PETROBRAS	TECHNICAL SPECIFICATION	No: I-ET-3010.00-1500-274-PLR-001		
	CLIENT:	DP&T	SHEET:	1 of 16
	PROGRAM:	-		-
	AREA:	-		-
SUB/ES	TITLE:	RISER TOP INTERFACE LOADS ANALYSIS		NP-1
				ECSS

INDEX OF REVISIONS

REV	DESCRIPTION AND/ OR AFFECTED SHEETS
0	ORIGINAL
A	ITEMS 3.5, 3.6 AND 6.3 (AS PER DP&T-SRGE/ESUP COMMENTS)
B	ITEM 5 (POSITIONING ERRORS DISREGARDED)
C	ITEM 3.5 (CONTINGENCY PULL-IN ASSESSMENT FOR RIGID RISERS ONLY)
D	PULL-IN CONDITION, MARK-UP FACTORS, PROCEDURE FOR EXTREME VALUES
E	CLARIFICATION ON THE RISER SUPPORT FIXED COORDINATE SYSTEM AND PULL-IN ENVIRONMENTAL CONDITIONS

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G
DATE	06/01/2017	22/02/2017	15/03/2017	19/05/2017	30/09/2019	21/05/2020		
DESIGN	ECSS	ECSS	ECSS	ECSS	ECSS	ECSS		
EXECUTION	Vinícius Prado	Vinícius Prado	Vinícius Prado	Vinícius Prado	Vinícius Prado	Vinícius Prado		
VERIFICATION	Raphael Brito	Raphael Brito	Raphael Brito	Raphael Brito	Raphael Brito	Raphael Brito		
APPROVAL	Gustavo Freitas	Gustavo Freitas	Gustavo Freitas	Gustavo Freitas	Gustavo Freitas	Gustavo Freitas		

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1. GENERAL

1.1. PURPOSE

The objective of this specification and documents hereinafter referenced is to provide the CONTRACTOR with the information and technical requirements necessary for the generation of extreme and fatigue loads of flexible and rigid risers, according to an uncoupled methodology, to be used in the structural design of the FPU riser balcony, receptacles and support structures.

For the FPU structural analysis, CONTRACTOR shall consider a coherent and consistent combination of the maximum and minimum reaction values identified in the Top Interface Loads Table (refer to Table 7) in order to preserve the conservatism of the design.

1.2. REFERENCE DOCUMENTS

[1] API RP 2RD – Design of risers for floating production systems (FPSs) and tension-leg platforms (TLPs) (Latest Edition)

[2] API RP 1111 – API Recommended Practice for Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design), (Latest Edition)

[3] DNV OS-F201 – Dynamic Risers (October/2010)

[4] DNV-OS-C201 – Structural Design of Offshore Units (WSD Method) (April/2011)

[5] ABS Rules – Floating Production Installations (July/2014)

1.3. ABBREVIATIONS

DoF	Degrees of Freedom
FPU	Floating Production Unit
Top loads	Forces (FX, FY, FZ) and moments (MX, MY, MZ) calculated at the riser top, to be used in the support design
METOCEAN	Meteorological and oceanographic data
CoR	Center of Reference
RAO	Response Amplitude Operator
SMS	Spread Moored System
SPM	Single Point Moored (turret system)
Hs	Significant Wave Height
WD	Water Depth

2. POSITIONS OF RISER CONNECTIONS

CONTRACTOR shall adopt one of the procedures below to estimate the top loads for each group of risers with similar functional and structural properties and configuration. The FPU heading to be considered is informed in the subsea layout provided by PETROBRAS.

i) Riser connected to its actual connection point and azimuth, as defined in the subsea layout and technical documentation provided by PETROBRAS.

ii) Riser connected to any possible connection point with any possible azimuth:

For SPM FPUs: for each riser function, 24 different connection points and riser azimuths, 15º apart from each other.

For SMS FPUs: riser connected to the forward and aftmost connection points of each riser function, as defined in the subsea layout provided by PETROBRAS. In this procedure, six different riser azimuths per connection point shall be considered, as shown in Figure 1: one perpendicular to the platform side, and the others ±22.5 and ±45 deg apart from it. Risers towards the portside or starboard of the FPU shall be evaluated only if the subsea layout provided by PETROBRAS presents such case.

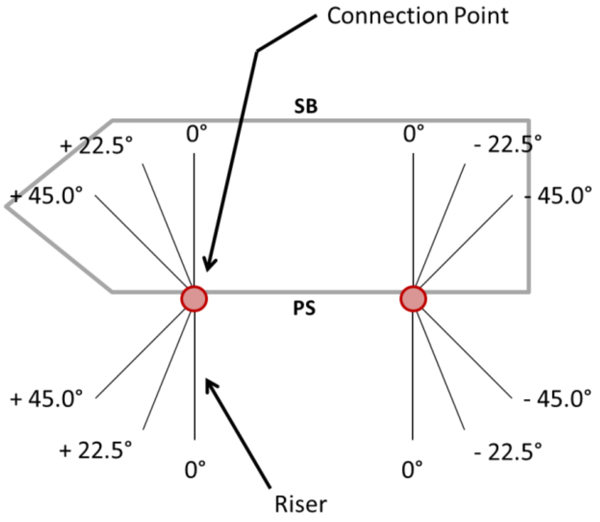

Figure 1 - Connection points and risers azimuths for SMS FPU

3. LOAD CASES

CONTRACTOR shall evaluate at least the six loading conditions defined in Table 1 in order to adequately and reliably estimate the riser top loads:

Table 1 - Load cases

LOADING CONDITION	DESCRIPTION
Functional loads	Loads that occur as a consequence of the physical existence of the system
Design operating condition (DOC)	Annual most probable maximum environmental loads and associated functional loads
Design environmental condition (DEC)	Maximum combination of environmental loads and associated functional loads
Accidental condition	Accidental loads and associated functional loads
Pull-in and pull-out	Pull-in and pull-out limiting environmental loads and associated functional loads
Fatigue loads	Operational cyclic environmental loads and associated functional loads

CONTRACTOR shall present results for all internal fluid densities informed in the RISER CONFIGURATION DATA.

3.1. FUNCTIONAL LOADS

Static functional loads are defined as loads that occur as a consequence of the physical existence of the system and by operation and handling of the system, without environmental or accidental loads. Examples of functional loads are weight, buoyancy modules and weight of internal fluid content. Static environmental loadings, such as current, shall not be considered.

3.2. DESIGN OPERATING CONDITION (DOC)

The minimum return period associated with the Design Operating Condition shall be 1-year for waves and currents with associated FPU offset. The mooring system is to be considered both in its intact and damaged conditions.

3.3. DESIGN ENVIRONMENTAL CONDITION (DEC)

The Design Environmental Condition is defined as the extreme condition for which the riser shall be designed, with a specific combination of waves and currents and associated FPU offsets. The DEC shall be one of the following combinations that results in the most severe loadings:

- 100-year wave and with 10-year current
- 100-year current with 10-year wave

The mooring system is to be considered both in its intact and damaged conditions.

3.4. ACCIDENTAL CONDITION

At least two accidental events shall be evaluated:

- FPU in heeled condition corresponding to a damage scenario
- Loss of riser buoyancy modules (if applicable)

These events shall not be considered simultaneously. The mooring system is to be considered intact in both cases.

For the heeled condition, it shall be verified the minimum inclination angle of 15 deg to all sides of the Unit (as applicable). The final angle shall be justified in the Design Premises Report according to the FPU Damaged Stability Report. The top loads shall be estimated for an environmental condition corresponding to DOC. RAOs for the FPU in even-keel position may be considered.

For the lost buoyancy modules condition, an environmental condition corresponding to DEC shall be considered. CONTRACTOR may estimate the riser top loads for the number of lost buoyancy modules based on the total number of modules on the riser, according to Table 2.

The loss of buoyancy modules shall be simulated in both the beginning and end of the floated sections of the risers.

Table 2 - Number of lost buoyancy modules

QTY OF MODULES ON THE RISER	LOST BUOYANCY MODULES FOR ANALYSIS
Less than 15	1
15 to 39	2
40 to 60	3
More than 60	4 or 4%, whichever is higher

3.5. PULL-IN AND PULL-OUT

In order to verify the pull-in system adequacy, the pull-in and pull-out operations shall be assessed. For this assessment, all risers shall be considered full of water.

The following limiting environmental conditions shall be taken into account for the analysis of normal pull-in/pull-out operations:

- Waves with Hs = 2.0 m and Tp limited to 16 s
- 1-year currents

For SPM FPUs, beam seas condition shall also be verified with the above limits.

Offset shall be limited to operational maximum as per ET-MOORING AND RISER SYSTEM REQUIREMENTS. The mooring system is to be considered intact.

For contingency during pull-in/pull-out operations of rigid risers, when the pull-in cable is holding the riser but the winch is not pulling, the most critical load case identified with the above method shall be evaluated for Hs = 3.5 m and Tp limited to 16 s. This result shall be used to check the safety factor of the pull-in cable.

3.6. FATIGUE

The methodology for fatigue top loads estimation shall be described in the Design Premises Report. The fatigue loads shall be informed in the Final Design Report.

4. LOAD CASES

4.1. COMBINATION OF ENVIRONMENTAL CONDITIONS

For each load case, the environmental conditions shall be considered in the several directions informed in the METOCEAN in order to cover all possible critical situations that the risers may have to withstand during operational life.

The analyses shall be performed combining surface currents and waves according to a collinear approach, with both coming from the same direction, and a noncollinear approach, with currents and waves up to 45 deg apart. See Figure 2.

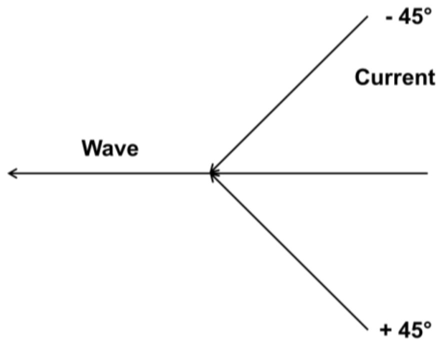

Figure 2 - Combination of environmental conditions

For SMS FPUs: environmental conditions shall be considered together with the FPU heading. See Figure 3.

The FPU offset shall be considered aligned with current and wave for collinear environmental conditions and with a misalignment of 22.5 deg between wave and current for noncollinear environmental conditions. Maximum offset shall be limited as per ET-MOORING AND RISER SYSTEM REQUIREMENTS.

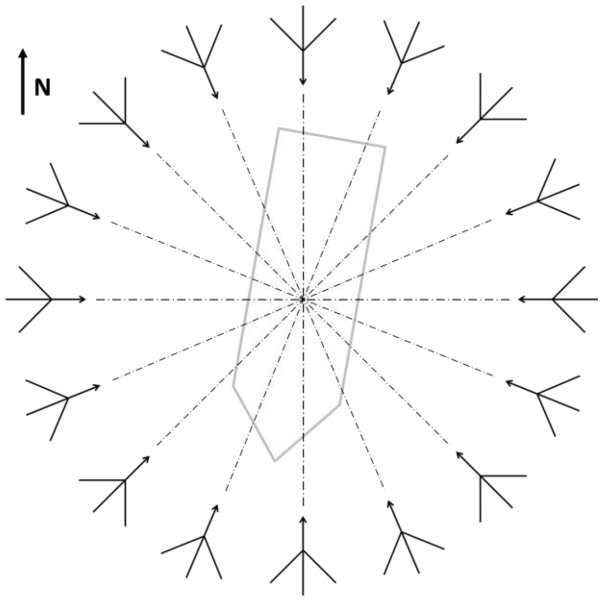

Figure 3 - Environmental conditions for SMS FPUs

For SPM FPUs: head seas conditions shall be considered with collinear wave and current only. Quartering seas shall be considered with waves and currents approaching the Unit ±22.5 deg from the bow, always 45 deg apart and in opposite directions considering the FPU longitudinal axis. See Figure 4. In total, 16 FPU heading directions shall be assessed.

The FPU offset and heading shall be considered aligned with current and wave for collinear environmental conditions (head seas) and with a misalignment of 22.5 deg between wave and current for noncollinear environmental conditions (quartering seas). Maximum offset shall be limited as per ET-MOORING AND RISER SYSTEM REQUIREMENTS.

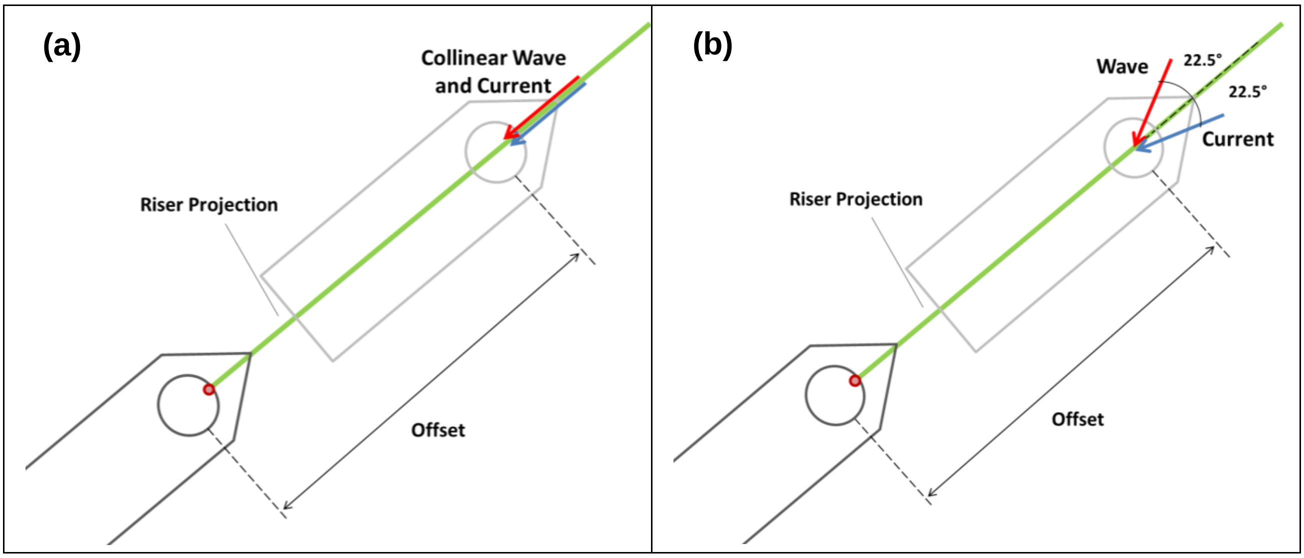

Figure 4 - Environmental conditions for SPM FPUs: (a) Head seas (b) Quartering seas

Besides head and quartering seas, beam seas conditions shall be evaluated, in order to represent swell conditions. This condition shall be assessed in the DEC load case (intact and damaged mooring), with 1-year waves and 1-year currents. In this case, the FPU offset and heading shall be considered in the same direction of current (coming from bow to stern), with waves misaglined ±90 deg with the FPU heading (waves approaching the Unit from portside and starboard).

4.2. FPU MOTION ANALYSIS (WAVE AND DRAFT SCREENING)

In the METOCEAN, for each recurrence period (1-year, 10-year and 100-year) and direction, there is a set of Hs-Tp pairs (contour curves).

When selecting waves to perform the dynamic analyses, one option is to process the entire number of existent pairs. An alternative approach is the previous calculation of the FPU short-term responses at the riser connection points based on the FPU RAOs for each recurrence period. For this procedure, at least three FPU drafts shall be considered: light, intermediate and full.

The calculation shall be performed for the entire set of waves informed in the METOCEAN. The results of this motion study shall be the estimated maximum amplitudes, velocities and accelerations at the riser connection points for three DoFs: vertical motion, roll and pitch. CONTRACTOR shall select, for each direction, at least the critical load cases (waves/drafts) stablished in Table 3:

Table 3 - Critical load cases according to the structural arrangement of supports

SINGLE SUPPORTS	CONTINUOUS STRUCTURES
▪ Maximum vertical motion acceleration ▪ Maximum roll amplitude ▪ Maximum pitch amplitude	▪ Maximum vertical motion acceleration ▪ Maximum angular motion (combination of roll and pitch)

See Figure 5 for examples of the definition of continuous structures and single supports.

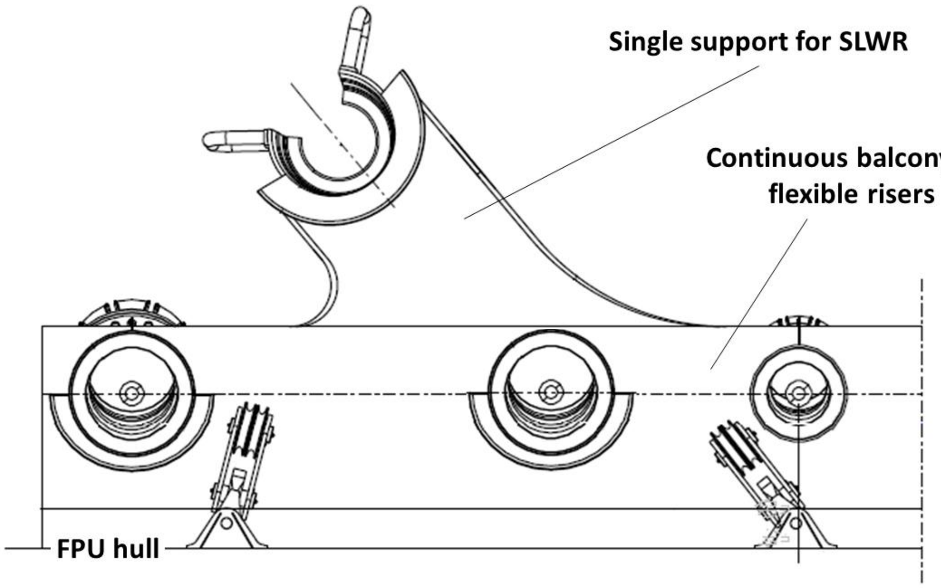

Figure 5 - Definition of continuous structures and single supports

Figure 6 presents a flowchart of the proposed motion analysis procedure.

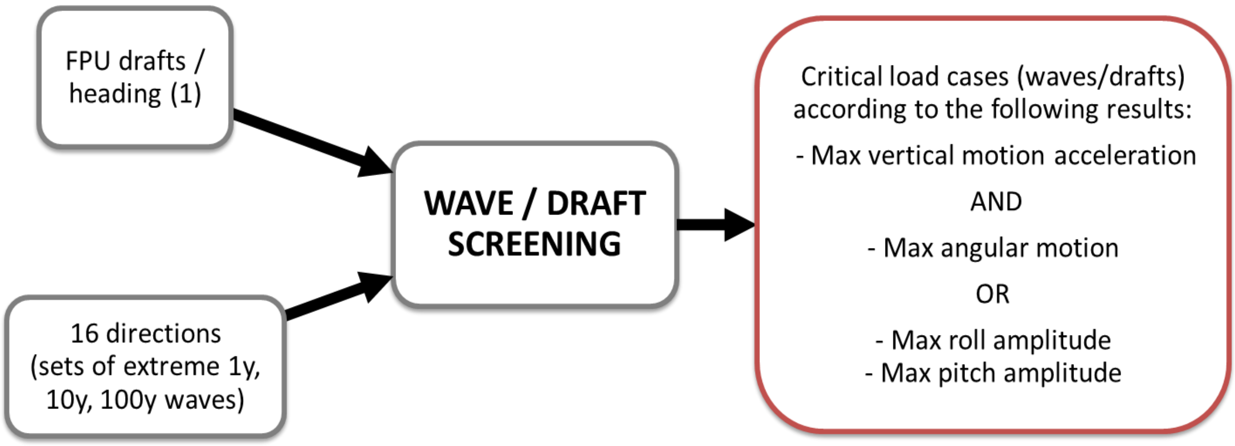

Figure 6 - Proposed motion analysis procedure

(1) Heading for SPM FPUs only.

4.3. LOAD CASE SCREENING

In order to reduce the number of dynamic analyses, the following methodology may be applied (refer to item 6.1 for the definition of the axes in the Fixed Support Reference System):

i) Analyze all directions specified in item 4.1 for the DEC condition with all mooring lines intact

ii) Select the 10 load cases obtained in i) in which the maximum and minimum components of top load forces and bending moments were observed (torsional bending, i.e., bending around the riser axis may be ignored)

iii) Analyze the load cases selected in ii) for the DEC condition with one mooring line broken

iv) Analyze the load cases selected in ii) for the Accidental lost buoyancy modules

v) Analyze all directions specified in item 4.1 for the DOC condition

vi) Select the 10 load cases obtained in v) in which the maximum and minimum components of top load forces and bending moments were observed (torsional bending may be ignored)

vii) Analyze the load cases selected in vi) for the DOC condition with one mooring line broken

viii) Analyze the load cases selected in vi) for the Accidental heeled condition

See Table 3 for a summary of the proposed screening procedure.

Table 3 - Screening procedure

STEP	LOAD CONDITION	WAVES	CURRENT	MOORING
1	DEC	As per FPU motion analysis (10y and 100y waves)	Associated collinear and noncollinear currents (item 3.3)	Intact
2	DEC	10 critical load cases (max/min components of top load forces and bending moments, as per 4.3.ii)		Damaged
3	Accidental Lost Buoyancy Modules	10 critical load cases (max/min components of top load forces and bending moments, as per 4.3.ii)		Intact
4	DOC	As per FPU motion analysis (1y waves)	Associated collinear and noncollinear 1y currents (item 3.2)	Intact
5	DOC	10 critical load cases (max/min components of top load forces and bending moments, as per 4.3.vi)		Damaged
6	Accidental Heeled Condition	10 critical load cases (max/min components of top load forces and bending moments, as per 4.3.vi)		Intact

5. DEFINITION OF DATA FOR ANALYSIS

The main data that will be input for the analyses are itemized in Table 4.

Table 4 - Analysis data

Item	Data	Data Source
1	**FPU Data**	
1.1	RAOs (operational drafts)	Provided by CONTRACTOR. The RAO used shall not include the contribution from risers to roll damping
1.2	Drafts	Provided by CONTRACTOR
1.3	Offsets (% WD)	Provided by CONTRACTOR. As per ET-MOORING AND RISER SYSTEM REQUIREMENTS. Positioning errors, as per item 5 of this table, shall be taken into account

1.4	Inclination angles	Provided by CONTRACTOR. Maximum inclination as per item 3.4
1.5	Heading	Provided by PETROBRAS
1.6	Drawings of the riser connection points	Provided by CONTRACTOR
2	**METOCEAN Data**	**Provided by PETROBRAS**
3	**Top Connection**	
3.1	Connection type	Provided by PETROBRAS
3.2	Stress/flexible joint stiffness data related to the dynamic angle variation	Provided by PETROBRAS
3.3	Length and geometry of the stress/flexible joint or bend stiffeners + extenders	Provided by PETROBRAS
4	**Riser Data**	
4.1	Riser configuration	Provided by PETROBRAS
4.2	VIV suppressor type, length and positions	Provided by PETROBRAS
4.3	Buoyancy modules characteristics (if applicable)	Provided by PETROBRAS
4.4	Hydrodynamic properties	Provided by PETROBRAS
4.5	Riser internal fluid	Provided by PETROBRAS

6. GENERAL METHODOLOGY

The general methodology requirements are presented in the following items:

i) According to uncoupled methodology, the effects of wind, current and mean drift waves acting on the FPU shall be incorporated as static offsets, calculated previously based on coupled analysis

ii) Static FPU offsets shall consider the positioning errors. The errors shall be added to the calculated offset always in the most conservative way. The relative phasing between motions and waves shall also be taken into account

iii) FPU motions shall be derived from RAO data. At least three FPU drafts shall be considered: light, intermediate and full. The RAO data shall not include the damping contribution from the risers (no-lines)

iv) The dynamic analysis shall consider the effects of wave and currents acting on the FPU and the effects of currents and waves acting directly on the risers

v) The markup factor of 1.2 (20% increase) for free-hanging risers and 1.4 (40% increase) for lazy-wave risers shall be applied to the estimated top loads for all directions and load cases

If available, RAOs shall be considered in accordance with Hs level of each load case. Refer to the GTD.

6.1. RISER SUPPORT FIXED REFERENCE SYSTEM

A fixed reference system at the supports shall be adopted and will be called Fixed Support Reference System. See Figure 6 for examples of the reference system definition.

The coordinate system shall follow the support top angle and azimuth definitions, according to the RISER BALCONY ARRANGEMENT, being the x-axis coincident with the support top angle and positive towards the riser TDP. The other axes shall coincide respectively with the riser out-of-plane (Fy, My) and in-plane orthogonal directions (Fz, Mz). This coordinate system shall move together with the vessel, i.e. independent from the risers. For flexible risers, the center of the reference system (CoR) shall be located at the upper end of the conic section of bend-stiffeners. For rigid risers, the CoR shall be located at the center of rotation of the stress/flexible joint. Refer to the RISER CONFIGURATION DATA for specific detailed information.

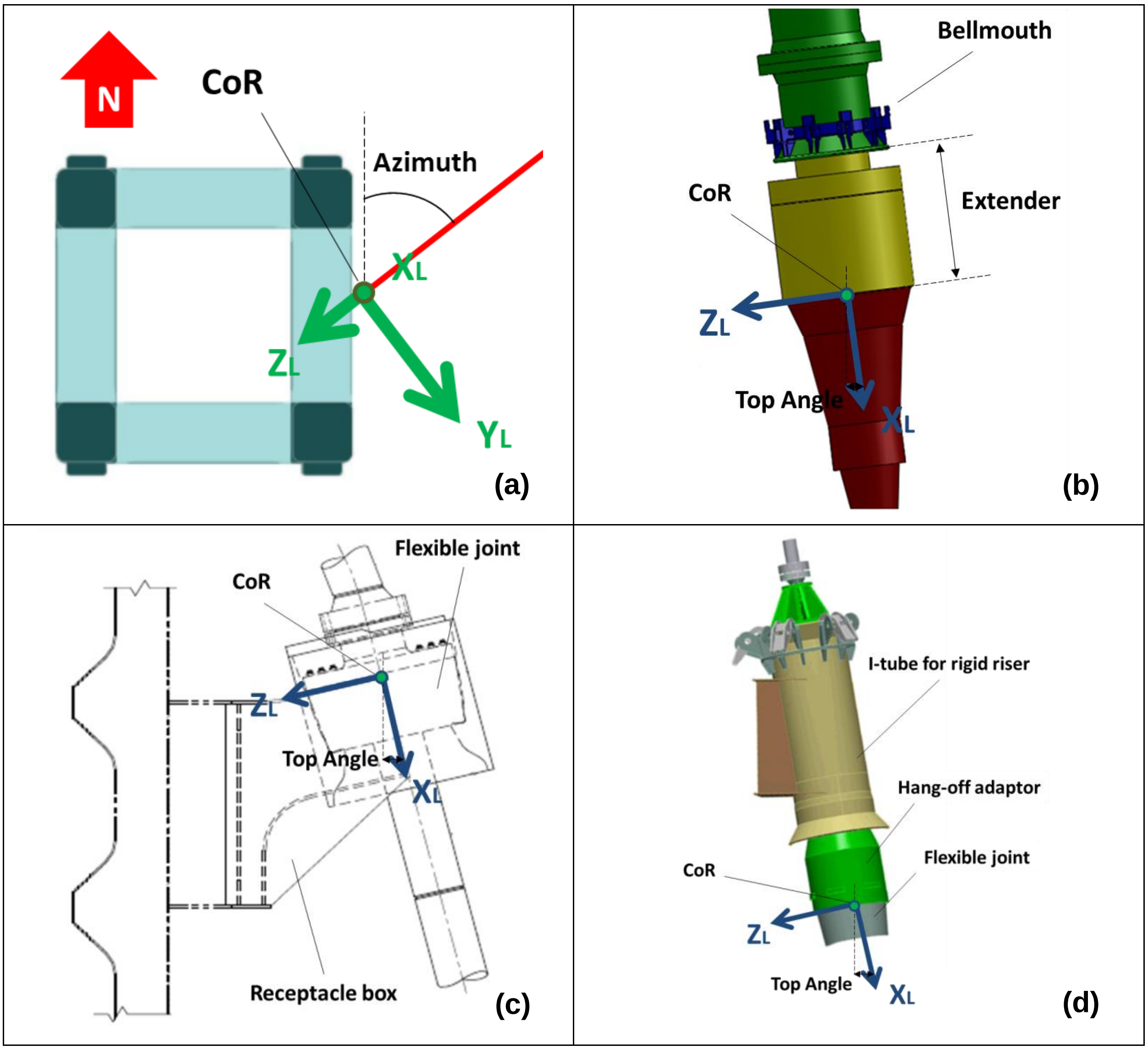

Figure 6 - Examples of definition of the Fixed Support Reference System:
(a) FPU top view (b) Flexible riser (c) Receptacle for rigid riser (d) I-tube for rigid riser

6.2. FINITE ELEMENT MODEL

The finite element model shall include the riser coatings (anti-corrosion and thermal insulation), VIV suppressors, intermediate connectors, bend stiffeners (flexible risers) or stress/flexible joint joints (rigid risers) with the detailed geometry of the respective extensions. This information is available in the RISER CONFIGURATION DATA.

The stress/flexible joint joint stiffening factor shall be considered in all dynamic analyses, as specified in the PETROBRAS documentation. This factor multiplies the basic reference stiffness value adopted in the static analyses.

6.3. STOCHASTIC AND DETERMINISTIC PROCEDURES

Time domain analyses shall be adopted in order to capture the nonlinearities present in the riser dynamic response under the environmental conditions and load cases described in items 3 and 4.

A realistic wave frequency range shall be considered, containing at least 300 frequency intervals for the wave spectra discretization. Other discretization may be proposed by CONTRACTOR after sensitivity studies to be included in the Design Premises Report.

Stochastic Procedure

Global analyses for the load cases specified in item 5 may be carried out adopting a stochastic procedure. Direct action of the waves on the risers shall be taken into account. Wave spreading shall not be adopted. When simulating the chosen load cases, two options are considered valid:

- Perform a 3-hour simulation
- Select at least 5 random seeds and 300-second time windows for the analysis, capturing the most critical motion parameter (refer to item 4.2) of the riser connection points during a 3-hour storm

The extreme values shall be obtained from the maximum values of each simulation and considering a Gumbel statistical distribution. The distribution parameters shall correspond minimally to the 57% percentile. PETROBRAS considers that MPM values (most probable maximum, corresponding to the 37% percentile) are not conservative enough.

Deterministic Procedure

Alternatively, global analyses may be performed according to a deterministic approach. In this case, at least the critical load cases for forces and bending moments, obtained for the DEC condition, shall be re-run considering the stochastic methodology.

Deterministic procedures accepted by PETROBRAS are described in Appendix A. Different procedures may be presented in the Design Premises Report.

6.4. ANALYSIS SOFTWARE

The software packages listed below are usually employed by PETROBRAS for these analyses. CONTRACTOR may propose different softwares in the Design Premises Report.

- ORCAFLEX
- RIFLEX

- DEEPLINES
- FLEXCOM

7. DELIVERABLES

The Design Premises Report to be submitted for PETROBRAS shall contain the data basis, design premises and methodologies and all relevant information used for the riser top loads estimation. The Final Design Report shall contain the results related to all risers, based on the premises and methodologies described in the Design Premises Report.

Table 6 presents a model for the top support loads publication. For each riser function and each critical load case (Table 1), the maximum and minimum values of each load component shall be identified with their algebraic values and signals.

Table 6 - Top loads table

Riser	Riser 1		Riser 2		Riser n		Max Vertical Acceleration	Max Angular Motion
Load	Min	Max	Min	Max	Min	Max		
LOAD CASE								
Fx [kN]								
Fy [kN]								
Fz [kN]								
BMx [kN.m]								
BMy [kN.m]								
BMz [kN.m]								

Notes:

(1) Axes in the Fixed Support Reference System

(2) F = force / BM = bending moment

APPENDIX – DETERMINISTIC PROCEDURES

A. Equivalent Harmonic Motion Procedure (EHMP)

The following steps shall be followed:

i) Transfer the RAO from the FPU center of motions to each riser top connection point

ii) Obtain the response spectrum for the motions of the connection by crossing the wave spectrum and RAO at the riser connection

iii) Determine, through Rayleigh statistical distribution and considering a 3-hour storm, the most probable maximum values of vertical displacement (d_{max}) and vertical acceleration (a_{max}) at the connection points

iv) Determine the dynamic motion period (T) at the riser top connection, using the most probable maximum of displacement (d_{max}) and acceleration (a_{max}), as determined in step iii) above, considering the following formulation:

$$T = 2\pi\sqrt{\frac{d_{MAX}}{a_{MAX}}}$$

v) Determine the wave height as the Rayleigh most probable maximum from Hs, as used to describe the wave spectrum in paragraph ii)

vi) Assume harmonic motions for the riser connections corresponding to the maximum amplitude values calculated, as per step v) above, and the single period evaluated for the reference DoF, according to step iv) above. Consider the same phase values of the transferred RAOs in step i), taken for the corresponding period of step iv)

B. Design Wave Procedure (DWP)

The following steps shall be followed:

i) Transfer the RAO from the FPU center of motions to each riser top connection point

ii) Obtain the response spectra for the motions of the connection points by crossing the wave spectrum and RAO at the riser connection

iii) Determine, through Rayleigh statistical distribution and considering a 3-hour storm, the most probable maximum values of vertical displacement and vertical acceleration at the connection points

iv) Determine the wave height (H_{design}) as the Rayleigh most probable maximum from Hs, as used to describe the wave spectrum in paragraph ii)

v) Determine periods ($T_{design1}$ and $T_{design2}$) which, associated with H_{design}, provide the maximum harmonic vertical displacement and maximum harmonic vertical acceleration, both calculated according to step iii)

vi) Among the possible T_{design} values, choose the nearest to the wave peak period (Tp)

vii) Assume harmonic motions for the riser connections corresponding to the maximum amplitude values calculated, as per step iv) above, and the single period evaluated for the reference DoF, according to step v) above. Consider the same phase values of the transferred RAOs in step i), taken for the corresponding period of paragraph vi)

C. Maximum Response Procedure (MRP)

The following steps shall be followed:

i) Transfer the RAO from the FPU center of motions to each riser top connection point

ii) Obtain the response spectrum for the motions of the connection by crossing the wave spectrum and RAO at the riser connection

iii) Determine, through Rayleigh statistical distribution and considering a 3-hour storm, the most probable maximum values for the 6 DoFs, vertical acceleration and angular motion at the connection points. The angular motion is defined by:

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

Where R_{MAX} and P_{MAX} are the maximum amplitudes for roll and pitch, respectively.

iv) The FPU draft with the highest maximum amplitude for the vertical acceleration and highest angular motion shall be selected. If the FPU draft with the highest maximum vertical acceleration is different from the draft with the highest angular motion, the load case shall be analyzed for the two drafts

v) For the selected draft(s), the period (T) of the regular wave is determined from the maximum vertical displacement and acceleration, according to the same expression of step iv) in item A

vi) The RAOs for the 6 DoFs at the riser connection point shall be redefined by the expression below, from the amplitude of the maximum motions (u_{max}) calculated in item iv) and the maximum wave height (H_{max}) assuming a Rayleigh distribution for the wave spectrum considered in item ii):

$$RAO_{RISER} = \frac{2 * u_{\max}}{H_{\max}}$$

vii) The RAO phases at the riser connection point are obtained from the RAOs determined in item i) considering the wave period (T) calculated in item vi)

viii) Dynamic analysis shall be performed considering the RAOs at the riser connection point (RAO_{RISER}) and a regular wave with maximum wave height (H_{max}) and period (T) determined in item vi)