BR PETROBRAS	TECHNICAL SPECIFICATION	No. I-ET-3000.00-1519-29B-PZ9-004	
	CLIENT:		SHEET 1 of 34
	JOB:		-
	AREA:		
SUB/ES/EISE/EDF	TITLE: LOAD-EFFECT ANALYSIS OF SUBSEA UMBILICALS		NP-1
			SUB/ES/EISE/EDF

INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	Original (this specification replaces former I-ET-3010.00-1500-960-PPC-008 Rev. B)
A	Division of the temporary mooring conditions in 2 (two) specific conditions: “Pull-in” and “First oil”

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	24/10/2019	30/03/2021							
DESIGN	SUB/ES/EISE/EDF	SUB/ES/EISE/EDF							
EXECUTION	CJME	CJME							
CHECK	UPOV	UPOV							
APPROVAL	BEIW	BEIW							

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1 Scope

This technical specification establishes the minimum requirements for the load-effect analysis of static and dynamic subsea umbilicals during installation and operating life phases. SUPPLIER is responsible to identify all hazards and define additional load cases to mitigate them based on risk assessment. The load conditions and methodologies specified herein for the design of dynamic subsea umbilicals are applicable to risers in free hanging and deep-water lazy wave configurations. The adoption of other configurations can be accepted upon request to PETROBRAS, but additional conditions might be necessary.

SUPPLIER shall investigate the particular cases where geometric parameters, deformations and/or stresses are relevant for the design of the subsea umbilical, and the whole set of analysis inputs and results shall be submitted to PETROBRAS. The required scope of global and structural analysis load cases for strength calculations of subsea umbilicals shall include the following: (i) the scope based on SUPPLIER experience regarding loading combinations; (ii) the scope based on PETROBRAS experience, as hereafter specified.

2 References

NOTE: Unless otherwise stated, the latest revision of the following documents must be considered.

2.1 International standards

[1] ISO 13628-5, *Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea umbilicals*

[2] API RP 17L2, *Recommended Practice for Flexible Pipe Ancillary Equipment*

[3] DNVGL-RP-F109, *On-bottom stability design of submarine pipelines*

2.2 PETROBRAS specifications

[4] I-ET-3000.00-1519-29B-PZ9-003, *Subsea umbilical systems*

[5] I-ET-3010.00-1519-274-PPC-001, *Riser Interference Analysis*

3 Terms & definitions, abbreviated terms and mathematical symbols

PETROBRAS adopts the same terms, abbreviated terms and definitions as in [1], with the amendments and supplements defined in this section.

3.1 Terms and definitions

fluid conduits
thermoplastic hoses and metallic tubes within a subsea umbilical

may
verbal form used to indicate a course of action permissible within the limits of this specification

metocean
meteorology and oceanography

shall
verbal form used to indicate requirements strictly to be followed in order to conform to this specification

should
verbal form used to indicate that a provision is not mandatory, but is recommended as good practice

structural components
components responsible to sustain the tensile loads in a subsea umbilical. Typical ones are steel wires, metallic tubes and fiber-reinforced plastic rods

SUPPLIER
subsea umbilical supplier

3.2 Abbreviated terms

AIP atmospheric internal pressure
CoM center of motion
DoF degree of freedom
EOL end of life
FPSO floating, production, storage, offloading
FPU floating production unit
Max maximum
Min minimum
MPM most probably maximum
RP return period
SOL start of life
SS semi-submersible
TDP touchdown point
UTS ultimate tensile strength
VLS vertical laying system
WD water depth

3.3 Mathematical symbols

H regular wave height
Hmax maximum regular wave height
Hs significant wave height
P_{MAX} MPM amplitude for pitch
R_{MAX} MPM amplitude for roll
T regular wave period
Tp peak period
T_{top} top tension
a angle between the riser and the bend stiffener neutral axis
k_p pseudo-curvature
θ angular motion

4 Documentation

4.1 Design Premises Report

Prior to the commencement of the load-effect analysis, SUPPLIER shall issue a Design Premises Report to PETROBRAS with the minimum content described in [4]. Starting the analysis without PETROBRAS approval is performed at SUPPLIER's own risk.

4.2 Design Report

After the completion of the load-effect analysis, all the information raised in the course of the analysis shall be gathered and compiled in a Design Report to be sent for PETROBRAS evaluation and approval. The minimum content of the Design Report is described in [4].

Note: Design Reports generated under the scope of a qualification process shall disregard the following items described in [4]:

- reference to material requisition
- termination and ancillary equipment drawings
- termination and ancillary equipment calculations design
- termination and ancillary equipment cathodic protection calculations

5 Extreme-load analysis

5.1 Load combinations and conditions

The subsea umbilical shall be designed and verified under functional, environmental, and accidental load combinations, as per [1]. The extreme-load conditions that shall be analyzed are normal operation, abnormal operation, and temporary conditions.

Extreme-load analysis cases shall be numerically simulated for the purpose of investigating and checking integrity, geometry, and stability of the umbilicals. Extreme-load analysis results provide the input for structural analysis to determine if the umbilical capacity and utilization factors are not exceeded under specified load conditions. Examples of main concerns are over tensioning of the umbilical section at the top connection, over bending at the TDP and crushing loads effects during installation.

Besides the prediction of utilization factors for the structural analysis load cases specified on sections 5.3.1 and 5.3.2, extreme-load 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 sections have to be evaluated in relation to axial tension or compression and bending radius worst combinations. For the TDP region, improved accuracy of the global analysis results is required considering the severe influence of relevant parameters, such as temperature and 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. Nonlinear behaviors like, for instance, the stick-slip effects in the armors layers which cause hysteretic bend behavior and nonlinear polymeric stiffness, can be used and the data dully informed in the Design Premise.

The Design Premise elaborated by the SUPPLIER shall specify a load case matrix, which shall include at least the load cases presented in Table 1 and Table 2.

5.1.1 Design load cases

The aim of the design load cases is to reproduce extreme-load conditions that the subsea umbilical might be subjected during installation and long-term operation. Design load cases stated in Table 1 are considered as a minimum for the design of a subsea umbilical and its ancillary equipment.

Table 1 - Design load cases

Load Condition	Design Case	Load Type		
		Functional	Environmental	Accidental
Normal Operation	A – DWP & intact mooring system	Fluid Conduits full at DWP, Interstices flooded, FPU intact mooring system	100-year RP environmental conditions	-
Abnormal Operation	B – DWP & one mooring line broken	Fluid Conduits full at DWP, Interstices flooded	100-year RP environmental conditions	FPU with one mooring line broken
	C – DWP & buoyancy modules losses over service life(1)	Fluid Conduits full at DWP, Interstices flooded, FPU intact mooring system	100-year RP environmental conditions	Buoyancy modules losses(2)
	D – DWP & FPU inclination	Fluid Conduits full at DWP, Interstices flooded, FPU intact mooring system	1-year RP environmental conditions	FPU inclination due to a compartment flooding
Temporary Conditions	E – AIP & installation vessel	Fluid Conduits full at AIP, Interstices flooded	1-year RP environmental conditions	-

(1) This design load case applies only when SUPPLIER proposes a deep-water lazy wave configuration

(2) The buoyancy modules losses shall be defined according to [2]

5.1.2 Verification load cases

Temporary mooring conditions might happen during the production system installation phase, when the FPU can be held in position for a relatively short period by a mooring pattern different from the permanent system, designed to moor the FPU for the whole service life. Under this temporary condition, the risers will be subjected to offsets greater than those expected for the operational conditions, but with reduced environmental loads. The temporary conditions to be analyzed are:

- Pull-in with temporary mooring system and
- First oil with temporary mooring system

The aim of the verification load cases on Table 2 is to reproduce such conditions.

The design premises and specified load cases for temporary mooring conditions shall not be used for configuration or structural design, neither for subsea umbilical and/or ancillary equipment dimensioning, they are intended for verification only. Nevertheless, SUPPLIER shall inform if all design criteria were met in these temporary mooring conditions, providing the components utilization factors in the Design Report.

Table 2 - Verification load cases

Load Condition		Verification Case	Load Type		
			Functional	**Environmental**	**Accidental**
Temporary Conditions	Pull-in	F – AIP & intact temporary mooring system	Fluid Conduits full at AIP, Interstices flooded, FPU intact temporary mooring system	1-year RP environmental conditions	-
	First oil	G – DWP & intact temporary mooring system	Fluid Conduits full at DWP, Interstices flooded, FPU intact temporary mooring system	10-year RP environmental conditions	-
		H – DWP & one mooring line broken	Fluid Conduits full at DWP, Interstices flooded FPU damaged temporary mooring system	10-year RP environmental conditions	FPU with one mooring line broken
		I – DWP & buoyancy modules losses over service life(1)	Fluid Conduits full at DWP, Interstices flooded, FPU intact temporary mooring system	10-year RP environmental conditions	Buoyancy modules losses(2)

(1) This verification load case applies only when SUPPLIER proposes a deep-water lazy wave configuration

(2) The buoyancy modules losses shall be defined according to [2]

5.2 Global analysis

The global analysis tables herein presented are related to one single riser. The design of one specific riser or a group of risers (when SUPPLIER is supplying a group of risers for the same FPU, with the same functional and system requirements) 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:

- 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;

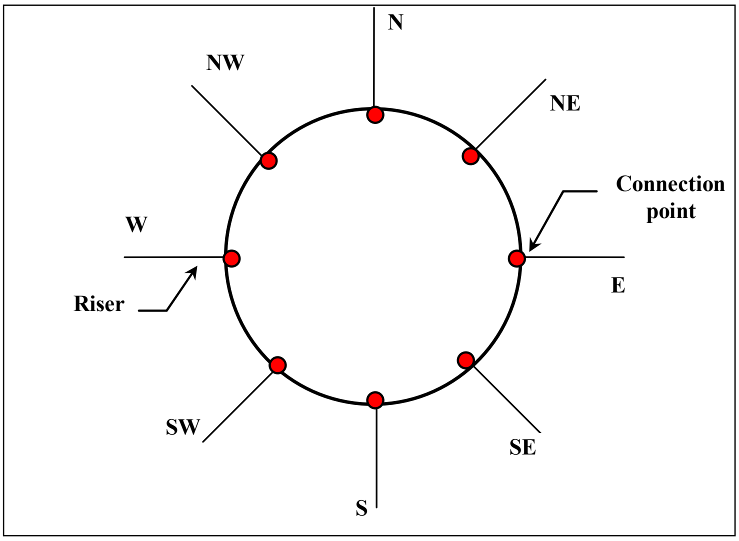

Figure 1 - Connection points and riser azimuths for turret moored systems

- Ship shape unit with spread mooring system – two connection points and ten different riser azimuths shall be considered as shown in Figure 2: one perpendicular to the platform side, and the others ±22.5º and ±45º apart from it, the same applies for keel hauling risers. 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.

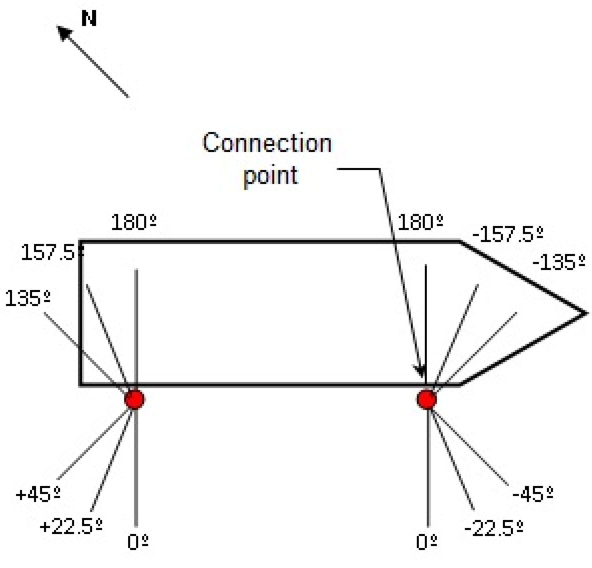

Figure 2 - Connection points and riser azimuths for ship shape units with spread mooring system

- SS unit – three different riser azimuths shall be considered at each side of the platform as shown in Figure 3: 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.

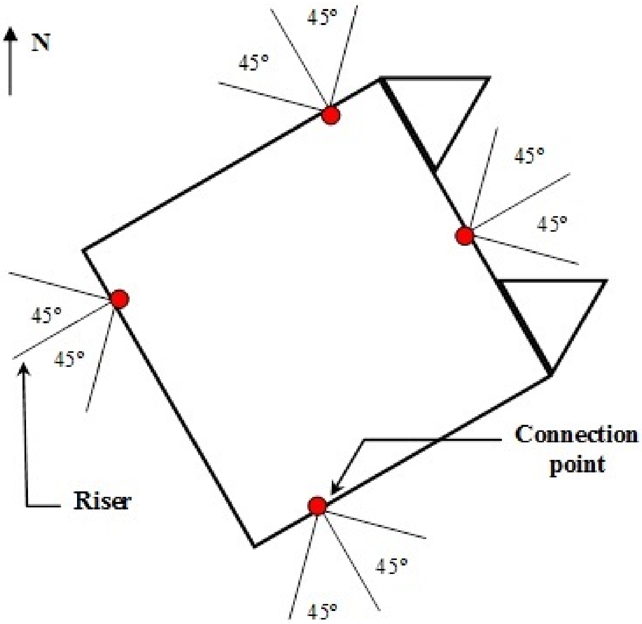

Figure 3 - Connection points and riser azimuths for SS units

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

In case of several risers with the same properties but different azimuths and connection points in the same FPU, SUPPLIER can present the results for the risers with most critical combinations of azimuth and connection point, considering their impact to the umbilical integrity (e.g. level of stress/strain), 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 and submitted to PETROBRAS for approval.

The following notes shall be observed for all load cases stated in sections 5.2.1 and 5.2.2:

1. The wave modeling procedures described on Appendix B 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, or 11.25º from N if 16 (sixteen) directions are available], the one with the largest 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 rotated, 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, or 11.25º from N if 16 (sixteen) directions are available], the one with the largest surface current velocity shall be selected.

4. Current profile may be truncated if the WD is shallower than the profile presented in PETROBRAS metocean technical documentation or may be expanded, repeating the last current direction and velocity if the WD is greater.

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 riser section is under effective compression, it means maximum effective compression at that section.

6. If other values are not specified by PETROBRAS, installation and positioning errors of 1.5% of WD and 7.5 m, respectively, shall be considered on the total FPU offset.

7. If SUPPLIER proposes a deep-water lazy wave configuration, it shall be verified for both the SOL and the EOL conditions of the buoyancy modules.

5.2.1 Design load cases global analysis

Global analysis of Design Load Case A shall include at least the load cases listed in Table 3. The motion analysis described in Annex A shall be used for selection of the wave parameters and FPU draft (any other procedure has to 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 [see note (3) of Table 3].

Global analysis of Design Load Case B shall include at least the load cases listed in Table 4. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 4 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 4 shall consider the same FPU draft and environmental loads of the original load cases from Table 3, but with a higher offset value due to the damaged mooring system. If the original load case is from GA-01 to GA-16, then the offset for the load case in Table 4 is 100-year RP, damaged mooring. If the original load case is from GA-17 to GA-20, then the offset for the load case in Table 4 is 1-year RP, damaged mooring.

Global analysis of Design Load Case C shall include at least the load cases listed in Table 5. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 5 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 5 shall consider the same FPU draft, FPU offset and environmental loads of the original load cases from Table 3, however considering the buoyancy losses as defined in Table 1.

Global analysis of Design Load Case D shall include at least the load cases listed in Table 6. These load cases are generated taking into consideration the results of the global analyses of Design Load Case A, according to the specified in Table 6 (e.g. maximum top tension, maximum angle etc.). The load cases in Table 6 shall consider 1-year RP environmental loads applied on the same directions of the original load cases from Table 3. The offset shall be 1-year RP, intact mooring. FPU inclination due to compartment flooding shall be applied on the longitudinal axis for ship shape unit and on the diagonal for semisubmersible. An angle of inclination of 10º (ten degrees) for ship shape unit and 15º (fifteen degrees) for SS or other units shall be adopted if it is not specified on PETROBRAS project-specific 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 (loss of functionality is not acceptable, but no strain limitation in the bend stiffness is required).

Global analysis of Design Load Case E shall include at least the load cases listed in Table 7. These load cases consider the umbilical (riser or flowline) connected to the installation vessel. A screening analysis shall be performed for selection of the wave period and installation vessel draft, regarding the fact that the wave height is already defined on Table 7. The effect of different lay azimuths shall be considered on the global analysis. If only one azimuth is considered, SUPPLIER shall prove by some spot check calculations that this azimuth is the worst one. Global analysis of Design Load Case E shall be performed considering the departure angles of 1º (one degree) and 3º (three degrees) with relation to the vertical. The purpose of Design Load Case E is to assure the installation feasibility of the subsea umbilical and its ancillary equipment, besides determining stresses and strains on the structural components of the subsea umbilical and the respective utilization factors.

Regarding the load cases on Table 7, if design criteria are not met for one or more wave direction (head seas, quartering seas or beam seas) considering the specified wave height [H (m)] and period (6 to 15 s), then, for this(these) wave direction(s), global analysis shall be performed again considering annual wave spectra (Hs and Tp taken from the applicable PETROBRAS metocean technical specification), where Hs shall be limited to the following values: head seas = 4.5 m, quartering seas = 4.0 m e beam seas = 3.2 m. If design criteria are still not met, then Hs shall be decreased (applying the previous procedure again) until the analysis finally succeeds. SUPPLIER shall explain this course of actions on the Design Report and clearly state the maximum allowable Hs according to its analysis.

Table 3 - Global analysis matrix for Design Load Case A

Load Case	Position	Functional Load					Environmental Load				Reference Figure
		FPU Draft	FPU Heading relative to the wave incidence direction		FPU offset		Wave		Current		
			FPSO Turret (Fig. 4)	Others	RP	Direction[(2)]	RP	Direction	RP	Direction	
GA-01	Near	Draft with the worst vertical acceleration and angular motion for each load case[(1)]	Head seas	Actual Heading	100-year, intact mooring	0º from the riser plane	100-year	Collinear	10-year	Collinear	Fig. 5 (a)
GA-02	Far					180º from the riser plane					Fig. 5 (b)
GA-03	Crossed					± 45º (cross near) and ± 135º (cross far) from the riser plane					Fig. 6 (a)
GA-04	Transverse					± 90º from the riser plane					Fig. 6 (b)
GA-05	Near					0º from the riser plane	10-year	Collinear	100-year	Collinear	Fig. 5 (a)
GA-06	Far					180º from the riser plane					Fig. 5 (b)
GA-07	Crossed					± 45º (cross near) and ± 135º (cross far) from the riser plane					Fig. 6 (a)
GA-08	Transverse					± 90º from the riser plane					Fig. 6 (b)
GA-09	Near		22.5° from bow			0º from the riser plane	100-year	Crossed ± 22.5 of the riser	10-year	Crossed ± 45 of the wave	Fig. 7 (a); (b)
GA-10	Far					180º from the riser plane					Fig. 8 (a); (b)
GA-11	Crossed					± 45º (cross near) and ± 135º (cross far) from the riser plane					Fig. 9 (a); (b), Fig. 10 (a); (b)
GA-12	Transverse					± 90º from the riser plane					Fig. 11 (a); (b)
GA-13	Near		22.5° from bow			0º from the riser plane	10-year	Crossed ± 22.5 of the riser	100-year	Crossed ± 45 of the wave	Fig. 7 (a); (b)
GA-14	Far					180º from the riser plane					Fig. 8 (a); (b)
GA-15	Crossed					± 45º (cross near) and ± 135º (cross far) from the riser plane					Fig. 9 (a); (b), Fig. 10 (a); (b)
GA-16	Transverse					± 90º from the riser plane					Fig. 11 (a); (b)
GA-17	Near		Beam seas (90°)		1-yr, intact mooring	0º from the riser plane	(3)	(4)	1-year	(5)	
GA-18	Far					180º from the riser plane					
GA-19	Crossed					± 45º (cross near) and ± 135º (cross far) from the riser plane					
GA-20	Transverse					± 90º from the riser plane					

(1) For selection of the FPU draft and waves for each load case, the motion analysis procedure presented in Appendix A shall be followed.

(2) Offset direction is defined by the riser azimuth and the load case position (NEAR, FAR, etc.) presented on the second column of the table.

(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) Hs for a RP of 1-year. For FPU's in operation at Campos Basin, Hs shall be limited to 4.5 m;

(ii) 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 follows:

(i) For turret mooring system the wave direction shall be ± 90º 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 ± 90º relative to the heading direction of the unit. The wave direction shall be in accordance with the offset direction, in such a way that the wave shall not be opposed to the offset. 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, the FPU shall be considered aligned with the current, running from bow to stern.

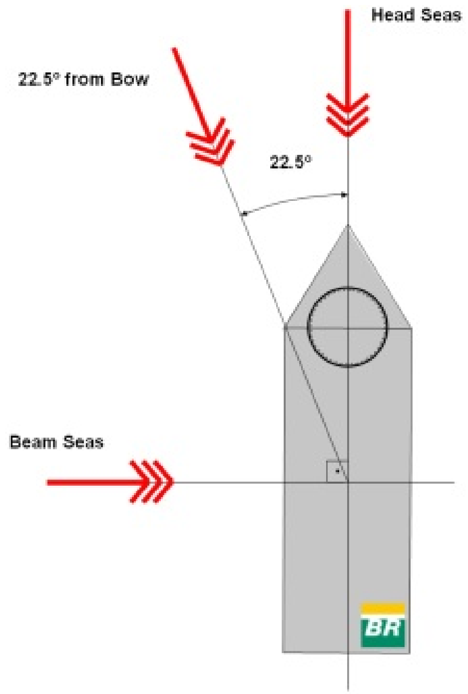

Figure 4 - Wave incidence direction for ship shape unit with turret moored system

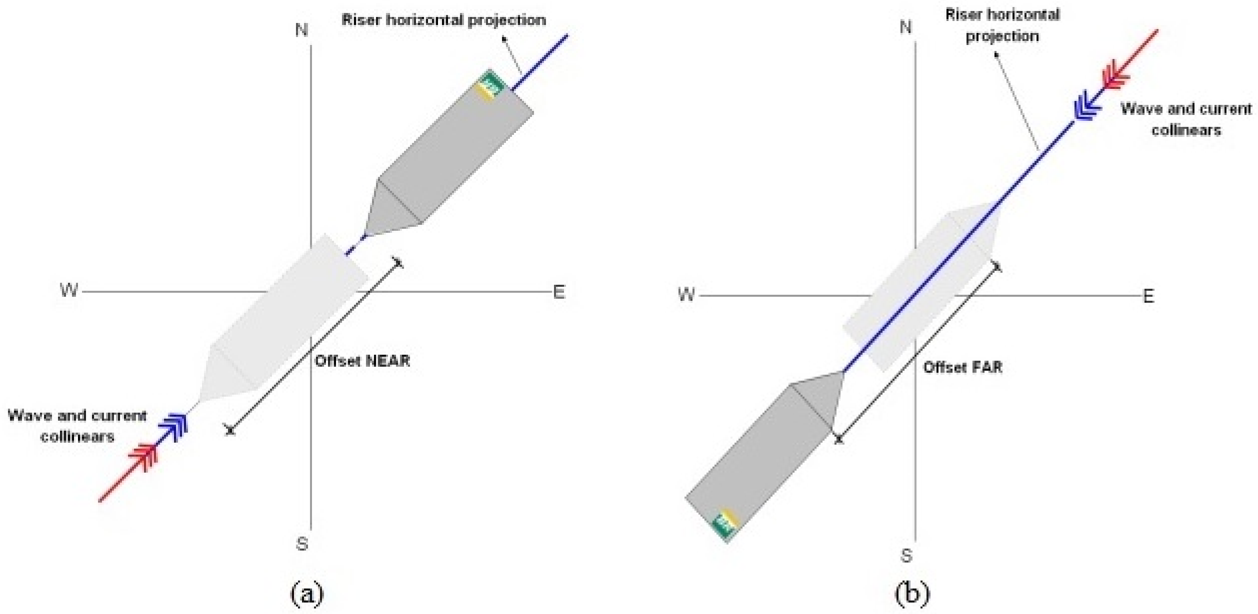

Figure 5 - Collinear environmental loads and offsets: (a) Near, (b) Far

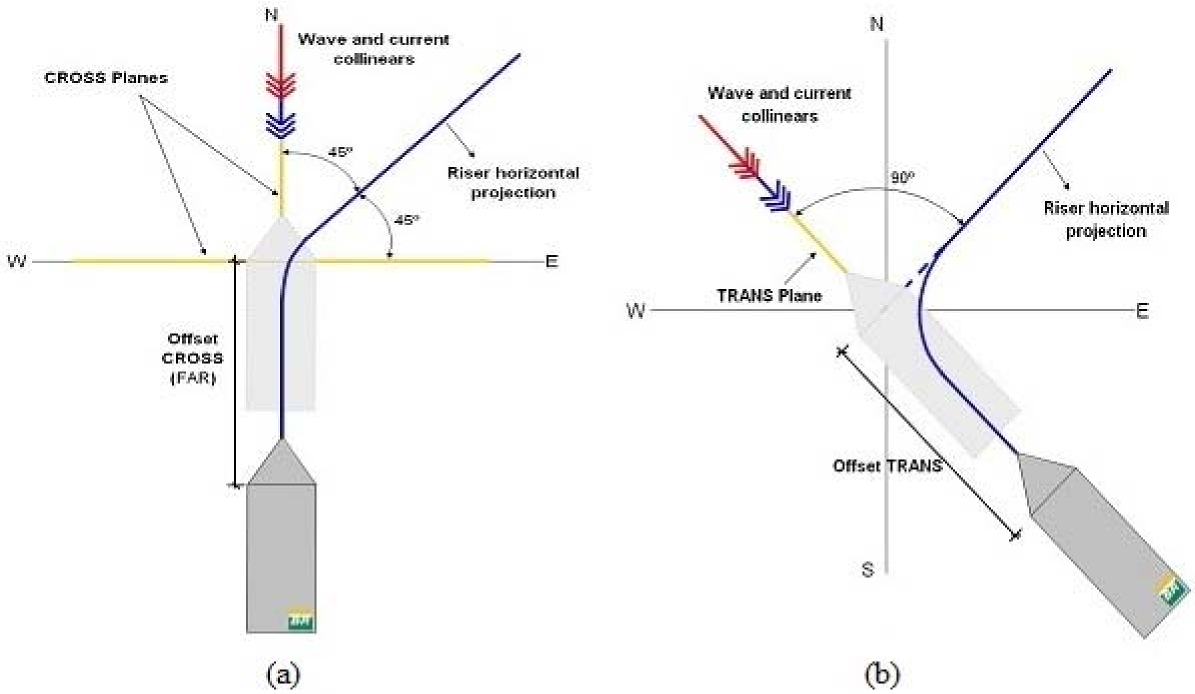

Figure 6 - Collinear environmental loads and offsets: (a) Crossed, (b) Transverse

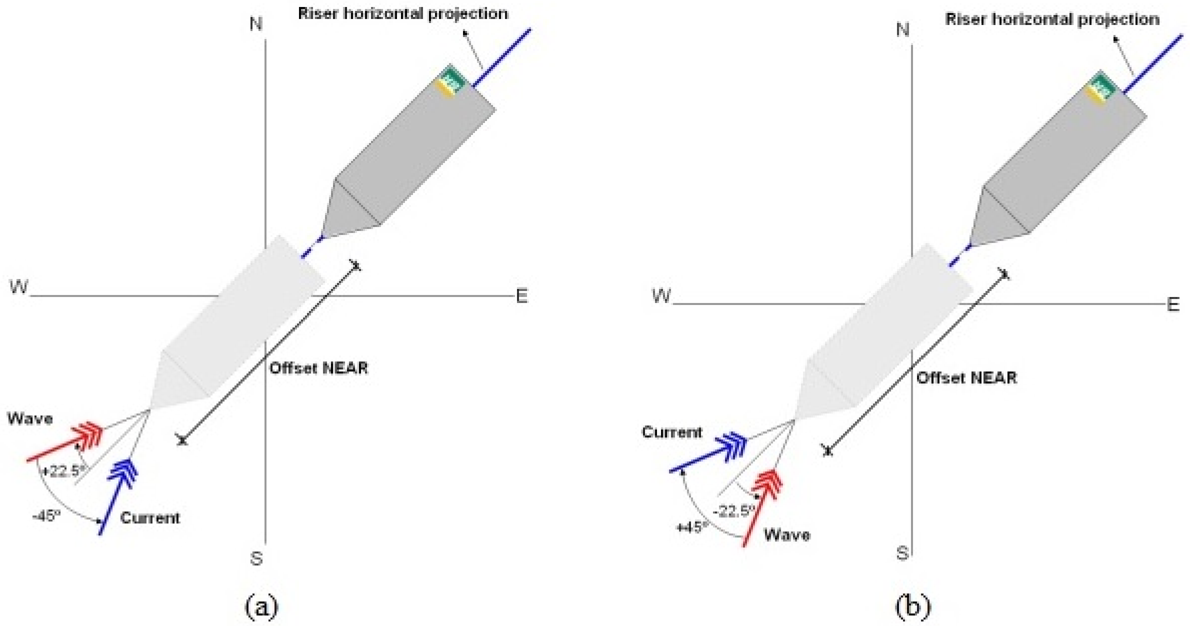

Figure 7 - Crossed environmental loads and offsets: (a), (b) Near

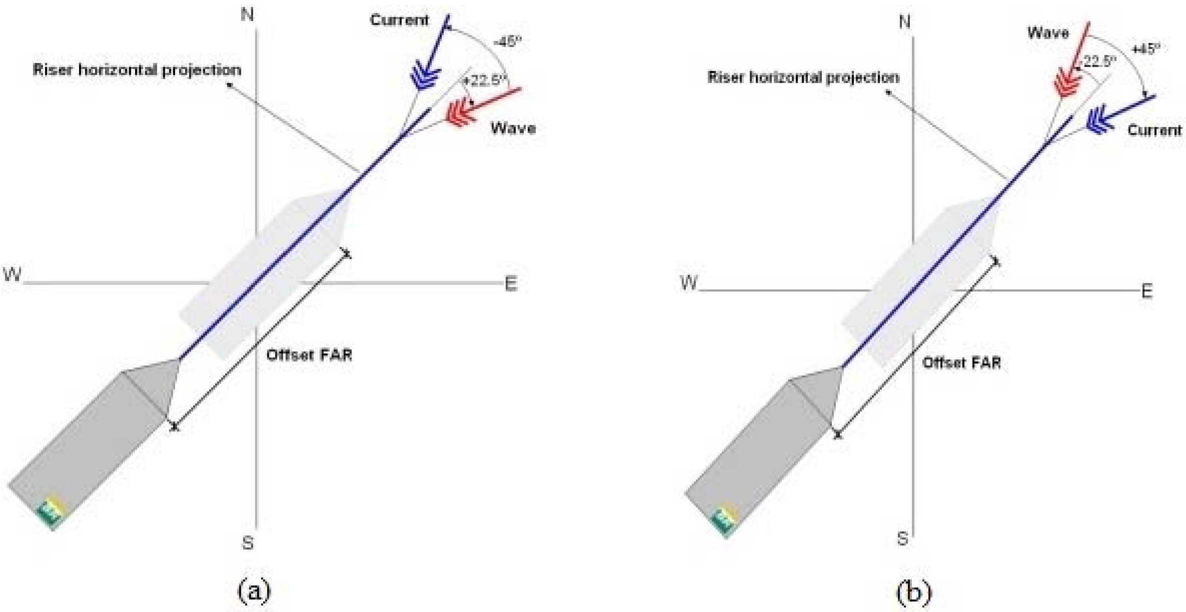

Figure 8 - Crossed environmental loads and offsets: (a), (b) Far

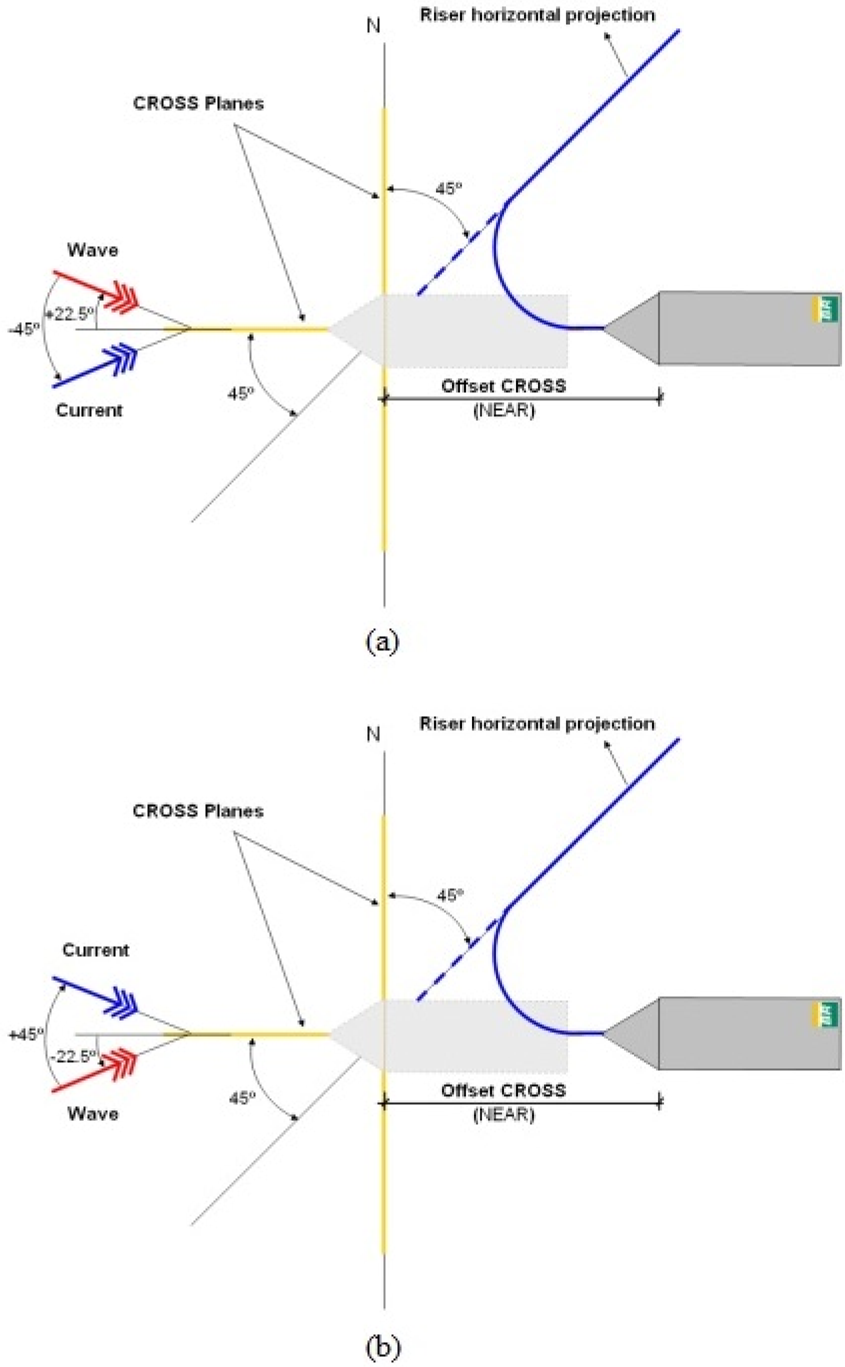

Figure 9 - Crossed environmental loads and offsets: (a), (b) Crossed Near

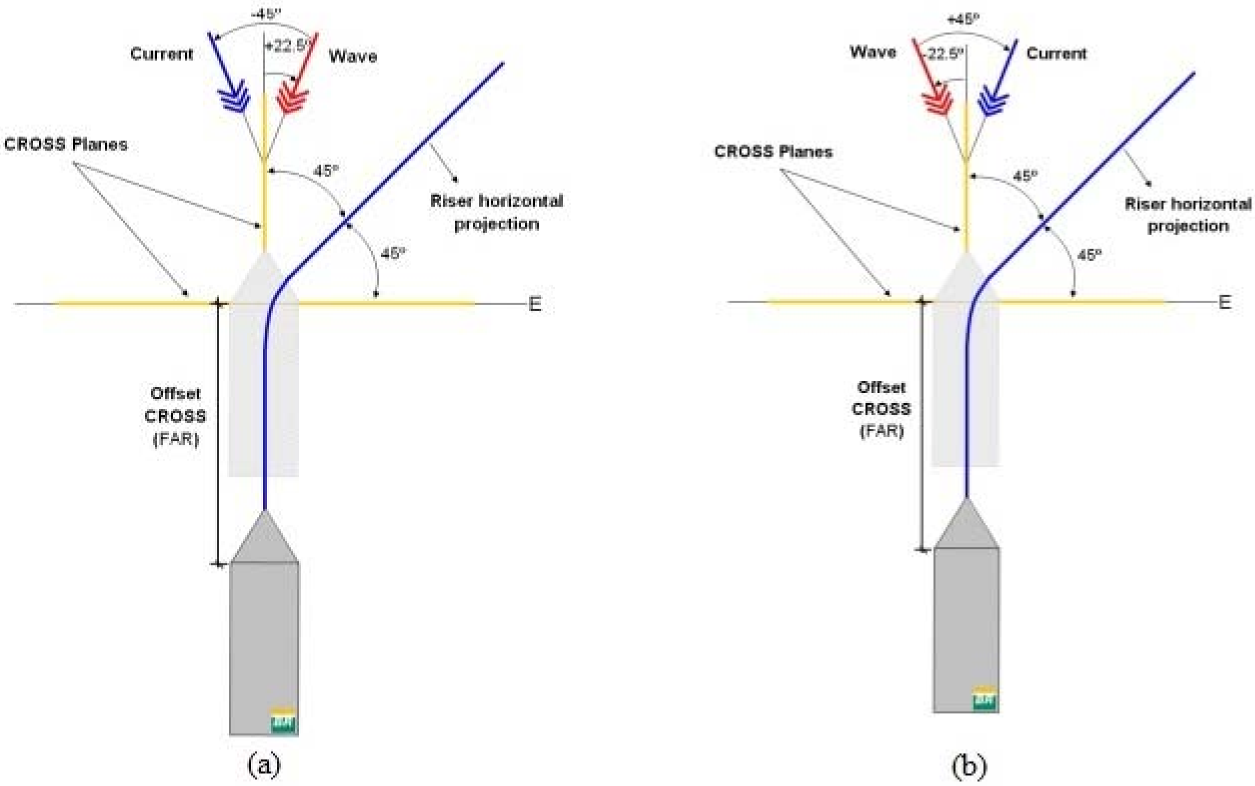

Figure 10 - Crossed environmental loads and offsets: (a), (b) Crossed Far

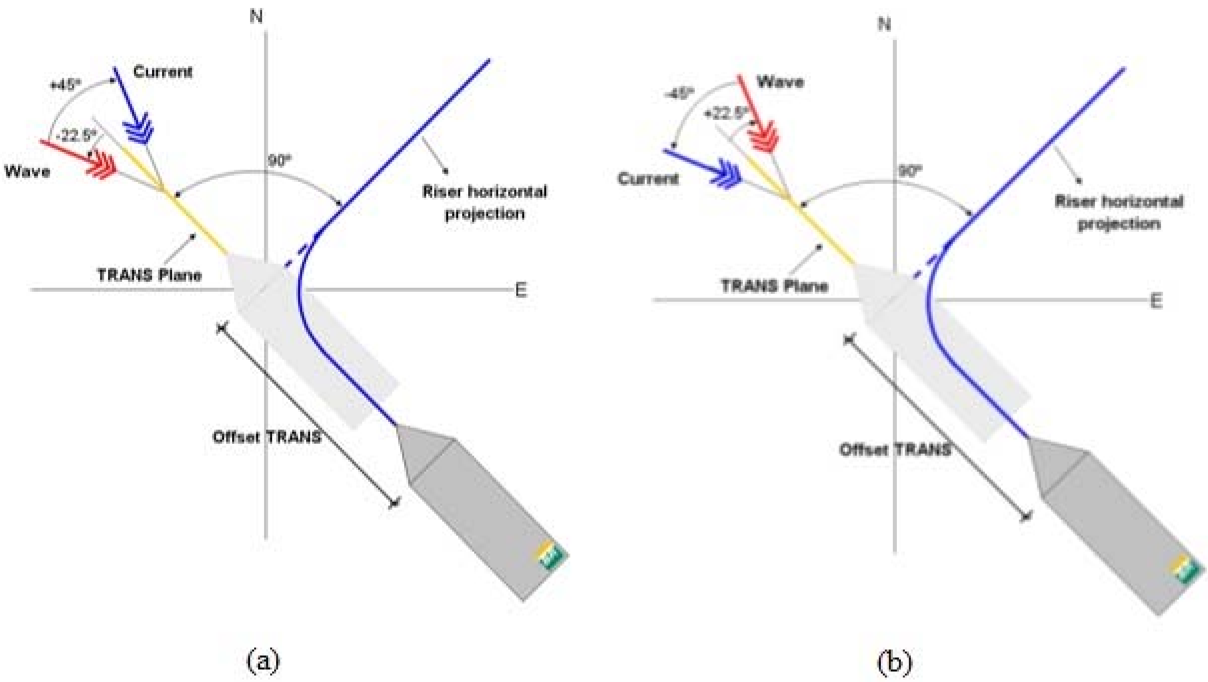

Figure 11 - Crossed environmental loads and offsets: (a), (b) Transverse

Table 4 - Global analysis matrix for Design Load Case B

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset(1)		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GB-01	Near	Same as the original load case from Table 3	Same as the original load case from Table 3	100-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20), damaged mooring	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	One mooring line broken	Maximum tension and angle on the top region among near cases(2)
GB-02	Far										Maximum tension and angle on the top region among far cases(2)
GB-03	Crossed										Maximum tension and angle on the top region among crossed cases(2)
GB-04	Transverse										Maximum tension and angle on the top region among transverse cases(2)
GB-05	Near										Maximum TDP, sag or hog curvature among near cases
GB-06	Far										Maximum TDP, sag or hog curvature among far cases
GB-07	Crossed										Maximum TDP, sag or hog curvature among cross cases
GB-08	Transverse										Maximum TDP, sag or hog curvature among transverse cases

(1) If not specified, offset for damaged mooring system for load cases originated from GA-17 to GA-20 shall be equal to the offset for 100-year environmental condition and intact mooring system.

(2) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 4 will become two different load cases.

Table 5 - Global analysis matrix for Design Load Case C

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GC-01	Near	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Same as the original load case from Table 3	Buoyancy losses over service life	Maximum tension and angle on the top region among near cases(1)
GC-02	Far										Maximum tension and angle on the top region among far cases(1)
GC-03	Crossed										Maximum tension and angle on the top region among crossed cases(1)
GC-04	Transverse										Maximum tension and angle on the top region among transverse cases(1)
GC-05	Near										Maximum TDP, sag or hog curvature among near cases
GC-06	Far										Maximum TDP, sag or hog curvature among far cases
GC-07	Crossed										Maximum TDP, sag or hog curvature among cross cases
GC-08	Transverse										Maximum TDP, sag or hog curvature among transverse cases

(1) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 5 will become two different load cases.

Table 6 - Global analysis matrix for Design Load Case D

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GD-01	Near	Same as the original load case from Table 3	Same as the original load case from Table 3	1-year, intact mooring	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	Compartment flooding	Maximum tension and angle on the top region among near cases(1)
GD-02	Far										Maximum tension and angle on the top region among far cases(1)
GD-03	Crossed										Maximum tension and angle on the top region among crossed cases(1)
GD-04	Transverse										Maximum tension and angle on the top region among transverse cases(1)

(1) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 6 will become two different load cases.

Table 7 - Global analysis matrix for Design Load Case E

Load Case	Position	Functional Load			Environmental Load				
		Installation Vessel Draft	Installation Vessel Heading relative to the wave incidence direction	Vessel offset	Wave			Current	
					H (m)	T (s)	Direction	RP	Direction
GE-01	Neutral	Draft with the worst vertical acceleration and angular motion for each load case(1)	Head seas	None	8.55	(1)	Collinear	1	Collinear
GE-02			Quartering seas		7.60			1	
GE-03			Beam seas		6.08			1	

(1) For each load case, a screening analysis shall be performed to choose the installation vessel draft and wave period (between 6 to 15 s) that give the highest vertical acceleration and highest angular motion.

5.2.1.1 Bend stiffener design

Considering the global analysis results for the design load cases, at least one of the following combinations of axial tension and angle between the riser and bending stiffener neutral axis shall be considered in the bending stiffener design:

- Maximum top tension associated with maximum angle between the riser and bend stiffener neutral axis, for load cases analyzed considering only a regular wave procedure
- Maximum top tension with associated angle between the riser and bend stiffener neutral axis, and maximum angle between the riser and bend stiffener neutral axis with associated top tension, for load cases analyzed considering an irregular wave procedure or for load cases analyzed considering an regular wave procedure checked by an irregular wave procedure (refer to Annex B)
- Top tension and angle between the riser and bend stiffener neutral axis that give the maximum bending moment calculated based on the maximum pseudo-curvature $[\kappa_p = T_{top} * (1 - \cos\alpha)$ or $\kappa_p = 2 * T_{top} * \sin^2(\alpha/2)]$

5.2.2 Verification load cases global analysis

5.2.2.1 Pull-in with temporary mooring system

Global analysis of Verification Load Case F shall include at least the load cases listed in Table 8. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 8 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 8 shall consider the FPU minimum draft and 1-year RP environmental loads, but with an offset value as follows: global analysis of Verification Load Case F shall consider an offset of 14.5% of the WD, and SUPPLIER shall clearly present in the Design Report if all design criteria were fulfilled or not. Risers and/or ancillary equipment which design criteria were not fulfilled considering this offset value shall be reevaluated considering a FPU offset of 12.5% of the WD, and again SUPPLIER shall clearly present in the Design Report if all design criteria were fulfilled or not for the latest offset value.

Table 8 - Global analysis matrix for Verification Load Case F

Load Case	Position	Functional Load				Environmental Load				From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset		Wave		Current		
				Value	Direction	RP	Direction	RP	Direction	
GF-01	Near	Minimum	Same as the original load case from Table 3	14.5% of WD (and, eventually, 12.5%)	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	Maximum tension and angle on the top region among near cases(1)
GF-02	Far									Maximum tension and angle on the top region among far cases(1)
GF-03	Crossed									Maximum tension and angle on the top region among crossed cases(1)
GF-04	Transverse									Maximum tension and angle on the top region among transverse cases(1)
GF-05	Near									Maximum TDP, sag or hog curvature among near cases
GF-06	Far									Maximum TDP, sag or hog curvature among far cases
GF-07	Crossed									Maximum TDP, sag or hog curvature among cross cases
GF-08	Transverse									Maximum TDP, sag or hog curvature among transverse cases

(1) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 8 will become two different load cases.

5.2.2.2 First oil with temporary mooring system

Global analysis of Verification Load Cases G, H and I shall consider the offset values in Table 9. Case I offsets shall be used for the riser verification with temporary mooring conditions, and SUPPLIER shall clearly present in the Design Report if all design criteria were fulfilled or not for this offset case. Risers and/or ancillary equipment which design criteria were not fulfilled considering Case I offsets shall be reevaluated considering Case II offsets. Again, SUPPLIER shall clearly present in the Design Report if all design criteria were fulfilled or not for Case II offsets.

Table 9 - Offset values for First oil with temporary mooring condition

Case	Environmental RP	Mooring condition	Total FPU Offset(1) (%WD)
I	1-year	Intact	8.5
	10-year	Intact	12.5
	10-year	One mooring line broken	14.5
II	1-year	Intact	6.5
	10-year	Intact	10.5
	10-year	One mooring line broken	12.5

(1) Including installation and positioning errors.

Global analysis of Verification Load Case G shall include at least the load cases listed in Table 10. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 10 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 10 shall consider the same FPU draft of the original load cases from Table 3, but with reduced environmental loads and with a higher offset value due to the temporary mooring system.

Global analysis of Verification Load Case H shall include at least the load cases listed in Table 11. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 11 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 11 shall consider the same FPU draft of the original load cases from Table 3, but with reduced environmental loads and with a higher offset value due to the damaged temporary mooring system.

Global analysis of Verification Load Case I shall include at least the load cases listed in Table 12. These load cases are generated taking into consideration the results of the global analysis of Design Load Case A, according to the specified in Table 12 (e.g. maximum top tension, maximum curvature etc.). The load cases in Table 12 shall consider the same FPU draft of the original load cases from Table 3, but with reduced environmental loads and with a higher offset value due to the temporary mooring system, together with the buoyancy losses as defined in Table 2.

Table 10 - Global analysis matrix for Verification Load Case G

<table>
<tr><th rowspan="3">Load Case</th><th rowspan="3">Position</th><th colspan="4">Functional Load</th><th colspan="4">Environmental Load</th><th rowspan="3">From Table 3, select the load case which present:</th></tr>
<tr><th rowspan="2">FPU Draft</th><th rowspan="2">FPU Heading</th><th colspan="2">FPU offset</th><th colspan="2">Wave</th><th colspan="2">Current</th></tr>
<tr><th>RP</th><th>Direction</th><th>RP</th><th>Direction</th><th>RP</th><th>Direction</th></tr>
<tr><td>GG-01</td><td>Near</td><td rowspan="16">Same as the original load case from Table 3</td><td rowspan="16">Same as the original load case from Table 3</td><td rowspan="16">10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20), intact temporary mooring</td><td rowspan="16">Same as the original load case from Table 3</td><td rowspan="4">(1)</td><td rowspan="16">Same as the original load case from Table 3</td><td rowspan="4">1-year</td><td rowspan="16">Same as the original load case from Table 3</td><td>Maximum tension and angle on the top region among near cases(2) (3)</td></tr>
<tr><td>GG-02</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2) (3)</td></tr>
<tr><td>GG-03</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2) (3)</td></tr>
<tr><td>GG-04</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2) (3)</td></tr>
<tr><td>GG-05</td><td>Near</td><td rowspan="4">1-year</td><td rowspan="4">(1)</td><td>Maximum tension and angle on the top region among near cases(2)</td></tr>
<tr><td>GG-06</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2)</td></tr>
<tr><td>GG-07</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2)</td></tr>
<tr><td>GG-08</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2)</td></tr>
<tr><td>GG-09</td><td>Near</td><td rowspan="4">(1)</td><td rowspan="4">1-year</td><td>Maximum TDP, sag or hog curvature among near cases(3)</td></tr>
<tr><td>GG-10</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases(3)</td></tr>
<tr><td>GG-11</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases(3)</td></tr>
<tr><td>GG-12</td><td>Transverse</td><td>Maximum TDP, sag or hog curvature among transverse cases(3)</td></tr>
<tr><td>GG-13</td><td>Near</td><td rowspan="4">1-year</td><td rowspan="4">(1)</td><td>Maximum TDP, sag or hog curvature among near cases</td></tr>
<tr><td>GG-14</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases</td></tr>
<tr><td>GG-15</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases</td></tr>
<tr><td>GG-16</td><td>Transverse</td><td>Maximum TDP, sag or hog curvature among transverse cases</td></tr>
</table>

(1) 10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20)

(2) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 10 will become two different load cases.

(3) For GG-01, GG-02, GG-03, GG-04, GG-09. GG-10, GG-11 and GG-12, if the original load case from Table 3 is from GA-17 to GA-20, then it is not necessary to perform the analysis, respectively, for load cases GG-05, GG-06, GG-07, GG-08, GG-13, GG-14, GG-15 and GG-16.

Table 11 - Global analysis matrix for Verification Load Case H

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GH-01	Near	Same as the original load case from Table 3	Same as the original load case from Table 3	10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20), damaged temporary mooring	Same as the original load case from Table 3	(1)	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	One mooring line broken	Maximum tension and angle on the top region among near cases(2) (3)
GH-02	Far										Maximum tension and angle on the top region among far cases(2) (3)
GH-03	Crossed										Maximum tension and angle on the top region among crossed cases(2) (3)
GH-04	Transverse										Maximum tension and angle on the top region among transverse cases(2) (3)
GH-05	Near					1-year		(1)			Maximum tension and angle on the top region among near cases(2)
GH-06	Far										Maximum tension and angle on the top region among far cases(2)
GH-07	Crossed										Maximum tension and angle on the top region among crossed cases(2)
GH-08	Transverse										Maximum tension and angle on the top region among transverse cases(2)
GH-09	Near					(1)		1-year			Maximum TDP, sag or hog curvature among near cases(3)
GH-10	Far										Maximum TDP, sag or hog curvature among far cases(3)
GH-11	Crossed										Maximum TDP, sag or hog curvature among cross cases(3)
GH-12	Transverse										Maximum TDP, sag or hog curvature among transverse cases(3)
GH-13	Near					1-year		(1)			Maximum TDP, sag or hog curvature among near cases
GH-14	Far										Maximum TDP, sag or hog curvature among far cases
GH-15	Crossed										Maximum TDP, sag or hog curvature among cross cases
GH-16	Transverse										Maximum TDP, sag or hog curvature among transverse cases

(1) 10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20)

(2) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 11 will become two different load cases.

(3) For GH-01, GH-02, GH-03, GH-04, GH-09. GH-10, GH-11 and GH-12, if the original load case from Table 3 is from GA-17 to GA-20, then it is not necessary to perform the analysis, respectively, for load cases GH-05, GH-06, GH-07, GH-08, GH-13, GH-14, GH-15 and GH-16.

Table 12 - Global analysis matrix for Verification Load Case I

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which present:
		FPU Draft	FPU Heading	FPU offset		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GI-01	Near	Same as the original load case from Table 3	Same as the original load case from Table 3	10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20), damaged temporary mooring	Same as the original load case from Table 3	(1)	Same as the original load case from Table 3	1-year	Same as the original load case from Table 3	Buoyancy losses over service life	Maximum tension and angle on the top region among near cases(2) (3)
GI-02	Far										Maximum tension and angle on the top region among far cases(2) (3)
GI-03	Crossed										Maximum tension and angle on the top region among crossed cases(2) (3)
GI-04	Transverse										Maximum tension and angle on the top region among transverse cases(2) (3)
GI-05	Near					1-year		(1)			Maximum tension and angle on the top region among near cases(2)
GI-06	Far										Maximum tension and angle on the top region among far cases(2)
GI-07	Crossed										Maximum tension and angle on the top region among crossed cases(2)
GI-08	Transverse										Maximum tension and angle on the top region among transverse cases(2)
GI-09	Near					(1)		1-year			Maximum TDP, sag or hog curvature among near cases(3)
GI-10	Far										Maximum TDP, sag or hog curvature among far cases(3)
GI-11	Crossed										Maximum TDP, sag or hog curvature among cross cases(3)
GI-12	Transverse										Maximum TDP, sag or hog curvature among transverse cases(3)
GI-13	Near					1-year		(1)			Maximum TDP, sag or hog curvature among near cases
GI-14	Far										Maximum TDP, sag or hog curvature among far cases
GI-15	Crossed										Maximum TDP, sag or hog curvature among cross cases
GI-16	Transverse										Maximum TDP, sag or hog curvature among transverse cases

(1) 10-year (if original load case from Table 3 is from GA-01 to GA-16) or 1-year (if original load case from Table 3 is from GA-17 to GA-20)

(2) If maximum tension and maximum angle on the top region occur on different load cases from Table 3, then the load case in Table 12 will become two different load cases.

(3) For GI-01, GI-02, GI-03, GI-04, GI-09. GI-10, GI-11 and GI-12, if the original load case from Table 3 is from GA-17 to GA-20, then it is not necessary to perform the analysis, respectively, for load cases GI-05, GI-06, GI-07, GI-08, GI-13, GI-14, GI-15 and GI-16.

5.2.3 Extreme-load global analysis input and output tables

SUPPLIER shall present tables containing the input and output data of the performed global analysis, for both the design load cases (specified in Table 1) and verification load cases (specified in Table 2).

The input data tables shall have at least the information presented on the template on Table 13. The output data tables shall have at least the information presented on the templates on Table 14, Table 15 and Table 16.

Table 13 - Minimum content for extreme-load global analysis input data table

Load Case	Offset		Wave								Current			Draft
	Value (m)	Direction (deg.)	Direction (deg.)	Compass Direction (N, NE…)	RP (years)	Hs (m)	Tp (s)	Gamma	H(1) (m)	T(1) (s)	Direction (deg.)	Compass Direction (N, NE…)	RP (years)	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

(1) Only if the analysis is performed considering a regular wave

Table 14 - Minimum content for extreme-load global analysis output data table – results for the top region

Load Case	Top Angle (deg.)		Top Tension (kN)		Max Shear Force (kN)	Max Bending Moment (kN.m)	MBR (m)
	Min	Max	Min	Max			
…	…	…	…	…	…	…	…

Table 15 - Minimum content for extreme-load global analysis output data table – results for the sag/hog region

Load Case	F Max (kN)	F Min & Associated Bending Radius		MBR & Associated F	
		F Min (kN)	Bending Radius (m)	MBR (m)	F (kN)
…	…	…	…	…	…

Table 16 - Minimum content for extreme-load global analysis output data table – results for the TDP region

Load Case	F Max (kN)	F Min & Associated Bending Radius		MBR & Associated F	
		F Min (kN)	Bending Radius (m)	MBR (m)	F (kN)
…	…	…	…	…	…

5.3 Structural analysis

The structural analysis load cases specified herein shall be performed to determine stresses and strains in the structural and functional components of the subsea umbilical and the respective utilization factors. The following general notes shall be observed for all load cases:

- The load cases shall consider the fluid conduits under the internal pressure defined in Table 1 and in Table 2, associated with the external pressure relative to the water depth of the analyzed region (top, sag, hog and TDP).
- Maximum global analysis results selection shall be made comparing effective tension, but when assessing applied stresses and deformations on metallic tubes, the true wall tension (or true wall compression) shall be adopted. The true wall tension is a function of the effective tension, the internal and external pressures at the analyzed region and of the internal and external cross-sectional areas of the tubes, using the assumption of tube closed ends.
- If any riser section is under effective compression, then “minimum effective tension” means “maximum effective compression”.
- On a same load case, when one load is defined as “associated” to another, it means that the value to be considered for the associated load shall be obtained at the same umbilical section and at the same simulation time when the other load is “maximum” or “minimum”.

Besides the ones listed herein, any other potential failure mechanism identified by SUPPLIER on components (functional or structural) shall be considered and relevant results shall be reported, including the utilization factors (UF).

The structural analysis results shall be condensed in summary tables, including at least:

(i) Values of the loads used to address stresses and strains. When applicable, SUPPLIER shall inform effective tension, bending radius, crushing load (force/meter/pad) due to tensioners radial compression and/or internal pressure of fluid conduits.

(ii) Stress and/or strain results for each component. When applicable, SUPPLIER shall inform stress of steel wires (umbilical armouring, electrical cable armouring and/or optical fiber cable armouring), stress of metallic tubes (fluid conduits and/or strength members of optical fiber cables), ovalization of metallic tubes, stress and strain of fiber reinforced plastic rods, strain on electrical cables copper conductors and/or strain of optical fibers.

(iii) Structural capacity of components. When applicable, SUPPLIER shall inform SMYS and UTS of structural components (steel wires, metallic tubes and/or fiber reinforced plastic rods), maximum allowable ovality of metallic tubes (fluid conduits only), maximum allowable strain of electrical cables copper conductors and maximum allowable strain of optical fibers.

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

Additionally, SUPPLIER may present graphics comparing the global analysis results for the extreme-load cases with the respective capacity curves. However, it does not exempt SUPPLIER of presenting the results as required above.

5.3.1 Design load cases structural analysis

Structural analysis of design load cases A to E – presented in Table 1 – shall include at least the load cases listed from Table 17 to Table 21.

Table 17 - Structural analysis matrix for Design Load Case A

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LA-01	Top	Maximum from GA-01 to GA-20	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LA-02	Top	Associated to the bending radius	Minimum from GA-01 to GA-20	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LA-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GA-01 to GA-20	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LA-04(1)	TDP, Sag or Hog	Minimum from GA-01 to GA-20	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 18 - Structural analysis matrix for Design Load Case B

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LB-01	Top	Maximum from GB-01 to GB-08	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LB-02	Top	Associated to the bending radius	Minimum from GB-01 to GB-08	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LB-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GB-01 to GB-08	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LB-04(1)	TDP, Sag or Hog	Minimum from GB-01 to GB-08	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 19 - Structural analysis matrix for Design Load Case C

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LC-01	Top	Maximum from GC-01 to GC-08	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LC-02	Top	Associated to the bending radius	Minimum from GC-01 to GC-08	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LC-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GC-01 to GC-08	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LC-04(1)	TDP, Sag or Hog	Minimum from GC-01 to GC-08	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 20 - Structural analysis matrix for Design Load Case D

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LD-01	Top	Maximum from GD-01 to GD-04	Associated to the effective tension	---	Yielding of structural components
LD-02	Top	Associated to the bending radius	Minimum from GD-01 to GD-04	---	Yielding of structural components
LD-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GD-01 to GD-04	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LD-04(1)	TDP, Sag or Hog	Minimum from GD-01 to GD-04	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 21 - Structural analysis matrix for Design Load Case E

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LE-01	Top	Maximum from GE-01 to GE-03	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LE-02	Top	Associated to the bending radius	Minimum from GE-01 to GE-03	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LE-03	Top	Maximum from GE-01 to GE-03	---	Maximum crushing load imposed by the tensioners	Excessive ovalization or collapse of fluid conduits
LE-04	TDP, Sag or Hog	Maximum from GE-01 to GE-03	---	External pressure relative to the water depth	Excessive ovalization or collapse of fluid conduits
LE-05	TDP, Sag or Hog	Associated to the bending radius	Minimum from GE-01 to GE-03	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LE-06(1)	TDP, Sag or Hog	Minimum from GE-01 to GE-03	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

5.3.2 Verification load cases structural analysis

Structural analysis of verification load cases F to I – presented in Table 2 – shall include at least the load cases listed from Table 22 to Table 25.

5.3.2.1 Pull-in with temporary mooring system

Table 22 - Structural analysis matrix for Verification Load Case F

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LF-01	Top	Maximum from GF-01 to GF-08	Associated to the effective tension	---	Yielding of structural components
LF-02	Top	Associated to the bending radius	Minimum from GF-01 to GF-08	---	Yielding of structural components
LF-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GF-01 to GF-08	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LF-04(1)	TDP, Sag or Hog	Minimum from GF-01 to GF-08	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

5.3.2.2 First oil with temporary mooring system

Table 23 - Structural analysis matrix for Verification Load Case G

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LG-01	Top	Maximum from GG-01 to GG-16	Associated to the effective tension	---	Yielding of structural components
LG-02	Top	Associated to the bending radius	Minimum from GG-01 to GG-16	---	Yielding of structural components
LG-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GG-01 to GG-16	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LG-04(1)	TDP, Sag or Hog	Minimum from GG-01 to GG-16	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 24 - Structural analysis matrix for Verification Load Case H

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LH-01	Top	Maximum from GH-01 to GH-16	Associated to the effective tension	---	Yielding of structural components
LH-02	Top	Associated to the bending radius	Minimum from GH-01 to GH-16	---	Yielding of structural components
LH-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GH-01 to GH-16	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LH-04(1)	TDP, Sag or Hog	Minimum from GH-01 to GH-16	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

Table 25 - Structural analysis matrix for Verification Load Case I

Load Case	Umbilical Region	Effective Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LI-01	Top	Maximum from GI-01 to GI-16	Associated to the effective tension	---	Yielding of structural components
LI-02	Top	Associated to the bending radius	Minimum from GI-01 to GI-16	---	Yielding of structural components
LI-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GI-01 to GI-16	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LI-04(1)	TDP, Sag or Hog	Minimum from GI-01 to GI-16	Associated to the effective tension	---	Buckling of structural components Deformation of copper conductors Deformation of optical fibers

(1) This load case applies only when the minimum effective tension is negative, i.e., the umbilical is under axial compression

6 Fatigue analysis

PETROBRAS has different technical specifications for the fatigue analysis of subsea umbilicals, where the load conditions are presented – including the load cases for global and structural analysis. SUPPLIER shall refer to the project-specific or qualification-purpose documentation that informs which specification – regarding fatigue analysis – shall be considered.

7 On-bottom stability analysis

SUPPLIER shall provide the results of on-bottom stability analysis for all umbilical cross-sections under evaluation, justifying the criteria used. For such analysis, SUPPLIER shall consider the requirements of [3].

8 Interference analysis

SUPPLIER shall perform interference analysis according to [5]. This specification describes the procedure defined by PETROBRAS to perform interference analysis with its minimum requirements, load cases and acceptance criteria.

Information about the neighboring risers shall be available to SUPPLIER at the applicable project-specific or qualification-purpose documentation.

APPENDIX A – MOTION ANALYSIS

The selection of wave spectrum properties per direction and FPU/installation vessel draft depends on the environmental data available on PETROBRAS metocean technical specification. If tables or curves of Hs as function of 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:

a) first, for each draft that RAO table is available (at least full and ballasted), the movements of the FPU/installation vessel shall be transferred from CoM to the riser's connection point, thus obtaining the RAO at the connection point;

b) 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 RAO at the connection point for each draft and, assuming a Rayleigh distribution, R_{MAX}, P_{MAX} and vertical acceleration shall be determined for a 3-hr storm;

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

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

It should be noted that the same load case may be analyzed for different drafts and different waves;

d) for each wave spectrum and draft selected, an irregular wave procedure or a regular wave procedure shall be adopted in dynamic analysis, following the recommendations presented in Annex B.

Otherwise, if the contour table is not available or Hs and Tp are specified as for the load cases GA-17 to GA-20, the following procedure shall be adopted:

a) first, for each draft that RAO table is available (at least full and ballasted), the movements of the FPU/installation vessel shall be transferred from CoM to the riser's connection point, thus obtaining the RAO at the connection point;

b) 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 at the connection point for each draft and, assuming a Rayleigh distribution, R_{MAX}, P_{MAX} and vertical acceleration shall be determined for a 3-hr storm;

c) the draft(s) that presents the highest vertical acceleration and highest angular motion are selected to be considered in dynamic analysis. Angular motion is defined according to the above equation.

d) For each wave spectrum and draft selected, an irregular wave procedure or a regular wave procedure shall be adopted in the dynamic analysis following the recommendations presented in Annex B.

For installation vessels the connection points are defined by the position of the wheel or the VLS.

APPENDIX B – WAVE MODELLING PROCEDURES

It is recommended (i.e., not mandatory) that the global extreme-load analyses should be performed adopting an irregular wave procedure as described in this appendix. The irregular wave procedure shall be presented in the Design Premises Report and submitted for PETROBRAS approval.

Alternatively, global extreme-load analyses may be performed considering a regular wave procedure. However, in this case, the irregular wave procedure must be performed for the most critical load cases as a validation check (refer to section B.1).

It is recommended (i.e., not mandatory) that the procedure adopted for regular wave analysis should be the maximum response procedure as described in this appendix, for operating and temporary conditions. A different regular wave procedure may be adopted, however it shall be presented in the Design Premises Report and submitted for PETROBRAS approval.

B.1 Irregular Wave Procedure

The irregular wave procedure is considered at least as a validation check of the results of any regular wave procedure. If used as validation check, only the most critical loading cases shall be analyzed according to this method. For each cross-section under analysis, a minimum number of 4 (four) full irregular analyses shall be chosen by the following criteria:

a) worst load case for top tension;

b) worst load case for bending radius;

c) worst load case for bending stiffener design and

d) worst load case for compression value;

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) The results coming from random analyses shall be statically processed in a way to give consistent and reliable maximum values. When simulating the chosen loading cases, 3 (three) options are considered valid:

i) to perform, at least 5 (five) 30-minute simulations varying random seed for the initial harmonic components phases. The significant wave height shall occur at least once in each simulation;

ii) from simulated long time history (minimum 60 hours) of critical pipe top movement, select a minimum of 10 (ten) 5-minute windows to be analysed;

iii) to perform a 3-hour simulation.

If SUPPLIER is supplying a set of risers of the same cross-section, which are going to be connected to the same FPU, PETROBRAS might accept, if dully justified by SUPPLIER, irregular wave analysis carried out for the riser(s) subjected to the most critical load conditions. For this purpose, the manufacturer shall submit analysis that includes the riser(s) worst conditions indicated in paragraphs a) to d) above.

B.2 Regular Wave Procedure

The following steps shall be considered:

a) transfer the RAO 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 (H_{design}) as the Rayleigh most probable maxima from Hs (significant wave height) as used to describe wave spectrum in paragraph b);

e) evaluate periods ($T_{design1}$ and $T_{design2}$) which, associated to H_{design}, provide, respectively, the maximum harmonic displacement and maximum harmonic acceleration, both calculated as per paragraph c); among the possible T_{design} values, chose the closest to the wave peak period (Tp). This procedure shall be carried out, at least, 2 (two) times, depending on top connection motion: (1) the most critical between surge/sway and heave, (2) the most critical between roll and pitch.

B.2.1 Maximum Response Procedure

The purpose of the maximum response procedure is to perform the global extreme-load analysis considering a regular wave that reproduces the same maximum angular motion and the same maximum vertical acceleration at the riser connection for a 3-hour storm. 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 FPU/installation vessel, the RAO for displacements and vertical acceleration at the riser connection shall be determined for each draft of the FPU/installation vessel;

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 RAO previously calculated:

$$\mathrm{Su(w)} = [\mathrm{RAO(w)}]^2 * \mathrm{S(w)}$$

3. The significant amplitude (u_{sig}) of displacements and vertical acceleration shall be calculated from the response spectrum as follows:

$$u_{sig} = 2 * \sqrt{m_0}$$

Where m_0 is the response spectrum (Su) area;

4. The maximum amplitude (u_{max}) for the movements (6 DoF) and for the vertical acceleration shall be determined for a storm duration of 3 hours (10,800 s), as follows:

$$u_{max} = \sqrt{2 * \ln(N)} * \frac{u_{sig}}{2}$$

Where $N = \frac{10{,}800}{Tz}$ and $Tz = \sqrt{\frac{m_0}{m_2}}$

5. The draft of the FPU/installation vessel that has the highest maximum amplitude for the vertical acceleration and highest angular movement shall be selected (the angular motion definition is in Appendix A). If the

FPU/installation vessel 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 regular wave period is determined from the maximum amplitude for the vertical motion ($u_{maxvert}$) and vertical acceleration ($a_{maxvert}$) by the following expression:

$$T = 2\pi\sqrt{\frac{u_{maxvert}}{a_{maxvert}}}$$

7. The RAO for the 6 DoF at the riser connection point are determined from the amplitude of the maximum displacements calculated in item 4 and H_{max} assuming a Rayleigh distribution for the wave spectrum (S), considered in item 2:

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

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

9. Global extreme-load analysis shall be performed considering the RAO at the riser connection point and a regular wave with maximum height (H_{max}) determined according to item 4 and period (T) defined as in item 6.