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	AREA: Umbilical Systems for Subsea Application		
CENPES	TITLE: **STRUCTURAL ANALYSIS OF UMBILICALS**	NP-1	
		CENPES/PDEP/TDUT	

INDEX OF REVISIONS

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

	ORIGINAL	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	20/OCT/03	August/09	09/09/2014						
DESIGN	PDP/MC	PDP/TS	PDEP/TDUT						
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APPROVAL	AMAIA	LOUISE	Arthur Saad						

INDEX

1. PURPOSE

The purpose of this Technical Specification is to provide basic requirements for structural analysis of static and dynamic umbilicals during installation and operating life phases. Load conditions and design methodologies specified for design of dynamic umbilicals are only applicable to free hanging catenary risers and do not cover fatigue life analysis. The utilization for other configurations can be accepted upon special request to PETROBRAS.

Particular cases, where geometric parameters, deformations or stresses are relevant in the umbilical dimensioning shall be investigated and the whole set of analysis inputs and results shall be submitted to PETROBRAS. The required scope of global and local load cases for strength calculations of umbilicals shall include the following: (i) the scope based on the MANUFACTURER experience regarding loading combinations; (ii) the scope based on PETROBRAS experience, as hereafter specified. In addition, MANUFACTURER shall provide results of interference and on bottom stability analyses.

2. ABBREVIATIONS AND DEFINITIONS

- MANUFACTURER Company responsible for the supply of the umbilicals
- shall Mandatory Requirement
- should Recommended Practice
- may Permission to
- Metocean Meteorological & Oceanographic
- TDP Touch Down Point
- Hs Significant wave height
- Tp Peak period
- IWP Irregular Wave Procedure
- DWP Design Wave Procedure
- RAO Response Amplitude Operator
- CoM Center of Motion
- DoF Degree of Freedom
- MPM Most Probably Maximum
- UF Utilization Factor
- SMYS Specified Minimum Yield Stress
- UTS Ultimate Tensile Stress

3. APPLIED DOCUMENTS

ISO 13628-5 - Petroleum and natural gas industries - Design and operation of subsea production systems - Subsea Umbilicals.

I-ET-3000.00-1500-29B-PAZ-001 - Technical Specification for Subsea Umbilical Systems.

I-ET-3000.00-1500-29B-PAZ-005 - Steel Tubes for Subsea Umbilicals.

4. STRENGTH CALCULATIONS

The design of one specific umbilical riser or a group of umbilical risers with the same cross-section, shall adopt one of the following procedures, depending on PETROBRAS technical documentation.

(i) Riser connected to any possible platform connection point with any possible azimuth. According to the type of the platform and the mooring system the following shall be considered:

- For ship shape unit with:
  - Turret moored system - eight different connection points and riser azimuths shall be considered, being each one 45º apart from the other as shown in Figure 1;
  - Spread mooring system - two connection points and five different riser azimuths shall be considered as shown in Figure 2a: one perpendicular to the platform side, and the others ±22.5º and ±45º apart from it. The connection points shall be forward and backward from midship along the balcony, if applicable. The worst connection points shall be selected and properly justified. If keel hauling installation is foreseen, riser pointing toward the opposite side shall be also analyzed, doubling the number of azimuths.
- For semi-submersible (SS) unit - three different riser azimuths shall be considered at each side of the platform as shown in Figure 2b: one perpendicular to the platform side, and the others ±45º apart from it. At each side, the worst connection point shall be selected and properly justified.

(ii) Riser connected to the actual connection point with its actual azimuth defined by the subsea lay-out and PETROBRAS technical documentation.

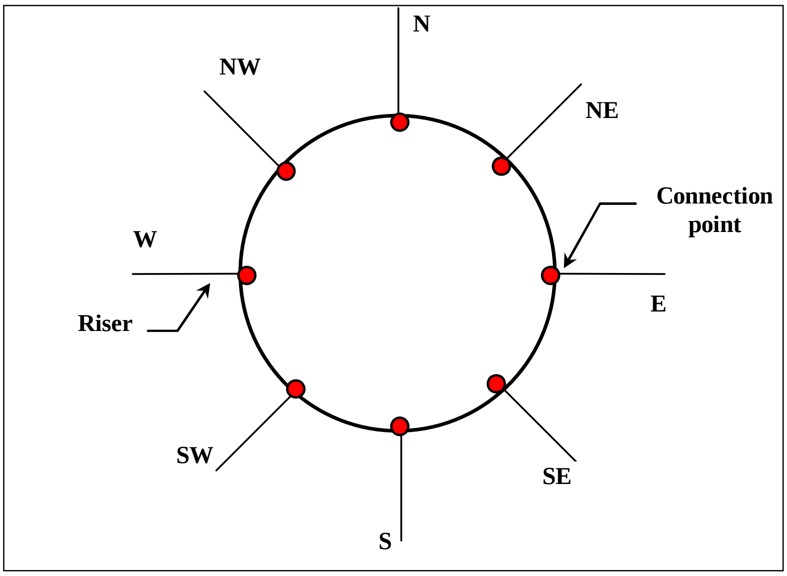
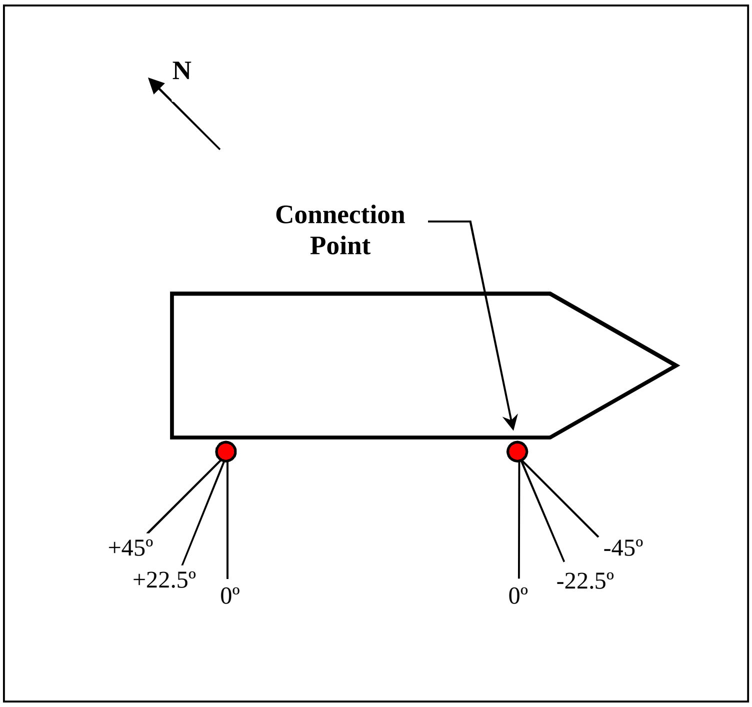
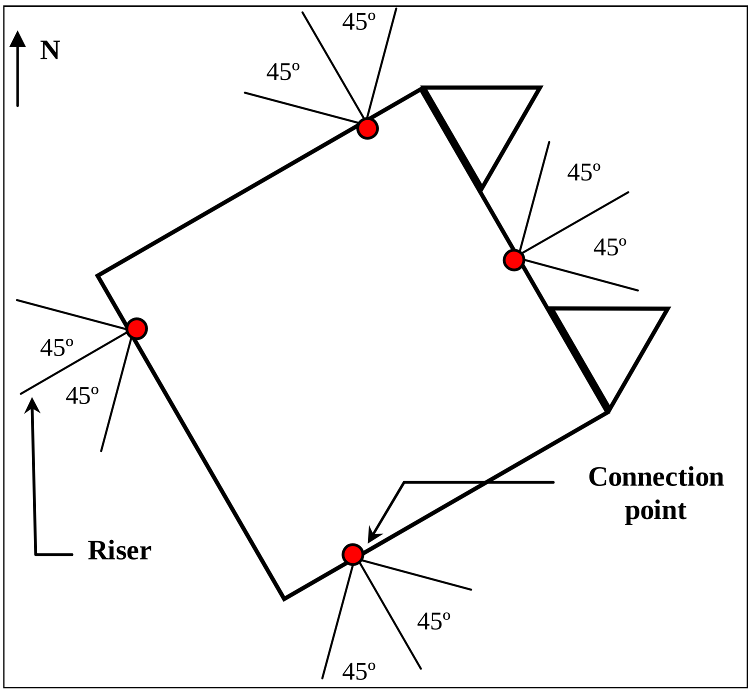


Figure 1 - Connection Points and risers azimuth for Turret Moored system



(a)Spread Mooring system



(b) Semi-Submersible unit

Figure 2 – Connection Points and risers azimuth for SS and ship shape units with Spread Mooring

4.1. UMBILICAL PROPERTIES

Besides the parameters required in the Material Requisition and other Umbilical Technical Specifications, the design report shall specify the following properties for the umbilical:

- External Diameter;
- Hose or tube internal diameter and internal volume per meter;
- Weight per meter (in air empty and seawater filled, and in seawater empty and seawater filled);
- Design pressures;
- Design temperatures;
- Design water depth;
- Minimum bending radius (storage and operation);
- Axial stiffness (in both tension and compression, and as a function of pressure, and temperature);
- Bending stiffness (as a function of tension, pressure, and temperature);
- Torsional stiffness (as a function of twist direction, tension, pressure and temperature);

The design report shall define, for the umbilical, the properties listed below. Wherever mentioned, “Allowable” means a maximum load to which the umbilical can be subjected without infringing design criteria or suffering loss of performance, damage or restrictions for future use, including its service life. The cause, origin, and location of the predicted damage or restriction shall be included in the report.

- Allowable tension;
- Allowable axial compression;
- Allowable Crushing Load for each tensioner pad (kN/m), for the specified installation vessels and tensioners, with the umbilical hoses/tubes under installation internal pressure and atmospheric external pressure;
- Allowable Crushing Load for each tensioner pad (kN/m), for the specified installation vessels and tensioners, with the umbilical hoses/tubes under atmospheric internal pressure and atmospheric external pressure;
- Allowable Tension (kN) over the vessel laying wheel for the specified installation vessels with the umbilical hoses/tubes under Installation Internal Pressure and atmospheric external pressure;
- Allowable Tension (kN) over the vessel laying wheel for the specified installation vessels with the umbilical hoses/tubes under atmospheric internal pressure and atmospheric external pressure;
- Allowable twist (as a function of relevant parameters);
- Pressure and temperature-induced axial and radial expansion;
- Pressure and design tension-induced twist;
- Drawings (not including manufacturing drawings), specification and properties of materials, data used in calculations, accurate dimensions regarding interfaces, and design calculations of end fittings, ancillary components and accessories (fatigue included for items subjected to relevant dynamic loading);

- Installation requirements and limitations: it shall be confirmed the critical parameters and requirements for the installation such as top installation angle, environmental conditions (umbilical flooded or empty, if allowable), and maximum radial and axial loads, taking into account the installation equipment and basic procedure specified by the purchaser, if any.

All properties used for the structural analysis shall be submitted to PETROBRAS, even properties that depend on applied loads. When properties depend on functional parameters (e.g. bend stiffness), the envelope of the values of parameters shall be in accordance with the structural analysis conditions and with the qualification test conditions.

For umbilicals with metallic tubes, manufacturer shall also submit Capacity Curves with allowable loads listed from (i) to (iv). These curves shall present at least ten points (load cases). For each pair of axial tension *versus* bending curvature, manufacturer shall inform the utilization factors, and also the respective failure mechanisms (e. g. cable excessive deformation, wire rupture, wire yielding, tube collapse, etc…), for all components (at least metallic tubes and electrical cables) and armour layers.

(i) Curve showing the Allowable Tension versus Allowable Curvature (curvature varying from 0 to 1/MBR) with the umbilical hoses/tubes under Design Working Pressure and atmospheric external pressure. (Normal Operation and Abnormal Operation)

(ii) Curve showing the Allowable Tension versus Allowable Curvature (curvature varying from 0 to 1/MBR) with the umbilical hoses/tubes under atmospheric internal pressure and atmospheric external pressure. For Umbilicals with chemical injection components, manufacturer shall adopt the external pressure associated to the design water depth, to take into account that hoses/tubes could be empty. (Normal Operation)

(iii) Curve showing the Allowable Tension versus Allowable Curvature (curvature varying from 0 to 1/MBR) with the umbilical hoses/tubes under Installation Internal Pressure and atmospheric external pressure. (Temporary Conditions)

(iv) Curve showing the Water Depth versus the Allowable Curvature with the umbilical hoses/tubes under atmospheric internal pressure.

4.2. DESIGN LOAD CASES

The umbilical structure shall be analysed under all functional, environmental, and accidental loading combinations. Design load cases shall encompass Normal (recurrent and extreme) Operation, Abnormal Operation and Temporary Conditions (installation).

Global non-linear analysis cases shall be numerically simulated considering integrity, geometry, and stability of the umbilicals. Global analysis results provide the input for local stress analysis in order to determine if the umbilical cross-section capacity and utilisation factors are not exceeded under specified load conditions. The main concerns are over tensioning of the umbilical section at the top region, over bending at the top region and at the TDP and crushing loads effects during installation. Besides the prediction of utilization factors for the local analysis load cases specified in Section 4.4, global analysis results shall be compared with the properties and allowable loads of the umbilical, and any undesired result, such as over-bending, or any load combination outside the adequate capacity curve, shall be clearly identified.

In order to adequately assess umbilical utilization factors considering all failure modes, critical section loads shall include axial tension or compression and curvature radius worst combinations. For the TDP region, improved accuracy of the global analysis results are required considering the severe influence of relevant parameters, such as temperature and interlayer contact pressures, on the umbilical mechanical properties. As these parameters vary along the riser, it is necessary to divide the umbilical riser (or flowline during installation) into some segments in order to represent different section properties. For each segment all relevant parameters and equivalent section properties shall be informed.

The design premise elaborated by the manufacturer shall specify a load case matrix, which shall include all potential load cases for the umbilical, including the sub-set of load cases presented in Table 1.

Table 1 – Design Load Cases

Load Condition	Design Load Case	Description
Normal Operation	A – Normal Recurrent Operation Design Working Pressure & Intact mooring system	Umbilical hoses/tubes and interstices full of fluid, hoses/tubes under Design Working Pressure, platform intact mooring system and 100-year environmental conditions.
	B – Normal Extreme Operation Design Working Pressure & One mooring line broken	Umbilical hoses/tubes and interstices full of fluid, hoses/tubes under Design Working Pressure, platform with one mooring line broken and 100-year environmental conditions.
	C – Normal Extreme Operation Atmospheric Pressure & One mooring line broken	Umbilical hoses/tubes and interstices full of fluid, hoses/tubes under Atmospheric Internal Pressure, platform with one mooring line broken and 100-year environmental conditions. (Note 1)
Abnormal Operation	D – Abnormal Operation Floating Unit inclination due to a compartment flooding	Umbilical hoses/tubes and interstices full of fluid, hoses/tubes under Design Working Pressure, platform intact mooring system, floating unit inclination due to a compartment flooding and 1-year environmental conditions.
Temporary Conditions	E – Installation	Umbilical hoses/tubes and interstices full of fluid, hoses/tubes under Installation Internal Pressure and 1-year environmental conditions. (Note 2)

Note 1: Manufacturer shall adopt umbilical hoses/tubes empty for umbilicals with chemical injection components.
Note 2: Manufacturer shall adopt Installation Internal Pressure equal to atmospheric pressure, if it is not informed by PETROBRAS.

4.3. GLOBAL NON-LINEAR ANALYSIS

4.3.1. Global Analysis Load Cases

The analysis tables herein presented are related to one single umbilical. In case of several umbilical risers with the same properties and same internal fluid parameters, but different azimuths and connection points in the same floating unit, MANUFACTURER can present the results for risers with the most critical combinations of azimuth and connection point, considering their impact to the umbilical integrity (e.g. level of stress/strain and possibility of interference), geometry, and stability. The selection shall be properly justified and confirmed with some spot check analysis. Output results of the global analyses shall be condensed in summary tables (see Section 4.3.3) and graphs, and submitted to PETROBRAS, for approval.

Global analyses of the Design Load Case A presented in Table 1 shall include at least the load cases listed in Table 2. The motion and wave modeling procedures described in Item 4.3.2 shall be used for selection of wave and draft of the floating unit (any other procedure shall be formally accepted by PETROBRAS).

The purpose of load cases GA-17 to GA-20 is to consider a swell condition based on PETROBRAS operational experience. If not specified, these load cases have significant wave height for a return period of 1-year and peak period equal to the natural period of roll motion of the floating unit. Significant wave height for a return period of 1-year higher than 4.5 m shall be limited to 4.5 m for floating units in operation at Campos Basin.

The offset for 1-year environmental condition and intact mooring system shall be considered for load cases GA-17 to GA-20. If not specified, the offset for damage mooring system for these load cases shall be equal to the offset for intact mooring system and 100-year environmental condition.

Global analyses of the Design Load Cases B and C presented in Table 1 shall include at least the load cases listed in Table 3. These load cases are selected considering the results of the dynamic analyses of the load cases in Table 2, according to specified in Table 3 (e.g. maximum top tension, maximum curvature, etc.).

Global analyses of the Design Load Case D presented in Table 1 shall include at least the load cases listed in Table 4. These load cases are selected considering the results of the dynamic analyses of the load cases in Table 2. The inclination shall be applied on the longitudinal axis for ship shape unit and on the diagonal for semisubmersible. The angle of inclination of 10º for ship shape unit and 15º for semisubmersible or other units shall be adopted if it is not specified on PETROBRAS technical documentation. This load case shall be considered to check the integrity of the umbilical and not to be used to size the bend stiffener or other ancillary equipment (no loss of functionality is acceptable but no strain level in the bend stiffness is required).

Global analyses of the Design Load Case E presented in Table 1 shall include at least the load cases listed in Table 5. These load cases consider the umbilical (riser or flowline) connected to the installation vessel. The effect of different lay azimuths shall be considered in the global analysis. If only one azimuth is considered, MANUFACTURER shall prove by some spot check calculations that this azimuth is the worst one.

The following general notes shall be observed for all load cases:

1. The motion and wave modeling procedures described in Item 4.3.2 are applicable for all load

cases including the installation load cases.

2. The wave data for the directions (e.g. N, NE, etc.) presented in PETROBRAS Metocean technical documentation closest to load case wave direction shall be chosen. If the load case wave direction is exactly on between two wave data (e.g. 22.5º from N), the one with the higher significant wave height shall be selected.

3. The current profile for the directions (e.g. N, NE, etc.) presented in PETROBRAS Metocean technical documentation closest to load case current direction shall be chosen. The entire current profile shall be rotate, based on its surface direction, in order to match the load case current direction. If the load case current direction is exactly on between two current data (e.g. 22.5º from N), the one with the largest surface current velocity shall be selected.

4. Current profile may be truncated if the water depth is shallower than the profile presented in PETROBRAS Metocean technical documentation or may be expanded, repeating the last current direction and velocity if the water depth is deeper.

5. Maximum top tension means maximum effective tension at the top connection region. Maximum TDP tension means maximum effective tension at the TDP region. Minimum TDP tension means minimum effective tension at the TDP region or, if any umbilical section is under effective compression, it means maximum effective compression at that section.

6. Installation and positioning errors of 1.5% of water depth plus 7.5 m shall be considered in the offset if no other values were specified.

Table 2 - Normal Recurrent Operation Load Case Matrix

Load Case	Position (Fig. 4)	Functional Load: Floating Unit Draft	Functional Load: Floating Unit Heading – FPSO Turret (Fig. 3)	Functional Load: Floating Unit Heading – others	Functional Load: Floating Unit offset	Environmental load: Wave – RP	Environmental load: Wave – Direction	Environmental load: Current – RP	Environmental load: Current – Direction	OBS.
GA-1	Near	Draft with the worst vertical acceleration and angular motion for each load case [1]	Head seas	Actual Heading	Extreme [2]	100	Collinear (Figure 4)	10	Collinear (Figure 4)	
GA-2	Far					100		10		
GA-3	Cross					100		10		Floating unit offset shall be applied ± 45º (cross near) and ± 135º (cross far) from the riser plane (Fig. 4 c)
GA-4	Transv.					100		10		Floating unit offset shall be applied ± 90º from the riser plane (Fig. 4 d)
GA-5	Near					10	Collinear (Figure 4)	100	Collinear (Figure 4)	
GA-6	Far					10		100		
GA-7	Cross					10		100		Floating unit offset shall be applied ± 45º (cross near) and ± 135º (cross far) from the riser plane (Fig. 4 c)
GA-8	Transv.					10		100		Floating unit offset shall be applied ± 90º from the riser plane (Fig. 4 d)
GA-9	Near		22.5° from bow			100	Crossed ± 22.5 of the riser (Figure 5)	10	Crossed ± 45 of the wave (Figure 5)	
GA-10	Far					100		10		
GA-11	Cross					100		10		Floating unit offset shall be applied ± 45º (cross near) and ± 135º (cross far) from the riser plane (Fig. 7)
GA-12	Transv.					100		10		Floating unit offset shall be applied ± 90º from the riser plane (Fig. 6)
GA-13	Near		22.5° from bow			10	Crossed ± 22.5 of the riser (Figure 5)	100	Crossed ± 45 of the wave (Figure 5)	
GA-14	Far					10		100		
GA-15	Cross					10		100		Floating unit offset shall be applied ± 45º (cross near) and ± 135º (cross far) from the riser plane (Fig. 7)
GA-16	Transv.					10		100		Floating unit offset shall be applied ± 90º from the riser plane (Fig. 6)
GA-17	Near		Beam seas (90°)			[3]	[4]	1	[5]	
GA-18	Far							1		
GA-19	Cross							1		Floating unit offset shall be applied ± 45º (cross near) and ± 135º (cross far) from the riser plane
GA-20	Transv.							1		Floating unit offset shall be applied ± 90º from the riser plane

Notes:

[1] For selection of the floating unit's draft and waves for each load case, the procedures presented in Item 4.3.2. shall be followed.

[2] Offset direction is defined by the riser azimuth and the load case position (NEAR, FAR, etc.) presented in the second column of the table. For load cases GA-17 to GA20 the offset for 1-year environmental condition and intact mooring system shall be considered. If not specified, offset for damage mooring system for load cases GA-17 to GA-20 shall be equal to the offset for 100-year environmental condition and intact mooring system.

[3] The purpose of these load cases is to represent a swell condition based on the PETROBRAS operational experience. If not specified, wave height and period shall be determined as follows:

(i) Significant wave height (Hs) for a return period of 1-year. For floating units in operation at Campos Basin significant wave height shall be limited to 4.5 m;

(ii) Peak period (Tp) shall be equal to the natural period of roll motion of the floating unit.

[4] Wave direction is defined according to the mooring system as follow:

(i) For turret mooring system the wave direction shall be ± 90.0º relative to the offset direction defined in note [2]. There are two possible wave directions for each load case.

(ii) For spread mooring system (SS or ship shape unit) the wave direction shall be ± 90.0º relative to the heading direction of the unit. Wave direction shall be in accordance with the offset direction so that wave and offset are not opposed. Therefore, there is one possible wave direction for each load case only.

[5] Current direction shall be the same of the offset direction. For turret moored systems current and the floating unit shall be considered aligned with the current coming from bow to stern.

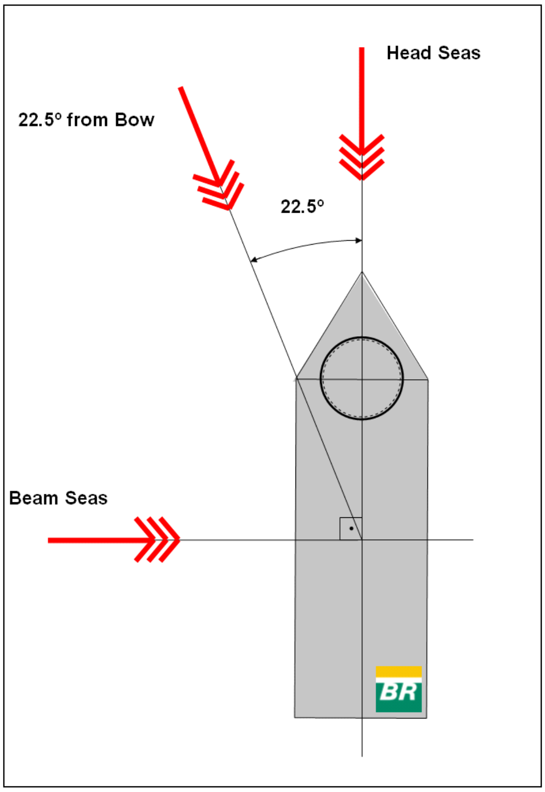


Figure 3 – Wave incidence for FPSO with turret mooring system

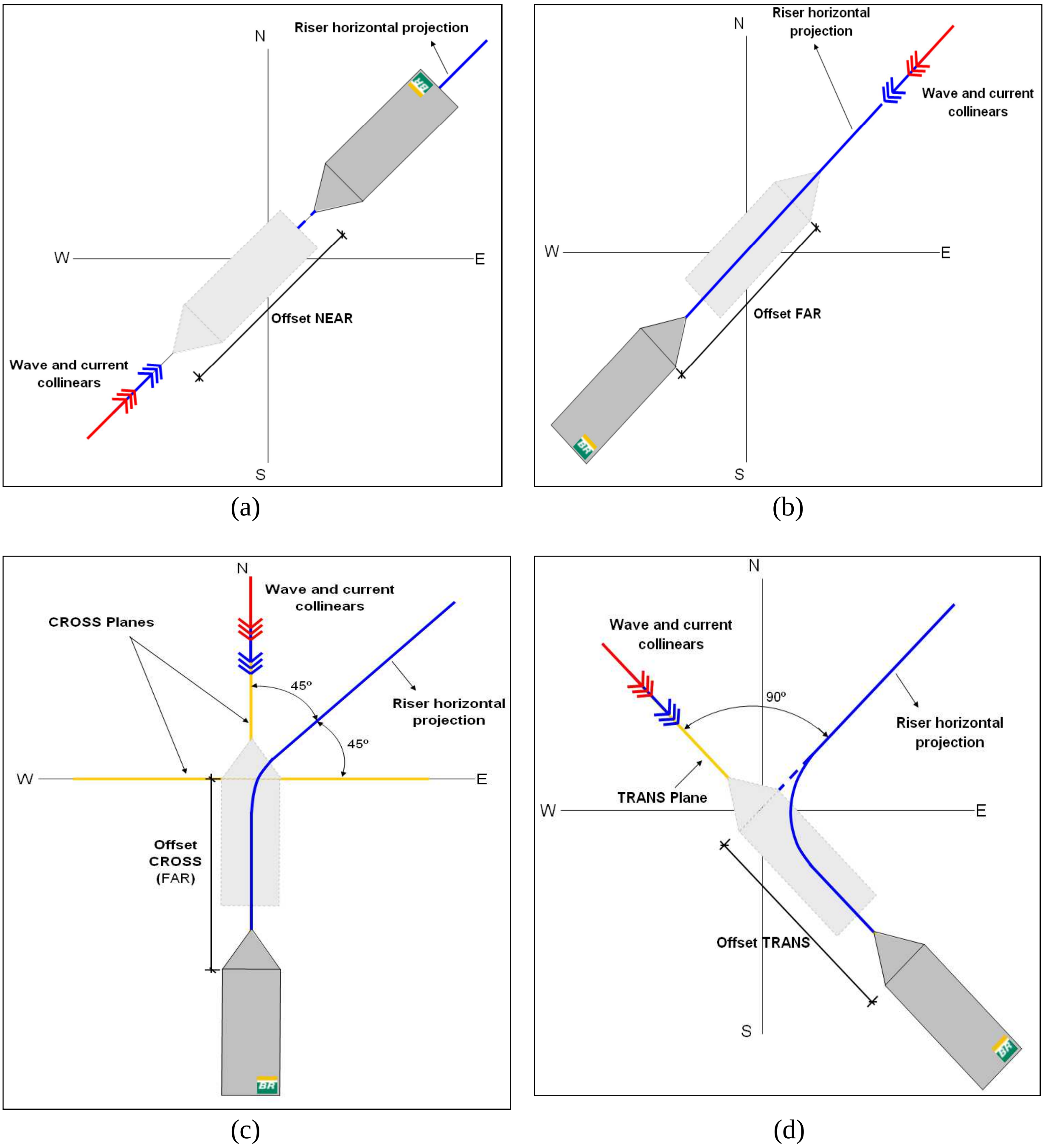
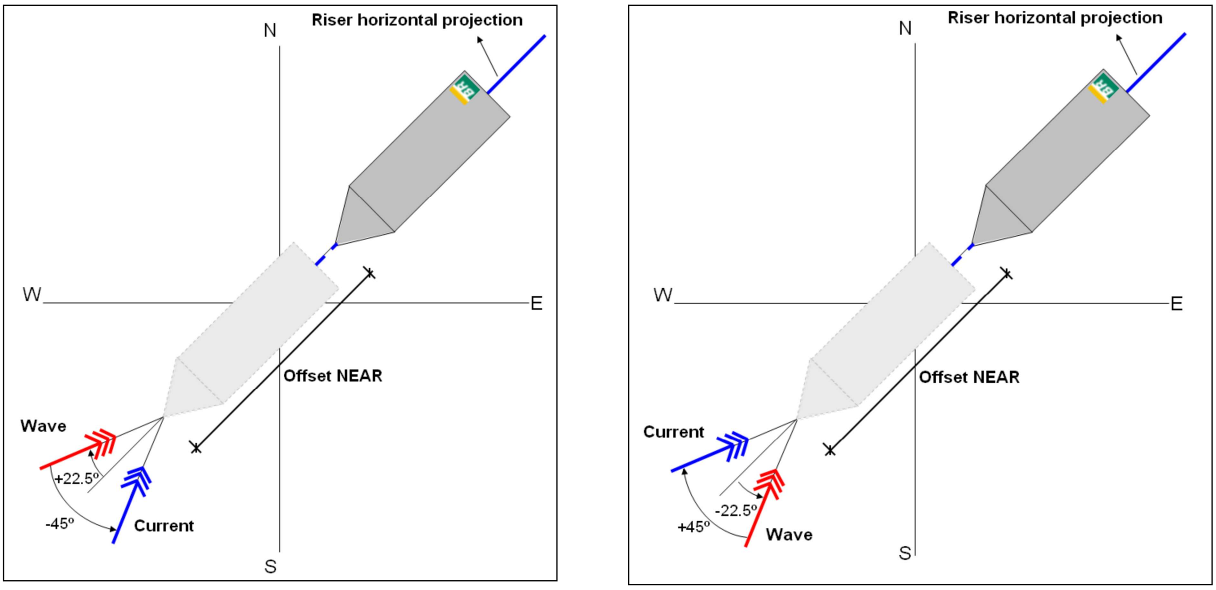
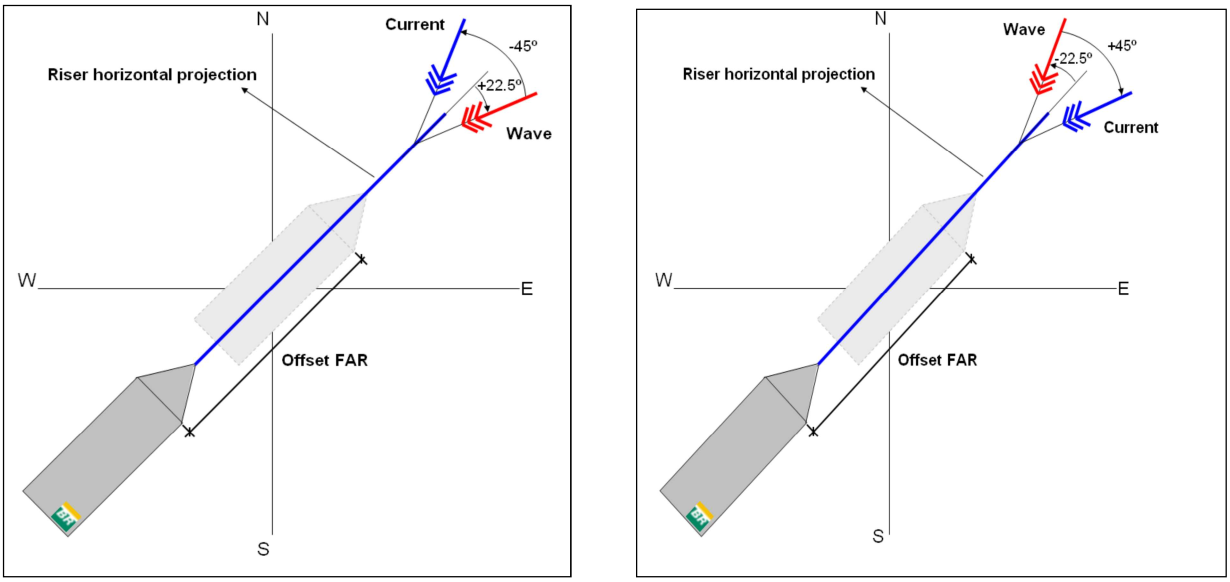


Figure 4 - Offsets convention for collinear conditions: (a) NEAR, (b) FAR, (c) CROSS and (d) TRANSVERSE



(a) NEAR



(b) FAR

Figure 5 - Crossed environmental conditions: (a) NEAR offset, (b) FAR offset

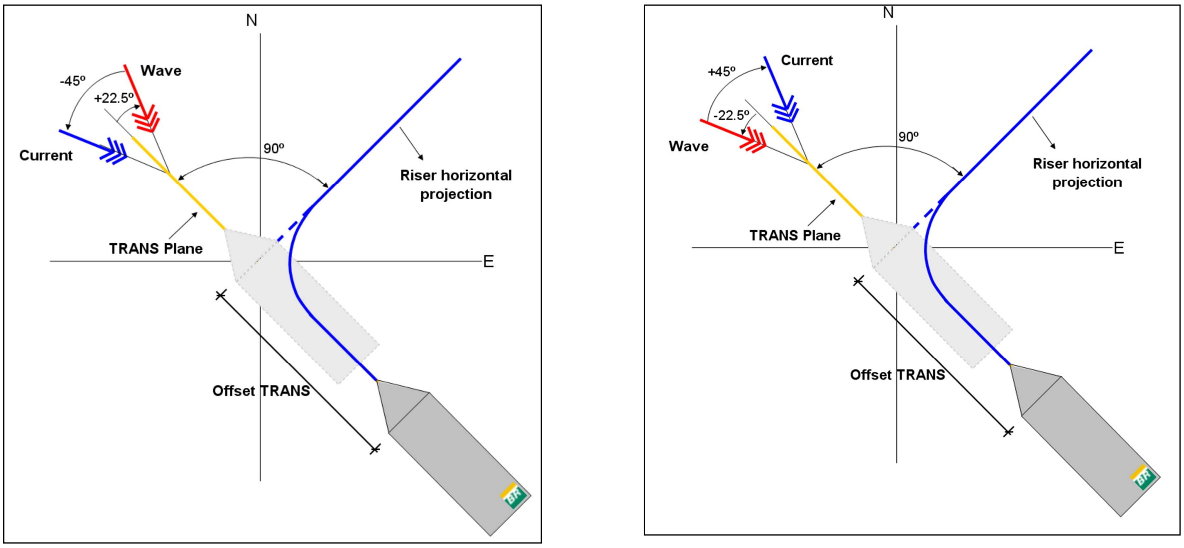


Figure 6 - Crossed environmental conditions: TRANSVERSE offset

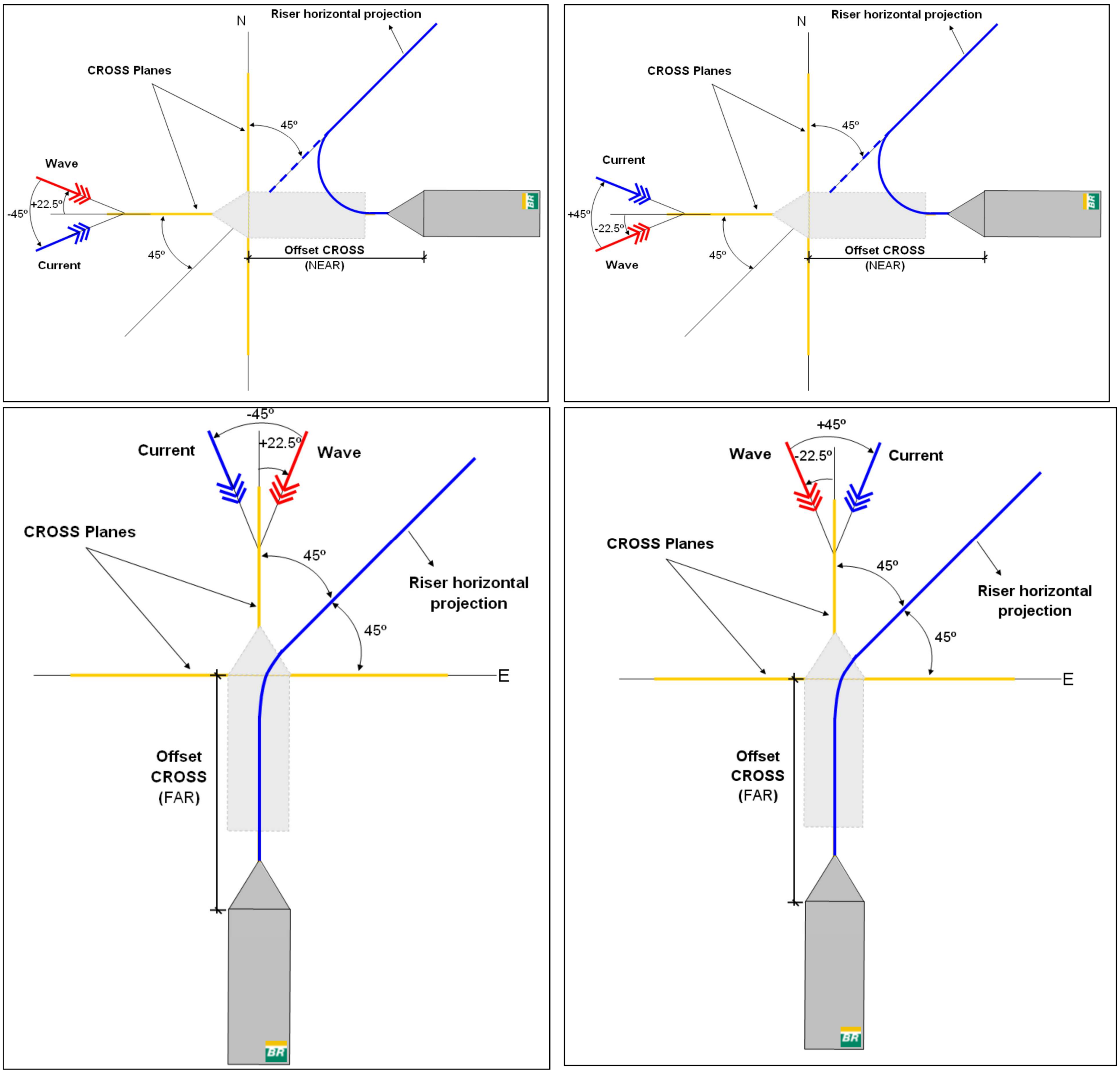


Figure 7 – Environmental crossed conditions: CROSS offset

Table 3 - Normal Extreme Operation Load Case Matrix

Load Case	Position	Functional Load			Environmental load				Accidental Loads	From Table 2 select the load cases which present:
		Floating Unit Draft	Floating Unit Heading	Floating Unit offset	Wave		Current			
					RP	Direction	RP	Direction		
GB-1	Near			Extreme					As per Table 5 of NI-2409 (one mooring line failed)	Maximum top tension and angle among near cases
GB-2	Far									Maximum top tension and angle among far cases
GB-3	Cross									Maximum top tension and angle among cross cases
GB-4	Transv.									Maximum top tension and angle among transv. cases
GB-5	Near									Maximum TDP curvature among near cases
GB-6	Far									Maximum TDP curvature among far cases
GB-7	Cross									Maximum TDP curvature among cross cases
GB-8	Transv.									Maximum TDP curvature among transv. cases

Table 4 - Abnormal Condition Load Case Matrix

Load Case	Position	Functional Load			Environmental load				Accidental Loads	From Table 2 select the load cases which present:
		Floating Unit Draft	Floating Unit Heading	Floating Unit offset	Wave		Current			
					RP	Direction	RP	Direction		
GD-1	Near	Survival (or the worst in each load case)		Annual	1		1		As per table 5 of NI-2409 (compartment flooding)	Maximum top tension and angle among near cases
GD-2	Far				1		1			Maximum top tension and angle among far cases
GD-3	Cross				1		1			Maximum top tension and angle among cross cases
GD-4	Transv.				1		1			Maximum top tension and angle among transv. cases

Table 5 – Installation Load Case Matrix

Load Case	Position	Functional Load				Environmental load					OBS.
		Internal Fluid	Floating Unit Draft	Floating Unit Heading	Floating Unit offset	Wave			Current		
						Hs (m)	Tp (s)	Dir.	RP	Dir.	
GE-1	Neutral	Full of water	Installation Vessel	Head seas	-	4,5	Worst period to maximize loads	Collinear	1	Collinear	
GE-2				Quartering seas		4,0			1		
GE-3				Beam seas		3,2			1		

Note: If the installation vessel to be considered was already informed by PETROBRAS the suggested wave Tp should be disregarded.

4.3.2. Motion and Wave Modelling Procedures

It is recommended the adoption of an irregular wave procedure (IWP) for the load cases specified, as described in Annex B. An irregular wave procedure different from Annex B may be adopted, but in this case the procedure shall be presented in the Design Premise Report and submitted for approval by PETROBRAS.

Alternatively, global analyses may be carried out considering a regular wave procedure (Design Wave Procedure - DWP), but in this case it is mandatory to re-run considering an irregular wave procedure (IWP) at least the load cases (GA) from Table 2 that present the highest top tension and the highest angle between the line and the bend stiffener's neutral axis.

It is recommended that the procedure adopted for regular wave analysis (DWP) should be the maximum response procedure described in Annex A. A procedure different from the procedure in Annex A may be adopted, but it shall be presented previously for PETROBRAS approval in a technical query or in the Design Premise Report, depending the schedule of approval foreseen.

The following combination of axial tension and angle between the umbilical riser and bending stiffener neutral axis shall be considered in the bending stiffener design:

- Maximum axial tension with associated angle and maximum angle with associated axial tension for load case that is analyzed by an irregular wave procedure (IWP) or by both wave procedures (DWP and IWP);

- Maximum axial tension associated with maximum angle for load case that is analyzed by a regular wave procedure (DWP) only.

The selection of wave spectrum properties per direction and unit draft depends on the environmental data available on PETROBRAS metocean technical specification. If tables or curves of extreme significant wave height (Hs) as function of the peak period (Tp) for each wave direction and for a given return period (e.g. 100-years) is available (Hs x Tp contour curves) the following procedure shall be adopted for the load cases analyzed:

1. First, for each draft that RAO table is available (at least full and ballasted), the movements of the floating unit shall be transferred from the center of motion (CoM) to the riser's connection point obtaining the RAOs of movements and vertical acceleration at the connection point;

2. For each wave direction, the wave spectrum defined by each pair of values Hs x Tp found in the contour table shall be crossed with the RAOs at the connection point for each draft and, assuming a Rayleigh distribution, the Most Probably Maximum (MPM) amplitude for roll, pitch and vertical acceleration shall be determined for a storm of 3 hr;

3. The pair (Hs, Tp) and draft that present the highest vertical acceleration and highest angular motion shall be selected to be considered in the dynamic analysis. Angular motion is defined as follow:

   $$\theta = \sqrt{R_{MAX}^2 + P_{MAX}^2} \quad (1)$$

   Where R_{MAX} and P_{MAX} are the MPM amplitudes for roll and pitch, respectively. It should be noted that the same load case may be analyzed for different drafts and different waves;

4. For each wave spectrum and draft selected, a regular wave procedure (DWP) or an irregular wave procedure (IWP) shall be adopted in the dynamic analyses following the recommendations presented previously.

Otherwise, if the contour table is not available and the significant wave height (Hs) and peak period (Tp) are specified as for the load cases GA-17 to GA-20 and for installation load cases the following procedure shall be adopted:

1. First, for each draft that RAO table is available (at least full and ballasted), the movements of the floating unit shall be transferred from the center of motion (CoM) to the riser's connection point obtaining the RAOs of movements and vertical acceleration at the connection point;

2. Considering the values of Hs and Tp for a given return period specified for each wave direction, the wave spectrum shall be crossed with the RAO´s at the connection point for each draft and, assuming a Rayleigh distribution, the MPM amplitude for roll, pitch and vertical acceleration shall be determined for a storm of 3 hr;

3. The draft(s) that presents the highest vertical acceleration and highest angular motion are selected to be considered in dynamic analyses. Angular motion is defined according to equation (1).

4. For each wave spectrum and draft selected, a regular wave procedure (DWP) or an irregular wave procedure (IWP) shall be adopted in the dynamic analyses following the recommendations presented previously.

If dynamic analyses for the installation load cases of umbilical risers and flowlines were performed considering a regular wave, it is recommended to adopt the maximum response procedure described in Annex A. A different procedure may be adopted, provided its presentation on the Design Premise Report and submitted for approval by PETROBRAS. For installation vessels the connection points are defined by the position of the laying wheel or by the vertical lay system (VLS).

4.3.3. Global Analysis Output

MANUFACTURER shall present the outputs for the global analysis, containing at least the following information:

- PETROBRAS Purchase Order: *PCM identification;*
- Material Requisition: *RM identification;*
- Umbilical Identification, according to respective RM: *Structure Identification;*
- Input Data: *MANUFACTURER shall inform the values considered in the analysis, as listed in Tables 7 and 8;*
- Top tension: *axial and orthogonal components;*
- TDP tension*;*
- Top angle;
- Minimum Bending Radius (and its location of occurrence);
- Top to TDP horizontal projection***;***
- Suspended length*;*
- Umbilical coordinates.

Table 7 – Initial condition for Dynamic Analysis

Riser code –			
Top angle (degree)		**Riser total length (m)**	
Number elements		**Weight in air empty (kN/m)**	
Type of elements (truss, beam, cable, etc)		**Weight in water empty (kN/m)**	
Bottom axial friction coefficient		**Weight in water full of fluid (kN/m)**	
Bottom longitudinal friction coefficient		**External diameter (m)**	
Morrison inertia coefficient (CM)		**Axial stiffness, EA (kN)**	
Morrison drag coefficient (CD)		**Bending stiffness, EI (kN.m^2)**	
Hydrodynamic diameter (m)		**Torsional stiffness ,GJ (kN.m^2)**	
Top condition (free (F), restrained (R), prescribed (P))		**X ( ) Y ( ) Z ( ) RX ( ) RY ( ) RZ ( )**	
Anchor condition (free (F), restrained (R), prescribed (P))		**X ( ) Y ( ) Z ( ) RX ( ) RY ( ) RZ ( )**	

Analysis Code	**Water depth**	**Line Azimuth**	**Riser mean connection coordinate**			**Riser mean anchor coordinate**			**Coordinate Offset**			**Current**	
	(m)	**(degree)**	**X (m)**	**Y (m)**	**Z (m)**	**X (m)**	**Y (m)**	**Z (m)**	**X (m)**	**Y (m)**	**Z (m)**	**Return Period**	**Surface Direction**
GA-1													
GA-2													
GA-3													
GA-4													
GA-5													
.													
.													
.													
GE-12													

Table 8 – Dynamic Analysis Input Data

Riser code –																
Total analysis time (s)						Time step (s)										
Top condition (free (F), restrained (R), prescribed (P))						X ( ) Y ( ) Z ( ) RX ( ) RY ( ) RZ ( )										
Anchor condition (free (F), restrained (R), prescribed (P))						X ( ) Y ( ) Z ( ) RX ( ) RY ( ) RZ ( )										
Analysis Code	Prescribed Movements on top (amplitude (m) and phase (degree))												Regular Wave			
	X	X phase	Y	Y phase	Z	Z phase	RX	RX phase	RY	RY phase	RZ	RZ phase	Height (m)	Period (s)	Direction	Offset (m)
GA-1																
GA-2																
.																
GE-12																

Table output: MANUFACTURER shall present a table output containing the information requested in tables 9 and 10.

Graphical output: MANUFACTURER shall present the graphical output of the deformed geometry of the riser, during the time of analysis, for each G load case. MANUFACTURER shall present also the graphical output of time histories and envelopes of the variables reported in tables 9 and 10. The envelopes shall cover the full length of the riser.

Table 9 – Results for the Riser Top

Analysis Code	Riser Top								
	Θ deg	F_{axial} (kN)		F_{xg} (kN)		F_{yg} (kN)		F_{zg} (kN)	
		max	min	max	min	max	min	max	min
GA-1									
GA-2									
.									
GE-12									

Notes:

1. Θ - angle between the riser and the vertical in the top connector;
2. F_{axial} - axial tension acting on the riser;
3. F_{xg} - global "x" horizontal component of axial tension acting on the riser;
4. F_{yg} - global "y" horizontal component of axial tension acting on the riser;
5. F_{zg} - global "z" vertical component of axial tension acting on the riser.

Table 10 – Results for the TDP Region and Sea Bottom

Analysis Code	TDP Region & Sea Bottom				
	F_{axial} Max (kN)	F_{axial} Min & Associated RC		RC Min & Associated F_{axial}	
		max	min	max	min
GA-1					
GA-2					
.					
GC-1					

Notes:

1. F_{axial} - axial tension acting on the riser;
2. RC - radius of curvature.

4.4. LOCAL STRESS ANALYSIS

4.4.1. Introduction

Structural layers and functional components (e.g. steel tubes, hoses, electric cables and fibre optics) of the umbilical shall be designed according to ISO-13628-5 and I-ET-3000.00-1500-29B-PAZ-001. Local stress analyses of Design Load Cases A to E from the load case matrix presented in Table 1 shall include at least the Local Stress Analysis Load Cases listed in Tables 11 to 15. Local loads shall not be selected at regions where bending is restricted, as for example, where the pipe is in permanent contact with arches/wheels, or where it is inside the I-tube. Exception shall be made for load cases LA-3, LB-3, and LE-1 to LE-4.

Besides the failure modes listed in tables 11 to 15, any other potential failure mechanism of components and its proper utilization factor (UF) shall be considered (e.g. excessive strain of fibre optics, tubes and hoses; collapse of tubes and hoses; excessive ovalization of tubes and hoses) and relevant results shall be reported. Local Stress Analysis Load Cases shall take into account internal fluid and internal pressure from Table 1. The analysis results shall be condensed in summary tables and submitted to PETROBRAS for analysis and approval.

These summary tables shall include at least:

(i) Section loads used to address stresses and strains. At least, manufacturer shall inform: effective tension, dynamic curvature or wheel radius, crushing load (force/meter/pad) due to tensioners radial compression, internal pressure of hoses and metallic tubes. Even if the used design numerical tool is able to assess stresses from the pair tension versus top angle, the curvature at the section where the maximum stress occurs shall be reported.

(ii) Applied stress/strain for each structural layer or functional component. At least, manufacturer shall inform: (i) applied stress of armouring layers, (ii) applied strain of conductors (iii) applied stress (axial stress, radial stress, hoop stress, and equivalent stress) and ovalization (loaded/residual) of metallic tubes.

(iii) Structural capacity for each armour layer or functional component. At least, manufacturer shall inform: (i) SMYS and UTS of armouring layers, (ii) maximum allowable strain of conductors (iii) SMYS, UTS and maximum ovalization (loaded/residual) of metallic tubes.

(iv) Utilization factor (UF) related to the combined stress/strain state assessed, defined as the ratio between the applied stress/strain and its structural capacity.

Alternatively, the section loads selected from dynamic analysis results (e. g. LA-1, LB-1, LC-1) could be compared to the respective Capacity Curve (Normal Operation, Abnormal Operation or Temporary Conditions). In this case, manufacturer shall present results (section loads, applied stress/strain, structural capacity, UF) for all components at each one of the Capacity Curve points. These results shall include all failure mechanisms considered for each component and not just the critical one.

4.4.2. Normal Operation Local Analysis Load Cases

Table 11 - Design Load Case A - Normal Recurrent Operation (hoses/tubes pressurized, interstices flooded)

Local Analysis Load Case	Umbilical Type/ Position	Effective Tension	Radius of Curvature	Other Loads	Potential Failure Mechanism
LA-1	RISER Top Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GA-1 to 20	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LA-2	RISER Top Region	Maximum from GA-1 to 20	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LA-3	RISER Top Region	Maximum from GA-1 to 20	---	---	Rupture of tensile armour wires, due to tension
LA-4	RISER TDP Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GA-1 to 20	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LA-5	RISER TDP Region	Maximum from GA-1 to 20	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature

Table 12 - Design Load Case B – Normal Extreme Operation (hoses/tubes pressurized, interstices flooded)

Local Analysis Load Case	Umbilical Type/ Position	Effective Tension	Radius of Curvature	Other Loads	Potential Failure Mechanism
LB-1	RISER Top Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GB-1 to 8	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LB-2	RISER Top Region	Maximum from GB-1 to 8	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LB-3	RISER Top Region	Maximum from GB-1 to 8	---	---	Rupture of tensile armour wires, due to tension
LB-4	RISER TDP Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GB-1 to 8	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LB-5	RISER TDP Region	Maximum from GB-1 to 8	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature

Table 13 - Design Load Case C – Normal Extreme Operation (hoses/ tubes full of fluid without pressure, interstices flooded)

Local Analysis Load Case	Umbilical Type/ Position	Effective Tension	Radius of Curvature	Other Loads	Potential Failure Mechanism
LC-1	RISER TDP Region	Minimum in the section where the minimum curvature radius occurs	Minimum from GB-1 to 8	---	Failure of any component due axial compression and curvature (Note 1)
LC-2	RISER TDP Region	Minimum from GB-1 to 8	Minimum in the section where the maximum effective tension occurs	---	Failure of any component due axial compression and curvature (Note 1)

Note 1 – Manufacture shall report the relevant failure mechanisms for each component and respective utilization factors (e.g. radial buckling of armour wires, rupture of outer sheath or bandage tapes over tensile armour wires, excessive deformation of outer sheath or bandage tapes over tensile armour wires, local buckling of metallic tubes, local buckling of conductors)

4.4.3. Abnormal Operation Local Analysis Load Cases

This load case shall be considered to check the integrity of the umbilical and not to be used to size the bend stiffener or other ancillary equipment (no loss of functionality is acceptable but no strain level in the bend stiffness is required). The following rules shall be considered:

- Umbilical does not infringe its specified MBR during an abnormal event;
- After an abnormal event umbilical should not have any damage or restrictions for future use, considering the utilization factors related to all structural and functional components;
- Bend Stiffener should remain attached to the umbilical end fitting or support, protecting the umbilical itself;
- Bend Stiffener will be inspected after an abnormal event in order to have its fatigue life evaluated.

Table 14– Design Load Case D - Abnormal Operation (floating unit inclination due to a compartment flooding, as specified; hoses/tubes pressurized, interstices flooded)

Local Analysis Load Case	Umbilical Type/ Position	Tension	Curvature Radius	Other Loads	Potential Failure Mechanism
LD-1	RISER Top Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GD-1 to 8	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LD-2	RISER Top Region	Maximum from GD-1 to 8	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature

4.4.4. Installation Local Analysis Load Cases

Table 15 – Design Load Case E - Installation (hoses/tubes filled, interstices flooded)

Local Analysis Load Case	Umbilical Type/ Position	Effective Tension	Curvature Radius	Other Loads	Potential Failure Mechanism
LE-1	RISER and FLOW Top Region	Maximum from GE-1 to 3	Radius of the Laying Wheel	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LE-2	RISER and FLOW Top Region	Maximum from GE-1 to 3	---	---	Rupture of tensile armour wires, due to tension
LE-3	RISER and FLOW Top Region	Maximum from GE-1 to 3	---	Maximum Crushing Load Imposed by the Tensioners	Excessive ovalization of metallic tubes and hoses
LE-4	RISER and FLOW Top Region	Maximum from GE-1 to 3	Radius of the Laying Wheel	Maximum Crushing Load over the Laying Wheel	Excessive ovalization of metallic tubes and hoses
LE-5	RISER and FLOW TDP Region	Maximum in the section where the minimum curvature radius occurs	Minimum from GE-1 to 3	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LE-6	RISER and FLOW TDP Region	Maximum from GE-1 to 3	Minimum in the section where the maximum effective tension occurs	---	Yielding of metallic tubes, yielding of tensile armour wires, and deformation of conductors, due to tension and curvature
LE-7	RISER and FLOW TDP Region	Minimum in the section where the minimum curvature radius occurs	Minimum from GE-1 to 3	---	Failure of any component due axial compression and curvature (Note 1)
LE-8	RISER and FLOW TDP Region	Minimum from GE-1 to 3	Minimum in the section where the maximum effective tension occurs	---	Failure of any component due axial compression and curvature (Note 1)

Note 1 – Manufacture shall report the relevant failure mechanisms for each component and respective utilization factors (e.g. radial buckling of armour wires, rupture of outer sheath or bandage tapes over tensile armour wires, excessive deformation of outer sheath or bandage tapes over tensile armour wires, local buckling of metallic tubes, local buckling of conductors)

5. FATIGUE ANALYSIS

The fatigue life of the umbilical shall be assessed according to a project specific fatigue analysis technical specification provided by PETROBRAS, considering umbilical hoses/tubes and interstices full of fluid and under normal operating pressure. If the normal operating pressure is not clearly informed by the purchaser, Maximum Working Pressure should be considered.

Fatigue resistance shall be based on S-N data obtained on all representative components. The effect of thickness, mean stresses, plastic pre-strain and rate of cyclic loading shall be considered when determining high cycle fatigue resistance.

For welded tubes, High Cycle Fatigue analysis should be based on results from tests on welded tube samples as per I-ET-3000.00-1500-29B-PAZ-005. The total accumulated plastic strain (APS) shall be calculated taking into account the number of reeling and unreeling operations that metallic tubes undergo during manufacture and installation phases as well as the number of reinstallations as per the specific I-RM. All these design premises and results of APS calculation shall be presented on the manufacturers Design Report. Strain based approach for fatigue calculation is not allowed under the scope of this Technical Specification.

6. SPECIAL ANALYSES

6.1. INTERFERENCE ANALYSIS

MANUFACTURER shall provide results of Interference Analysis proving that there is no interference of the UMBILICAL risers being supplied with adjacent rigid risers and between the UMBILICAL risers being supplied and mooring systems, tendons, vessel hull/ components (e.g. turret), seabed, and any other obstruction.

If there is an intermediate ancillary component or auxiliary equipment (such as buoyancy modules, dead weight system and bend stiffener stoppers) MANUFACTURER shall present results from the Interference Analysis showing that there is no interference with adjacent flexible risers.

If MANUFACTURER approach permits contact between risers, MANUFACTURER shall provide evidences that the effects of contact will not cause damage or failure of any component of the production system. For this sake, in case of adjacent flexible pipes, MANUFACTURER shall consider that the external sheaths of the flexible pipes are made of Rilsan (Young modulus of 350 MPa) or MDPE (Young modulus of 700 MPa) with a medium thickness of 10 mm.

In case of supply of umbilicals with different configurations and/or different connection points and/or azimuths, the interference analysis shall be performed considering the worst case among those, considering the weight/diameter ratio of all the structures concerned, as well as their position and azimuths in relation to the floating production unit.

6.2 ON-BOTTOM STABILITY ANALYSIS

MANUFACTURER shall provide results of on-bottom stability analysis for all umbilical flowlines being supplied. In addition, MANUFACTURER shall provide and justify the criteria used. API RP 17B shall be used as a reference for such analysis.

ANNEX A – Maximum Response Procedure

The purpose of the maximum response procedure it is to carry out the global dynamic analysis considering a regular wave that reproduces the same maximum movements (6 DoF) and the same maximum vertical acceleration at the riser connection for a storm of 3 hours. The following procedure determines the height (H) and period (T) of a regular wave and the response amplitude operator for the riser connection:

1. For a given wave direction relative to the floating unit, the RAOs for the movements in 6 DoF and the RAO for the vertical acceleration at the riser connection shall be determined for each draft of the floating unit;

2. For a wave spectrum (S) defined by Hs, Tp and gamma, the response spectrum (Su) for the movements and vertical acceleration shall be determined, crossing the wave spectrum and the RAOs previously calculated in the following way:

   $$Su(w) = [RAO(w)]^2 * S(w)$$

3. The significant amplitude (usig) of the movements (6 DoF) and vertical acceleration shall be calculated from the response spectrum as follow:

   $$usig = 2 * \sqrt{m_0}$$

   Where m_0 is the response spectrum (Su) area;

4. The maximum amplitude (umax) for the movements (6 DoF) and for the vertical acceleration shall be determined for a storm duration of 3 hours (10800 s) as follow:

   $$umax = \sqrt{2 * \ln(N)} * \frac{usig}{2}$$

   Where $N = \frac{10800}{Tz}$ and $T_Z = 2\pi\sqrt{\frac{m_0}{m_2}}$

5. The draft of the floating unit that has the highest maximum amplitude for the vertical acceleration and highest angular movement shall be selected. The following definition shall be considered for angular movement:

   $$\theta = \sqrt{R_{MAX}^2 + P_{MAX}^2}$$

   Where R_{MAX} and P_{MAX} are the maximum amplitudes for roll and pitch, respectively. If the floating unit's draft with the highest maximum vertical acceleration is different for the draft with the highest angular movement, the load case shall be analyzed for the two drafts.

6. For the selected draft(s) the period (T) of the regular wave is determined from the maximum amplitude for the vertical motion and vertical acceleration by the following expression:

   $$T = 2\pi\sqrt{\frac{umax_{vert}}{amax_{vert}}}$$

7. The response amplitude operators for the 6 DoF at the riser connection point are determined by the following expression from the amplitude of the maximum motions calculated in item 4 and the maximum wave height (Hmax) assuming a Rayleigh distribution for the wave spectrum (S) considered in item 2:

$$RAO_{ampl} = \frac{2 * umax}{Hmax}$$

8. The phases for the response amplitude operators at the riser connection point are obtained from the RAOs determined in item 1 considering the wave period (T) calculated in item 6.

9. Dynamic analysis shall be performed considering the response amplitude operator at the riser connection point (RAO_{RISER}) and a regular wave with maximum wave height (Hmax) and period (T) determined in item 6.

ANNEX B – Modeling Procedures

The motion and wave modelling procedures described hereafter shall be applied, according to the indicated analysis purpose, riser configuration and vessel motion, as per TABLE B1.

Table B1 - Required Analysis Procedure

	Vessel Motion	**Design Phase**	**Analysis Purpose** **Maximum Top and Bottom Tension, Minimum Bending Radius, Minimum Riser Length** **Bending Stiffener Verification and Dynamic Riser Top Region when Installing**
I - Dynamic Riser (All configurations)	SS or F(P)SO	Initial	DWP
		Final	DWP & IWP
II - Installation (Static and Dynamic Pipes)	Installation vessel	Initial	DWP
		Final	DWP or IWP

Notes:
1. SS means semi-submersible vessel.
2. F(P)SO means a ship-like vessel.
3. Initial design phase is to be reported in the design load report.
4. Final design phase is to be reported in the design report

B.1 Design Wave Procedure (DWP)

The Maximum Wave Response present in ANNEX A is the preferred procedure but following steps can also be followed:

a. transfer the RAOs from the vessel center of movements to the riser top connection coordinates;
b. obtain the response spectrum for the movements of the top connection by crossing the wave spectrum and RAOs for the riser top connection;
c. determine the Rayleigh most probable maxima of motion displacements and accelerations, for the connection movements;
d. determine the wave height (Hdesign) as the Rayleigh most probable maxima from Hs (significant wave height) as used to describe wave spectrum in paragraph b);
e. evaluate periods (Tdesign1 and Tdesign2), which associated with Hdesign, shall furnish, respectively, the maximum harmonic displacement and maximum harmonic acceleration, both calculated as per paragraph c); among the possible T design values, chose the closest value to the wave peak period (Tp); this procedure shall be carried out, at least, 3 times, depending on top connection motion: (1) the most critical between surge and sway, (2) heave, and (3) the most critical between roll and pitch.

B.2 Irregular Wave Procedure (IWP)

This procedure is to be considered as a validation check of the results of the above-mentioned procedures. Therefore, only the most critical loading cases, shall be analyzed according to this method. For each pipe, a minimum number of 4 full irregular analyses shall be chosen by following criteria:

a. worst loading case for compression value;
b. worst loading case for top tension;
c. worst loading case for bending radius;
d. worst loading case for bending stiffener design.

Notes:

1) When considering the specification of the number of harmonic components to describe wave spectra, a minimum number of 100 shall be considered.
2) A maxim distribution is to be adjusted from the analysis. When simulating the chosen loading cases, 2 options are considered valid:
   a) to perform, at least 5, 30 minutes simulations varying random seed for the initial harmonic components phases;
   b) from simulated long time history (minimum 60 hours) of critical pipe top movement, select a minimum of 10, 5 minutes windows to be analyzed.

If the manufacturer is supplying a set of risers of the same structure which are to be connected to the same floating unit, purchaser might accept, if duly justified by the manufacturer, irregular wave analysis carried out for the riser(s) subjected to the most critical load conditions. For this purpose, manufacturer shall submit analyses that include the riser(s) that presents the worst conditions (a) to (d) above.