2xL (L for each side) see Table 4.

Interference is characterized by the contact of the upstream and downstream riser outer diameters (see Figure 1), considering coatings, floaters, or any other appurtenances that may exist in the riser section.

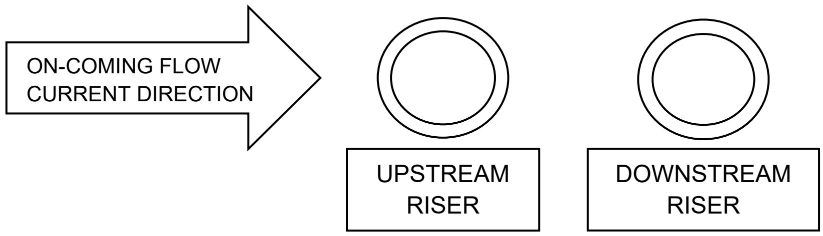

FIGURE 1 - PHYSICAL RISERS RELATED POSITION

Unless otherwise specified by PETROBRAS, it's not allowed for flexible or rigid risers to cross below mooring lines in annual conditions and umbilical risers in 98% non-exceedance conditions due to the risk of mooring line rupture and consequent riser (or umbilical) damage.

The general environmental loading cases herein presented are intended to provide only the sea state conditions and combinations. The actual number of loading cases to be simulated will depend on riser configurations and internal fluid density combinations.

6. LOADING CASES

The riser interference analysis shall combine riser conditions (fluid content, pipe hydrodynamic parameters, soil parameters) with the following parameters: FPU offset (magnitude and direction), current (profile, direction, and return period), and waves (direction and return period), performing them on Phases, as presented in Table 2. Each Phase will be used to select critical load conditions for the next Phase. If the riser configuration does not fulfill the acceptance criteria, it shall be adjusted with proper configuration staggering, and the analysis restarted from Phase 1.

TABLE 2 - DESIGN PHASES (FOR EACH COMBINATION OF RISER INTERNAL FLUID DENSITY)

LOAD CASE	PHASE DESCRIPTION	OBJECTIVE
PHASE 1	Quasi-static Analysis without Offset	Choose worst currents
PHASE 2	Quasi-static Analysis with Offset	Choose worst offset
PHASE 3	Quasi-static Analysis with Offset and varying current direction	Sensitivity of current direction
PHASE 4	Dynamic Analysis	Evaluate contact progression and riser drift due to dynamic movements
PHASE 5	Damage conditions	Sensitivity of damaged conditions

Dynamic analysis may be performed only for the worst cases obtained from quasi-static analysis, with the critical combinations of vessel data (draft, heading, RAOs) with wave data (Hs, Tp, direction), choosing the conditions that maximize motions at the riser top and deflections along the riser length in the presence of currents.

All phases of interference analysis shall consider any possible variation on normal operation for internal fluid density during the service life as well buoyancy module water absorption and flexible pipe anulus condition. In addition, eventual operations conditions (temporary) using a non-operational fluid density in a particular environmental window may also be requested by PETROBRAS, considering the duration of the event and that the combined probability has to be lower than 10^{-4}.

To confirm modeling accuracy, a sensitivity study to define the following parameters refinement must be previously submitted to Petrobras for approval: DAF discretization along the line, transported fluid specific weight profile, buoyancy module water absorption rate, seawater specific weight profiles, mid-depth current profiles, and recurrent period. The study will define the Net Thrust Upper and Lower bounds as well the $DAF_{(Upper)}$ and $DAF_{(Lower)}$ conditions, ensuring that all parameters required for an efficient staggering were considered.

TABLE 3 -RISER PAIR COMBINATIONS

	Assessed Riser				Neighbor Riser[5]			
	Position	Riser Content[1]	Drag Coefficient[3]	Soil	Position	Riser Content[1]	Drag Coefficient[3]	Soil
1	Upstream	Lower	$Cd(Re)_{bare}$ x $DAF_{(Upper)}$ (bare sections) $Cd_{straked}$ x $DAF_{(Upper)}$ (straked sections)	25% Embedment	Downstream	Lower	$Cd(Re)_{bare}$ x $DAF_{(Lower)}$ (bare sections) $Cd_{straked}$ x $DAF_{(Lower)}$ (straked sections)	100% Embedment
2						Average		
3						Upper		
4		Average[2]				Lower		
5						Average		
6						Upper		
7		Upper				Lower		
8						Average		
9						Upper		
10	Downstream	Lower	$Cd(Re)_{bare}$ x $DAF_{(Lower)}$ (bare sections) $Cd_{straked}$ x $DAF_{(Lower)}$ (straked sections)	100% Embedment	Upstream	Lower	$Cd(Re)_{bare}$ x $DAF_{(Upper)}$ (bare sections) $Cd_{straked}$ x $DAF_{(Upper)}$ (straked sections)	25% Embedment
11						Average		
12						Upper		
13		Average[2]				Lower		
14						Average		
15						Upper		
16		Upper				Lower		
17						Average		
18						Upper		

1- Riser condition embraces all possible foreseen Riser fluid contents [A5] and buoyancy water abortion.
2- For Riser pairs with similar Hog height.
3- $Cd_{(Re)}$, as per Equation (1).
4- Different DAFs shall be calculated based on Riser fluid content.
5- For each riser, the interference analysis shall involve not only the two close-by risers, but all risers hanging on two or more slots apart. The riser pairs selection shall be fully justified for Petrobras approval.

$DAF_{(Upper)}$ and $DAF_{(Lower)}$ or No DAF may be obtained eider from each load case combination or envelopes of environmental data recurrent period (1yr, 100yr, 98% non-exceedance).

As per Table 1 for centenary conditions, the main critical sections are the lazy wave buoyance region (BM) and riser TDZ. As the contact can start on an allowable section and progress toward to a BM or TDZ, an additional length, "L" (see Table 4) shall be considered to evaluate interference. For annual and 98% non-exceedance conditions, the entire riser length shall be verified.

TABLE 4 - ADDITIONAL LENGTH NEAR BM FOR CENTENARY CONDITIONS

Additional Length (L in meters)	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**	**Phase 5**
Umbilical Risers	100	100	50	12	12
Rigid Risers	150	100	50	12	12
Flexible Risers	200	200	100	25	12

6.1. Phase 1 – Quasi-static Analysis without offset

Load cases of Phase 1 are presented in Table 5 and Table 6. The objective is to define critical current profiles. It shall include all current profiles available on Metocean Data Technical considering all referenced levels (surface, mid-depth, 1200m, …) including profiles truncated by water depth:

- extreme current conditions (1 and 100-year conditions) and

- currents for fatigue analysis (to evaluate the 98% non-exceedance conditions).

TABLE 5 - LOAD CASES FOR QUASI-STATIC INTERFERENCE ANALYSIS FOR RISER X RISER - WITHOUT OFFSET

CASE	CURRENT	OFFSET	ASSESSED RISER	NEIGHBORS RISER	NUMBER OF CASES(1)
SURF 1.1	100 years	w/o offset	PerTable 3		2 x 16 x 9
SURF 1.2	98% non-exc.	w/o offset	Per Table 3		2 x 16 x 9
MID 1.1	100 years	w/o offset	Per Table 3		2 x 16 x 9
MID 1.2	98% non exc.	w/o offset	Per Table 3		2 x 16 x 9
MID 1.X(2)	100 years	w/o offset	Per Table 3		2 x 8 x 9
MID 1.X(2)	98% non exc.	w/o offset	Per Table 3		2 x 8 x 9
			ESTIMATED NUMBER OF CASES		**1440**

1: Number of cases estimated considering 16 current profiles directions. Riser combination related to current flow and riser contents: 2 x 9, as per Table 3:
2: To consider all other Mid depth current profiles, usually described with 8 directions

TABLE 6 - LOAD CASES FOR QUASI-STATIC INTERFERENCE. ANALYSIS FOR RISER X MOORING LINE - WITHOUT OFFSET

CASE	CURRENT	OFFSET	UPSTREAM RISER	DOWNSTREAM	# OF CASES(1)
MOOR- SURF 1.1	100 years	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- SURF 1.2	1 year	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- SURF 1.3	98% non exc. (umb x moor.)	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- MID 1.1	100 years	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- MID 1.2	1 year	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- MID 1.3	98% non exc. (umb x moor.)	w/o offset	Lower Bound Weight	Mooring line	16
MOOR- MID 1.X(2)	100 years	w/o offset	Lower Bound Weight	Mooring line	8
MOOR- MID 1.X(2)	1 year	w/o offset	Lower Bound Weight	Mooring line	8
MOOR- MID 1.X(2)	98% non exc. (umb x moor.)	w/o offset	Lower Bound Weight	Mooring line	8
				ESTIMATED NUMBER OF CASES	**120**

1: Number of cases estimated considering 16 directions of current profiles
2: To consider all other Mid depth current profiles, usually described with 8 directions

If any acceptance criteria are not fulfilled, the risers configuration shall be adjusted, and Phase 1 shall be repeated before proceeding to the next Phase.

All cases where allowable clashing occurs under 100yr conditions shall be selected to be deeper analyzed in the following Phases. Additionally, at least three others critical cases at SAG & HOG plus "2xL" and three others critical cases at TDZ plus "2xL" shall be selected to proceed to the next Phase.

These $N_{dircrit}$ ($N_{dircrit}$: number of risers clashing cases plus critical cases) cases shall be analyzed in Phase 2.

At least three critical cases, $N_{dircrit\_moor}$ ($N_{dircrit\text{-}moor}$: number of critical cases for interference between risers and mooring) among the interference check between risers and mooring lines cases (Table 6) shall be selected to be analyzed in Phase 2.

In this first Phase, CONTRACTOR may model all risers together to catch the overall behavior of the risers system, including critical relations of upper/lower/mid-weight, for the following phases.

6.2. Phase 2 – Quasi-static Analysis with offset

Once there is no correlation between current and wave, for each current direction chosen on the previous Phase ($N_{dircrit}$ plus $N_{dircrit\_moor}$ cases), any offset direction is possible, but not all relative directions between wave and current incur in the maximum offset. Four offsets are defined for each set of current profiles (maximum at surface or maximum at mid-water) to represent that. The 2nd Phase objective is to define critical offset directions and load cases presented in Table 7 for interference Riser x Riser and Table 8 for interference Riser x Mooring line. If any acceptance criteria are not fulfilled, the Risers configuration shall be adjusted by the CONTRACTOR, and the procedure shall be restarted from Phase 1, ensuring that any other new load combinations unfold to new interference cases.

TABLE 7 - LOAD CASES FOR QUASI-STATIC ANALYSIS WITH OFFSET – INTERFERENCE RISER X RISER

CASE	CURRENT	OFFSET DIRECTION		MAX OFFSET	# OF CASES
SURF 2.1	100 years	Collinear		Maximum 100 years	$N_{dircrit}$
SURF 2.2		Non-collinear	up to +/- 45° apart	Maximum 100 years	4 * $N_{dircrit}$
SURF 2.3			from +/- 67.5° up to +/- 135° apart	Half of the Maximum 100 years	8 * $N_{dircrit}$
SURF 2.4			more than +/- 157.5° apart	(Already analyzed in the previous Phase)(1)	
SURF 2.5	98% non exc.	Collinear		Maximum 1 year	$N_{dircrit}$
SURF 2.6		Non-collinear	up to +/- 45° apart	Maximum 1 year	4 * $N_{dircrit}$
SURF 2.7			from +/- 67.5° up to +/- 135° apart	Half of Maximum 1 year	8 * $N_{dircrit}$
SURF 2.8			more than +/- 157.5° apart	(Already analyzed in the previous Phase)(1)	
MID 2.1	100 years	Collinear		Half of Maximum 100 years	$N_{dircrit}$
MID 2.2		Non-collinear	up to +/- 45° apart	Half of Maximum 100 years	4 * $N_{dircrit}$
MID 2.3			from +/- 67.5° up to +/- 135° apart	(Already analyzed in the previous Phase) (1)	
MID 2.4			more than +/- 157.5° apart	Half of Maximum 100 years, opposite direction	3 * $N_{dircrit}$
MID 2.5	98% non exc.	Collinear		Half of Maximum 1 year	$N_{dircrit}$
MID 2.6		Non-collinear	up to +/- 45° apart	Half of Maximum 1 year	4 * $N_{dircrit}$
MID 2.7			from +/- 67.5° up to +/- 135° apart	(Already analyzed in the previous Phase) (1)	
MID 2.8			more than +/- 157.5° apart	Half of Maximum 1 year, opposite direction	3 * $N_{dircrit}$
				ESTIMATED NUMBER OF CASES	**42 * $N_{DIRCRIT}$**

Note 1: Some relative direction of current and wave cases could end up with null offset (opposite direction of wave and current for the surface current and around 90º for mid-water currents with its maximum at 800 m, 1200m, etc.). In these cases, the worst case is already chosen in Phase 1 and shall be further analyzed in the next phases.

TABLE 8 - LOAD CASES FOR QUASI-STATIC ANALYSIS WITH OFFSET – INTERFERENCE RISER X MOORING

CASE	CURRENT	OFFSET DIRECTION		MAX OFFSET	# OF CASES
MOOR - SURF 2.1	100 years	Collinear		Maximum 100 years	$N_{dircrit\text{-}Moor}$
MOOR - SURF 2.2	100 years	Non-collinear	up to +/- 45° apart	Maximum 100 years	4 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.3	100 years	Non-collinear	from +/- 67.5° up to +/- 135° apart	Half of Maximum 100 years	8 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.4	100 years	Non-collinear	more than +/- 157.5° apart	(Already analyzed in the previous Phase)(1)	
MOOR - SURF 2.5	1 year	Collinear		Maximum 1 year	$N_{dircrit\text{-}Moor}$
MOOR - SURF 2.6	1 year	Non-collinear	up to +/- 45° apart	Maximum 1 year	4 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.7	1 year	Non-collinear	from +/- 67.5° up to +/- 135° apart	Half of Maximum 1 year	8 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.8	1 year	Non-collinear	more than +/- 157.5° apart	(Already analyzed in the previous Phase)(1)	
MOOR - SURF 2.9	98% non exc. (umb. x moor.)	Collinear		Maximum 1 year	$N_{dircrit\text{-}Moor}$
MOOR - SURF 2.10	98% non exc. (umb. x moor.)	Non-collinear	up to +/- 45° apart	Maximum 1 year	4 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.11	98% non exc. (umb. x moor.)	Non-collinear	from +/- 67.5° up to +/- 135° apart	Half of Maximum 1 year	8 * $N_{dircrit\text{-}Moor}$
MOOR - SURF 2.12	98% non exc. (umb. x moor.)	Non-collinear	more than +/- 157.5° apart	(Already analyzed in the previous Phase)(1)	
MOOR - MID 2.1	100 years	Collinear		Half of Maximum 100 years	$N_{dircrit\text{-}Moor}$
MOOR - MID 2.2	100 years	Non-collinear	up to +/- 45° apart	Half of Maximum 100 years	4 * $N_{dircrit\text{-}Moor}$
MOOR - MID 2.3	100 years	Non-collinear	from +/- 67.5° up to +/- 135° apart	(Already analyzed in the previous Phase)(1)	
MOOR - MID 2.4	100 years	Non-collinear	more than +/- 157.5° apart	Half of Maximum 1-year, opposite direction	3 * $N_{dircrit\text{-}Moor}$
MOOR - MID 2.5	1 year	Collinear		Half of Maximum 1 year	$N_{dircrit\text{-}Moor}$
MOOR - MID 2.6	1 year	Non-collinear	up to +/- 45° apart	Half of Maximum 1 year	4 * $N_{dircrit\text{-}Moor}$
MOOR - MID 2.7	1 year	Non-collinear	from +/- 67.5° up to +/- 135° apart	(Already analyzed in the previous Phase)(1)	
MOOR - MID 2.8	1 year	Non-collinear	more than +/- 157.5° apart	Half of Maximum 1-year, opposite direction	3 * $N_{dircrit\text{-}Moor}$
MOOR - MID 2.9	98% non exc. (umb. x moor.)	Collinear		Half of Maximum 1 year	$N_{dircrit\text{-}Moor}$
MOOR - MID 2.10	98% non exc. (umb. x moor.)	Non-collinear	up to +/- 45° apart	Half of Maximum 1 year	4 * $N_{dircrit\text{-}Moor}$
MOOR - MID 2.11	98% non exc. (umb. x moor.)	Non-collinear	from +/- 67.5° up to +/- 135° apart	(Already analyzed in the previous Phase)(1)	
MOOR - MID 2.12	98% non exc. (umb. x moor.)	Non-collinear	more than +/- 157.5° apart	Half of Maximum 1-year, opposite direction	3 * $N_{dircrit\text{-}Moor}$
				ESTIMATED NUMBER OF CASES	**42 * $N_{dircrit\text{-}Moor}$**

Note 1: Some relative direction of current and wave cases could end up with null offset (opposite direction of wave and current for the surface current and around 90º for mid-water currents with its maximum at 800 m, 1200m, etc.). In these cases, the worst case is already chosen in Phase 1 and shall be further analyzed in the next phases.

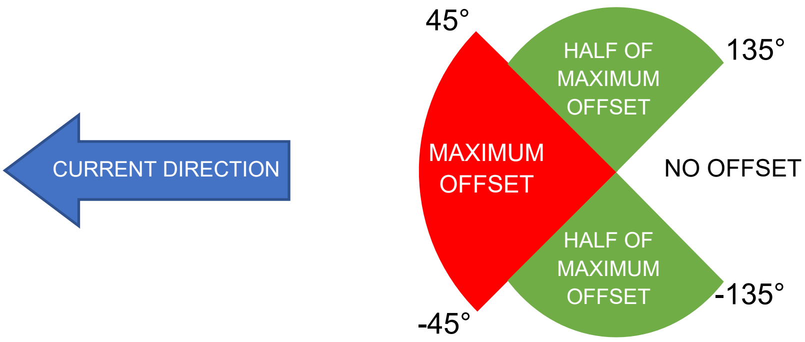

FIGURE 2 - OFFSET DISTRIBUTION FOR SURFACE REFERENCED CURRENT CASES

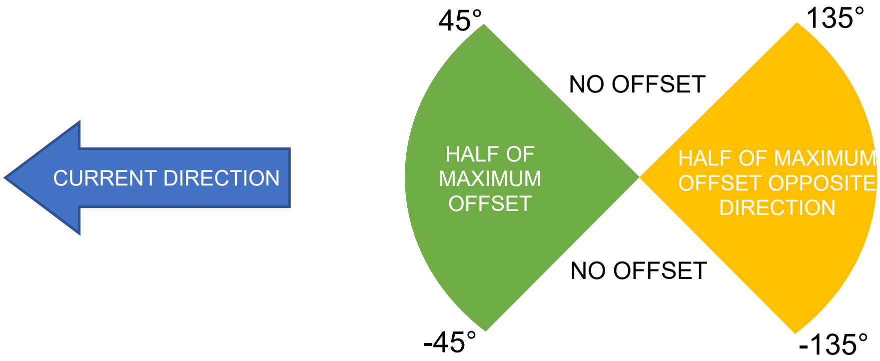

FIGURE 3 - OFFSET DISTRIBUTION FOR MID-WATER REFERENCED CURRENT CASES

6.3. Phase 3 – Quasi-static Analysis with current rotation

Each current profile direction represents not only the Compass direction (e.g., N, NNE, NE …) but a range of directions that could be 22,5º or 45º wide, depending Metocean Data refinement. The main goal of the 3rd Phase is to find the critical direction within the sector of the current direction chosen in Phase 1. Load cases are presented in Table 7 for interference riser x riser and Table 8 for interference riser x mooring line.

If any acceptance criteria is not fulfilled, the risers configuration shall be adjusted by the CONTRACTOR, and the procedure shall be restarted from phase 1.

TABLE 9 - LOAD CASES FOR QUASI-STATIC ANALYSIS WITH CURRENT DIRECTION ROTATION – INTERFERENCE RISER X RISER

CASE	CURRENT	OFFSET	# OF CASES
SURF 3.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 2	4
SURF 3.2	Worst Current profile of 98% of non-exceedance	Worst associated offset defined in Phase 2	4
MID 3.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 2	4
MID 3.2	Worst Current profile of 98% of non-exceedance	Worst associated offset defined in Phase 2	4
	TOTAL NUMBER OF CASES (BASED ON SECTORS OF 22,5º)		**16**

TABLE 10 - LOAD CASES FOR QUASI-STATIC ANALYSIS WITH CURRENT DIRECTION ROTATION – INTERFERENCE RISER X MOORING LINE

CASE	CURRENT	OFFSET	# OF CASES
MOOR - SURF 3.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 2	4
MOOR - SURF 3.2	Worst Current profile of 1 year	Worst associated offset defined in Phase 2	4
MOOR - SURF 3.3	Worst Current profile of 98% of non-exceedance (umb x moor.)	Worst associated offset defined in Phase 2	4
MOOR - MID 3.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 2	4
MOOR - MID 3.2	Worst Current profile of 1 year	Worst associated offset defined in Phase 2	4
MOOR - MID 3.3	Worst Current profile of 98% of non-exceedance (umb x moor.)	Worst associated offset defined in Phase 2	4
	TOTAL NUMBER OF CASES (BASED ON SECTORS OF 22,5º)		**16**

For cases presented in Table 9 and Table 10, entire current profiles shall be rotated from their original Compass direction ±7,5º and ±15º if sectors are defined each 22,5º degrees in Metocean Data or ±10, ±20, and ±30º if sectors are defined each 45º.

6.4. Phase 4 – Dynamic Analysis

Following Quasi-static Phases, Dynamic Analysis shall be performed to evaluate the wave contribution to the interference. The worst cases chosen among those analyzed in previous phases shall be dynamic analyzed considering waves with the same direction of the offset applied (if no specific directions are available). Load cases are presented in Table 9 for the interference of riser x riser and Table 10 for interference riser x mooring line.

For each direction, the worst wave among the contour curve of extreme Hs x Tp presented in the Metocean data shall be considered (e.g., Spectrum, which may cause the Maximum Heave Acceleration or other fully justified). Regular or irregular wave analysis methodologies are acceptable. In both cases, sufficient analysis time shall be simulated to confirm a stable position. It should be noted that a deterministic wave approach may incur in a long transient with unreal TDP displacement, been preferable to perform an irregular wave approach.

TABLE 11 - LOAD CASES FOR DYNAMIC ANALYSIS – INTERFERENCE RISER X RISER

CASE	CURRENT	OFFSET	WAVE	# OF CASES
SURF 4.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 3	10 years	1
SURF 4.2	Worst Current profile of 98% of non-exceedance	Worst associated offset defined in Phase 3	1 year	1
MID 4.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 3	10 years	1
MID 4.2	Worst Current profile of 98% of non-exceedance	Worst associated offset defined in Phase 3	1 year	1
		TOTAL NUMBER OF CASES		**4**

TABLE 12 - LOAD CASES FOR DYNAMIC ANALYSIS – INTERFERENCE RISER X MOORING LINE

CASE	CURRENT	OFFSET	WAVE	# OF CASES
MOOR - SURF 4.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 3	10 years	1
MOOR - SURF 4.2	Worst Current profile of 1 year	Worst associated offset defined in Phase 3	1 year	1
MOOR - SURF 4.3	Worst Current profile of 98% of non-exceedance (umb x moor.)	Worst associated offset defined in Phase 3	1 year	1
MOOR - MID 4.1	Worst Current profile of 100 years	Worst associated offset defined in Phase 3	10 years	1
MOOR - MID 4.2	Worst Current profile of 1 year	Worst associated offset defined in Phase 3	1 year	1
MOOR - MID 4.3	Worst Current profile of 98% of non-exceedance	Worst associated offset defined in Phase 3	1 year	1
			TOTAL NUMBER OF CASES	**4**

If any acceptance criteria is not fulfilled, risers configuration shall be adjusted by the CONTRACTOR, and the procedure shall be restarted from phase 1.

As stated before, if interference between risers is identified, its progression shall be evaluated considering contact enabled between them. The time step, riser segment discretization and pipe stiffness shall be adequately modeled to ensure the correct modeling of the phenomenon. The progression of the contact with the sliding of one riser over the other shall not, in any condition, extend to a region where interference is not allowed.

6.5. Phase 5 – Sensitivity Analysis

The sensitivity loading cases matrix for interference analysis between risers in Table 11 and between risers and mooring lines is presented in Table 12. The critical loading cases selected and analyzed in Phase 4 shall be considered for this Phase.

Two sensitivity studies shall be performed, one for offset with one mooring line damaged and the other to account for the loss of buoyance modules as per Ref. [A4] (applicable to risers with configurations with attached flotation or weight modules, e.g. lazy-wave, steep-wave, pliant-wave, etc.) or one compartment flooding of buoyance tanks in subsea arch (applicable to risers with configurations like: lazy-s, RHAS, MHR, etc.).

TABLE 13 - SENSITIVITY (DYNAMIC) ENVIRONMENTAL LOADING CASES MATRIX

CASE	CURRENT	OFFSET	WAVE		# OF CASES
SURF 5.1	Worst Current profile of 100 years	Damaged offset in the worst direction defined in Phase 2	10 years		1
SURF 5.2	Worst Current profile of 98% of non-exceed.	Damaged offset in the worst direction defined in Phase 2	1 year		1
SURF 5.3	Worst Current profile of 100 years	Intact offset in the worst direction defined in Phase 2	10 years	Loss of buoyance modules or compartment flooding	1
SURF 5.4	Worst Current profile of 98% of non-exceedance	Intact offset in the worst direction defined in Phase 2	10 years	Loss of buoyance modules or compartment flooding	1

MID 5.1	Worst Current profile of 100 years	Damaged offset in the worst direction defined in Phase 2	10 years		1
MID 5.2	Worst Current profile of 98% of non-exceedance	Damaged offset in the worst direction defined in Phase 2	1 year		1
MID 5.3	Worst Current profile of 100 years	Intact offset in the worst direction defined in Phase 2	10 years	Loss of buoyance modules or compartment flooding	1
MID 5.4	Worst Current profile of 98% of non-exceedance	Intact offset in the worst direction defined in Phase 2	1 year	Loss of buoyance modules or compartment flooding	1
				TOTAL NUMBER OF CASES	**8**

TABLE 14 - SENSITIVITY (DYNAMIC) ENVIRONMENTAL LOADING CASES MATRIX

CASE	CURRENT	OFFSET	WAVE		# OF CASES
MOOR - SURF 5.1	Worst Current profile of 100 years	Damaged offset in the worst direction defined in Phase 2	10 years		1
MOOR - SURF 5.2	Worst Current profile of 1 year	Damaged offset in the worst direction defined in Phase 2	1 year		1
MOOR - SURF 5.3	Worst Current profile of 98% of non-exceedance (umb x moor.)	Damaged offset in the worst direction defined in Phase 2	1 year		1
MOOR - SURF 5.4	Worst Current profile of 100 years	Intact offset in the worst direction defined in Phase 2	10 years	Loss of buoyance modules or compartment flooding on midwater buoy	1
MOOR - SURF 5.5	Worst Current profile of 1 year	Intact offset in the worst direction defined in Phase 2	1 year	Loss of buoyance modules or compartment flooding on midwater buoy	1
MOOR - SURF 5.6	Worst Current profile of 98% of non-exceedance (umb x moor.)	Intact offset in the worst direction defined in Phase 2	1 year	Loss of buoyance modules or compartment flooding on midwater buoy	1
MOOR - MID 5.1	Worst Current profile of 100 years	Damaged offset in the worst direction defined in Phase 2	10 years		1
MOOR - MID 5.2	Worst Current profile of 1 year	Damaged offset in the worst direction defined in Phase 2	1 year		1
MOOR - MID 5.3	Worst Current profile of 98% of non-exceedance (umb x moor.)	Damaged offset in the worst direction defined in Phase 2	1 year		1
MOOR - MID 5.4	Worst Current profile of 100 years	Intact offset in the worst direction defined in Phase 2	10 years	Loss of buoyance modules or compartment flooding on midwater buoy	1
MOOR - MID 5.5	Worst Current profile of 1 year	Intact offset in the worst direction defined in Phase 2	1 year	Loss of buoyance modules or compartment flooding on midwater buoy	1
MOOR - MID 5.6	Worst Current profile of 98% of non-exceedance (umb x moor.)	Intact offset in the worst direction defined in Phase 2	1 year	Loss of buoyance modules or compartment flooding on midwater buoy	1
				TOTAL NUMBER OF CASES	**12**

7. INTERFERENCE ANALYSIS RESULTS AND CONCLUSIONS

As a minimum, the following analysis outputs shall be provided for the critical loading cases:

- Table presenting the minimum clearance between risers and neighboring structures (others risers, mooring lines, RHAS/MHR, etc.) along the riser length occurring during each Phase (for quasi-static and dynamic simulations);
- For each Phase shall be presented a result summary showing the worst cases and the justification for the chosen cases to be analyzed in the following phases;
- For each pair analyzed, a graphic of the critical cases with clearance between risers and neighboring structures (others risers, mooring lines, RHAS/MHR, etc.), along the riser length, from top view;
- For each riser, pictures showing the most critical interference (if any) in 3D model view and decomposed view (top view, lateral view, and front view);
- For compliant configurations such as lazy-wave, pliant-wave, and lazy-s, the maximum horizontal displacement of the sag bend and the hog bend regions for each riser function shall be presented;
- Results of 100-year and 1-year environmental conditions shall be presented separately, considering both criteria (interference and crossing below mooring lines);
- Conclusions and recommendations of the interference analysis shall be included in a separate chapter (beginning of the interference report);
- Clashing energy, force, or velocity (what CONTRACTOR considers necessary) of the critical loading cases selected to evaluate the potential damage and compare with the allowed damage capacity.
- A critical analysis of the results shall be presented, with main conclusions and technical recommendations.
- Updated Riser Configuration Data Sheet as per [B3].