INDEX OF REVISION

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”
B	Inclusion of “pull-in/pull-out operations” Design Case F Change on the FPU draft selection for Design Case D
C	Table 1: inclusion of new Design Case F (PLSV to FPU transference operation) Table 9: global analysis matrix for Verification Case H changed Section 4.2.3: input and output tables updated Section 4.2.3: inclusion of the extreme-load global analysis summary output data table Section 4.3.3: definition of the minimum content for input and output table of structural analysis Table 23: structural analysis matrix for Design Case E changed

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E
DATE	24/10/2019	30/03/2021	17/05/2021	06/02/2024		
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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 operation phases. Load-effect analysis includes extreme-load (section 4), fatigue (section 5), on-bottom stability (section 6) and interference (section 7) analyses.

SUPPLIER is responsible to identify all hazards and define additional load cases to mitigate them based on risk assessment. It shall investigate the cases where geometric parameters, deformations, strains 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 and discussed with PETROBRAS.

The load conditions and methodologies specified herein are applicable to dynamic umbilicals in free hanging catenary and lazy wave configurations. The adoption of other configurations may be accepted upon request to PETROBRAS, but additional conditions may be necessary.

2 References

Note: for the documents referenced in section 2.1, the indicated revision must be adopted. For the documents referenced in section 2.2, SUPPLIER shall adopt the revision indicated on project-specific documentation.

2.1 International Standards

[1] API SPEC 17E, 5th Edition (2017-07), *Specification for Subsea Umbilicals*

[2] API RP 17L2, 2nd Edition (2021-06), *Recommended Practice for Ancillary Equipment for Flexible Pipes and Subsea Umbilicals*

[3] DNV-RP-F109, Edition May 2021, *On-bottom stability design of submarine pipelines, cables and umbilicals*

2.2 PETROBRAS specifications

[4] I-ET-3000.00 – 1519-29B-PZ9-003, *Subsea Umbilical Systems*

[5] I-ET-3010.00-1500-274-P56-001, *Riser Interference analysis*

3 Terms, abbreviated terms and definitions

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

associated load
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 main load is “maximum” or “minimum”

departure angle
angle between the subsea umbilical and the vertical axis on the top connection

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
meteorologic and oceanographic

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

neutral position
analysis condition where the FPU or the PLSV is on an intermediate draft with no offset, no current and no waves applied

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

assoc.	associated
AIP	atmospheric internal pressure
BM	bending moment
BR	bending radius
BSR	bend stiffener *or* bend strain reliever
CoM	center of motion
F	axial force (tension *or* compression)
FPU	floating production unit

H	regular wave height
Hs	significant wave height
Max *or* max	maximum
Min *or* min	minimum
N/A	not applicable
PLSV	pipe laying support vessel
RP	return period
ShF	shear force
T	regular wave period
Tp	wave peak period
TA	top angle
TDP	touchdown point
UF	utilization factor
WD	water depth

4 Extreme-load analysis

Extreme-load analysis determine if the umbilical capacity and utilization factors are not exceeded under specified load conditions and its main concerns are over tensioning at the top connection, overbending at the sag/hog region (for lazy wave configurations), overbending at the TDP and crushing load effects during installation.

Besides the prediction of utilization factors for the structural analysis load cases specified on section 4.3.2, extreme-load analysis results shall be compared with the properties and allowable loads of the subsea umbilical. Any undesired result such as overbending or any load combination outside the 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, so it may be necessary to divide the subsea umbilical into some segments in order to represent different section properties. For each segment, these section properties and all relevant parameters must be informed. Nonlinear behaviors (like the stick-slip effects in the armor layers – which cause hysteretic bend behavior – and nonlinear polymeric stiffness) may be used and the data dully informed in the Design Premise.

4.1 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.

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

4.1.1 Design cases

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

Table 1 - Design cases

Load Condition	Design Case	Load Type		
		Functional	Environmental	Accidental
Normal Operation	A – Operation with intact mooring system	Fluid Conduits full at DP, Interstices flooded, FPU intact mooring system	100-year RP environmental conditions	-
Abnormal Operation	B – Operation with a mooring line failure	Fluid Conduits full at DP, Interstices flooded	100-year RP environmental conditions	Mooring line failure
	C – Operation with buoyancy loss over service life(1)	Fluid Conduits full at DP, Interstices flooded, FPU intact mooring system	100-year RP environmental conditions	Buoyancy modules losses(2)
	D – Operation with FPU inclination due to a compartment flooding	Fluid Conduits full at DP, Interstices flooded, FPU intact mooring system	1-year RP environmental conditions	FPU inclination due to a compartment flooding
Temporary Conditions	E – Installation	Fluid Conduits full at AIP, Interstices flooded, PLSV	Installation conditions	-
	F – PLSV to FPU transference operation	Fluid Conduits full at AIP, Interstices flooded, PLSV	Installation conditions	-
	G – Pull-in / pull-out operations	Fluid Conduits full at AIP, Interstices flooded, FPU intact mooring system	Pull-in / pull-out conditions	-

(1) This design case applies only when SUPPLIER proposes a lazy wave configuration

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

4.1.2 Verification cases

Temporary mooring conditions may happen during the production system installation phase, when the FPU will be held in position for a relatively short period of time by a mooring pattern different from the one designed to moor the FPU for the whole service life. Under these temporary conditions, subsea umbilicals 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 cases on Table 2 is to reproduce such conditions.

The verification cases shall not be used for configuration or structural design, neither for subsea umbilical nor 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 cases

Load Condition	Verification Case	Load Type		
		Functional	Environmental	Accidental
Temporary Conditions	H – Pull-in with intact temporary mooring system	Fluid Conduits full at AIP, Interstices flooded, FPU intact temporary mooring system	1-year RP environmental conditions	-
	I – First oil with intact temporary mooring system	Fluid Conduits full at DP, Interstices flooded, FPU intact temporary mooring system	10-year RP environmental conditions	-
	J– First oil with damaged temporary mooring system	Fluid Conduits full at DP, Interstices flooded, FPU damaged temporary mooring system	10-year RP environmental conditions	Mooring line failure
	K – First oil with temporary mooring system and buoyancy loss over service life(1)	Fluid Conduits full at DP, Interstices flooded, FPU intact temporary mooring system	10-year RP environmental conditions	Buoyancy modules losses(2)

(1) This design case applies only when SUPPLIER proposes a lazy wave configuration

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

4.2 Global analysis

The load cases for global analysis herein presented are related to one single umbilical. The design of one specific umbilical or a group of umbilicals (when SUPPLIER is supplying a group of umbilicals with the same cross-section for the same FPU) shall adopt one of the following procedures, depending on the project-specific documentation:

(i) Umbilical connected to any possible FPU connection point with any possible azimuth

According to the FPU type and the mooring system, the following shall be considered:

- Ship shape unit with turret moored system – eight different connection points and umbilical azimuths shall be considered being each one 45° apart from the other, as shown in Figure 1;

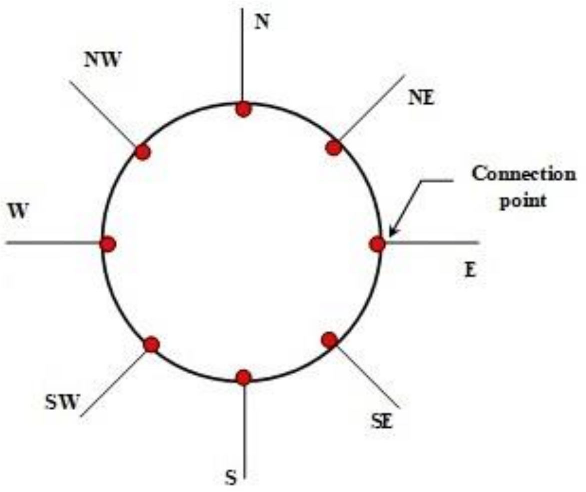

Figure 1 - Connection points and umbilical azimuths for turret moored systems

- Ship shape unit with spread mooring system – two connection points and umbilical 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 applying for keel hauling umbilicals. The connection points shall be forward and backward from midship along the balcony. The worst connection points shall be selected and properly justified.

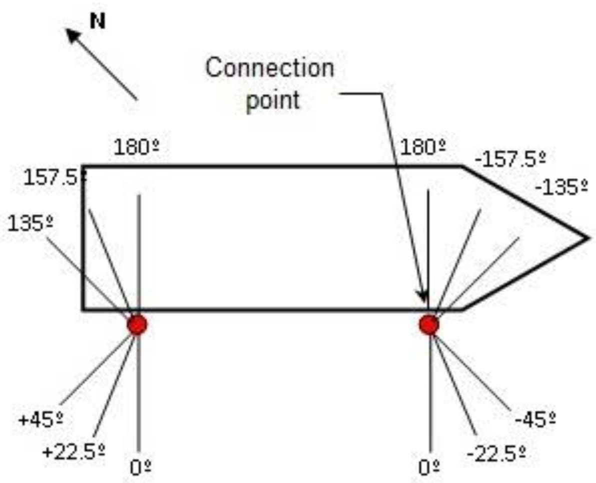

Figure 2 - Connection points and umbilical azimuths for spread moored systems

- Semi-submersible unit – three different umbilical 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.

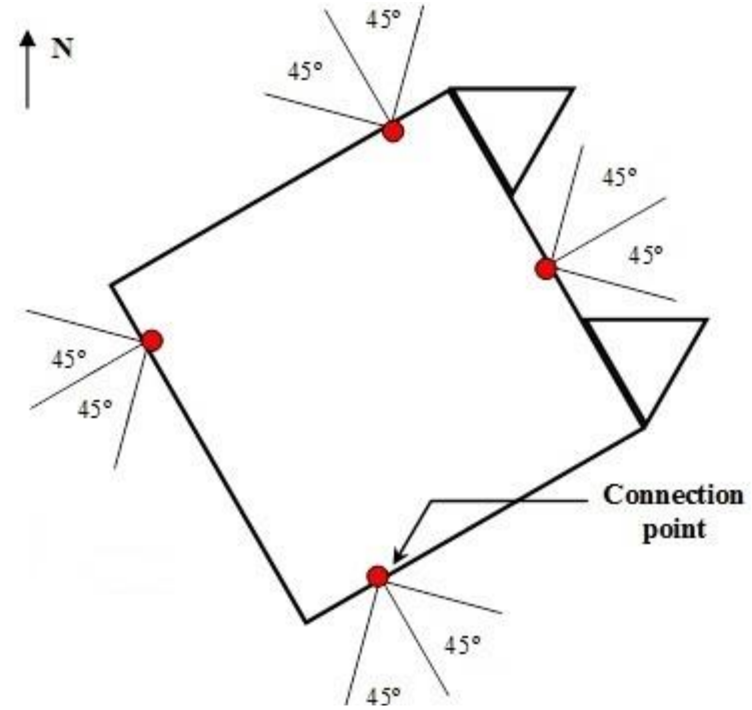

Figure 3 - Connection points and umbilical azimuths for semi-submersible units

(ii) Umbilical connected to the actual connection point with its actual azimuth defined by the subsea layout and project-specific documentation

In case of several umbilicals with the same cross-section but different azimuths and connection points in the same FPU, SUPPLIER may present the results for the umbilicals 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.

4.2.1 General notes

The following notes shall be observed for all load cases stated in section 4.2.2:

- SUPPLIER shall consider the metocean data provided on the project-specific documentation.
- The wave modeling procedures described on Appendix B are applicable for all load cases, including installation (Design Case E) and PLSV to FPU transference operation (Design Case F).
- The wave data for the compass directions (N, NE etc.) closest to load case wave direction shall be chosen, according to the provided metocean document. If the load case wave direction is exactly between two wave data [e.g., 22.5° from N, or 11.25° from N if 16 (sixteen) directions are available], the one with the largest significant wave height shall be selected.
- The current profile for the compass directions (N, NE etc.) closest to load case current direction shall be chosen, according to the provided metocean document. 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 between two current data [e.g., 22.5° from N, or 11.25° from N if 16 (sixteen) directions are available], the one with the largest surface current velocity shall be selected.

- 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.
- 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.
- If SUPPLIER proposes a lazy wave configuration, it shall be verified for both the start-of-life (SOL) and the end-of-life (EOL) conditions of the buoyancy modules.

4.2.2 Load cases

Global analysis of Design Case A shall include at least the load cases listed on Table 3. The motion analysis described in Appendix A shall be performed for selection of the wave parameters and FPU draft (any other procedure must 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 Case B shall include at least the load cases listed on Table 4. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 4 (e.g., maximum top tension, maximum curvature etc.). The load cases on 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 on 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 on Table 4 is 1-year RP, damaged mooring.

Global analysis of Design Case C shall include at least the load cases listed on Table 5. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 5 (e.g., maximum top tension, maximum curvature etc.). The load cases on 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 on Table 1.

Global analysis of Design Case D shall include at least the load cases listed on Table 6. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 6 (e.g., maximum top tension, maximum angle etc.). The load cases on Table 6 shall consider 1-year RP environmental loads applied on the same directions of the original load cases from Table 3. A motion analysis shall be performed for selection of the wave parameters and FPU draft considering the 1-year RP environmental loads. 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 units and 15º (fifteen degrees) for semi-submersible or other units shall be adopted if not specified on PETROBRAS project-specific documentation. This design case shall be considered to check the integrity of the umbilical and not to size the bend stiffener or other ancillary equipment (loss of functionality is not acceptable, but no strain limitation in the bend stiffener is required).

Global analysis of Design Case E shall include at least the load cases listed on Table 7. The load cases must consider the umbilical connected to the proper exit point(s) at the PLSV in a free hanging catenary. The umbilical shall be considered parallel to the longitudinal axis of the PLSV, which is moving away from the TDP. A screening analysis shall be performed for the selection of the wave period and PLSV draft, regarding the fact that the wave heights are already defined on Table 7. As the wave heights, wave directions and period ranges are already defined and the umbilical relative position to the PLSV is fixed, then the actual azimuth of the umbilical is not relevant for this analysis. The load cases shall be performed considering the departure angles of 1º (one degree) and 3º (three degrees). The purpose of Design Case E is to assure the installation feasibility of the subsea umbilical and ancillary equipment.

Global analysis of Design Case F shall include at least the load cases listed on Table 8. The load cases consider the umbilical being hung by the PLSV winch prior to its transference to the FPU during installation. The PLSV must have the same heading of the FPU and shall be placed 50 m away from the board of the FPU following the laying route (it must be observed if keel hauling will be adopted or not), considering the umbilical actual azimuth and the FPU at near offset, 1-yr intact mooring. The winch top connection must have its position defined in accordance with the project documentation, and its other end must be at 200 m WD. The length of the installed umbilical from the hang-off to a reference point on the seabed (typically the anchoring collar, but any other point can be chosen according to SUPPLIER's convenience) shall then have its top end attached to the winch end at 200 m WD while not changing the position of the reference point on the seabed. When a lazy-wave configuration is proposed by SUPPLIER, the load cases must be performed in steps of 5 (five) flotation modules, i.e., they must be performed with the umbilical in free hanging catenary, then performed again with 5 (five) flotation modules, then performed again with 10 (ten) flotation modules and so forth. Winch cable properties are available on project-specific documentation. A screening analysis shall be performed for the selection of the wave period and PLSV draft, regarding the fact that the wave heights are already defined on Table 8.

Regarding the load cases on Table 7 and Table 8, if design criteria are not met for one or more wave direction considering the specified wave height and period (6 to 15 s), then, for this(these) wave direction(s), global analysis shall be performed again considering 1-year 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 and 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.

Global analysis of Design Case G shall include at least the load cases listed on Table 9. The load cases are representative of the pull-in/pull-out operations and shall consider the umbilical connected to the FPU in its final configuration (free hanging catenary or lazy wave). A screening analysis shall be performed for the selection of the wave period and FPU draft, regarding the fact that the wave height is already defined on Table 9. The simulation results from these load cases shall be considered especially for the design of the umbilical pull-in head, but the whole umbilical and ancillary equipment must be verified.

Global analysis of Verification Case H shall include at least the load cases listed on Table 10. The load cases are based on the load cases of Design Case G (Table 9), but with higher offset value: global analysis of Verification Case H 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. Umbilical and 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.

Global analysis of Verification Cases I, J and K shall consider the offset values on Table 11. Case I offsets shall be used for the umbilical 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. Umbilical and 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.

Global analysis of Verification Case I shall include at least the load cases listed on Table 12. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 12 (e.g., maximum top tension, maximum curvature etc.). The load cases on 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.

Global analysis of Verification Case J shall include at least the load cases listed on Table 13. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 13 (e.g., maximum top tension, maximum curvature etc.). The load cases on Table 13 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 Case K shall include at least the load cases listed on Table 14. The load cases are generated taking into consideration the results of the global analysis of Design Case A, according to the specified on Table 14 (e.g., maximum top tension, maximum curvature etc.). The load cases on Table 14 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 on Table 2.

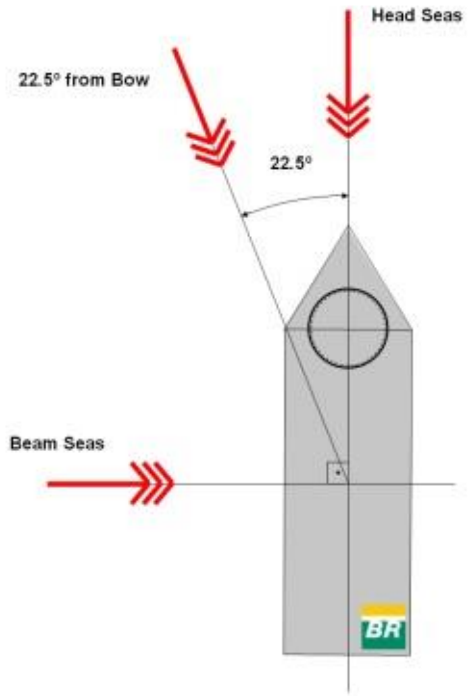

Figure 4 - Wave incidence direction for ship shape units with turret moored system and for PLSV

Table 3 - Global analysis matrix for Design Case A

Load Case	Position	Functional Load					Environmental Load				Reference Figure
		FPU Draft	FPU Heading		FPU offset		Wave		Current		
			FPU Turret (Fig. 4)	Others	RP	Direction(2)	RP	Direction	RP	Direction	
GA-01	Near	Draft with the worst vertical acceleration and/or 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 offset direction	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 offset direction	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, a motion analysis shall be performed

(2) Offset direction is defined by the umbilical 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, limited to 4.5 m;
   (ii) Tp 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

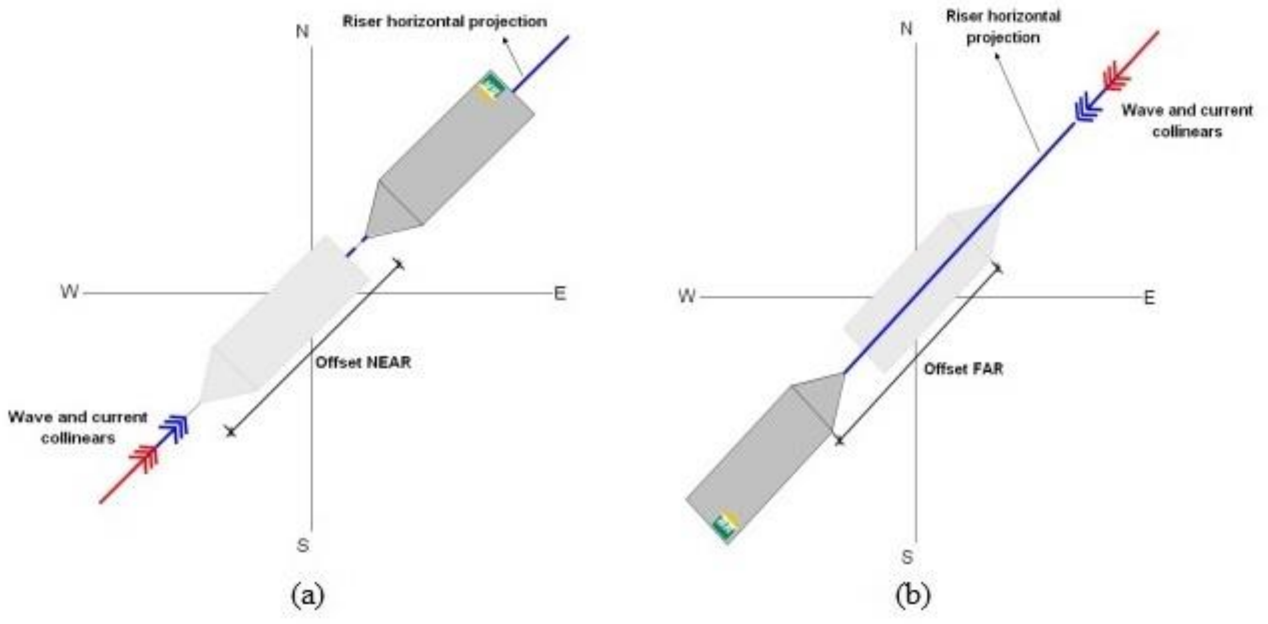

Figure 5 - Collinear environmental loads and offsets: (a) Near ; (b) Far

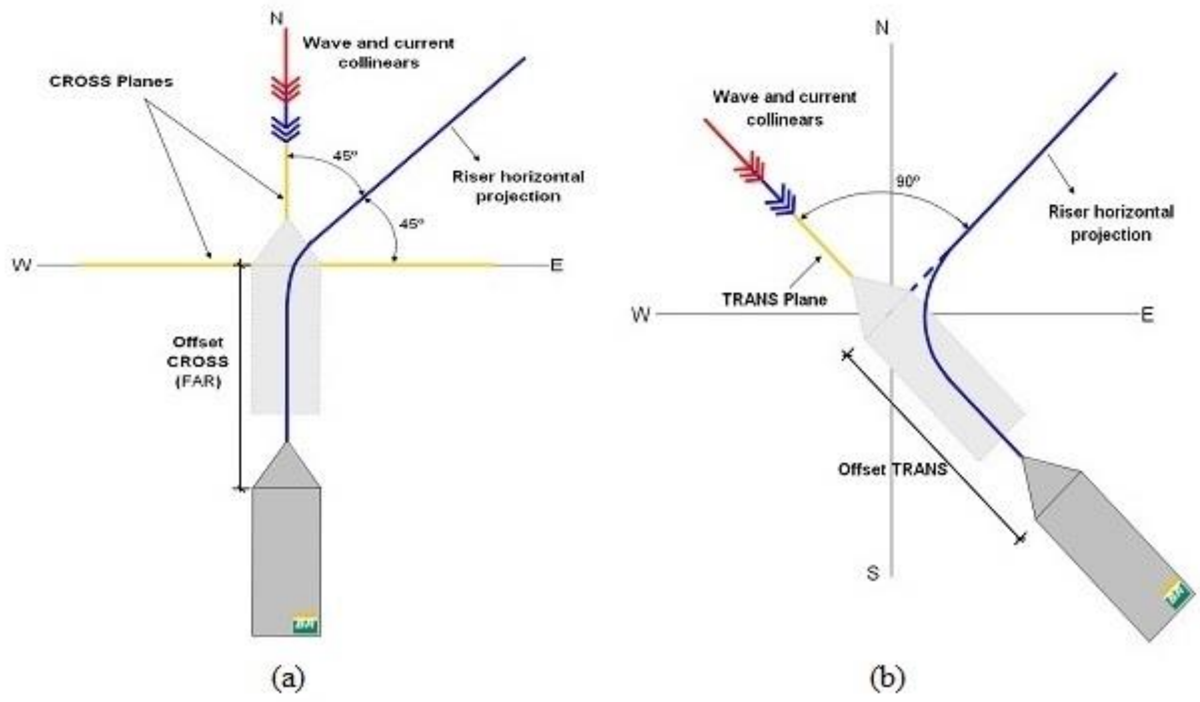

Figure 6 - Collinear environmental loads and offsets: (a) Crossed ; (b) Transverse

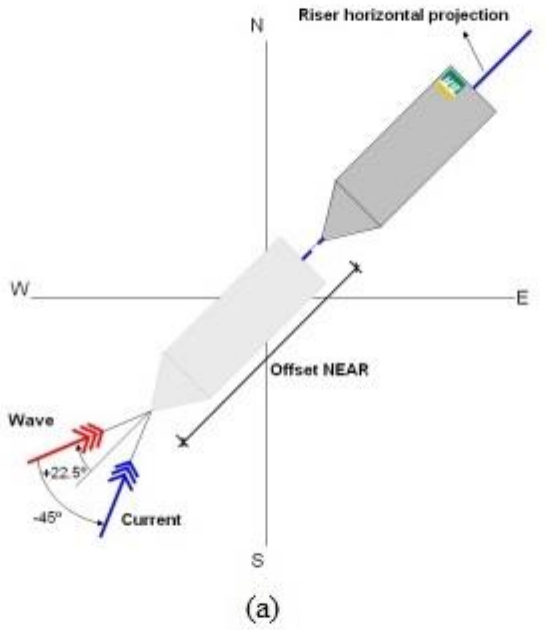

Figure 7 - Crossed environmental loads and offsets: (a), (b) Near

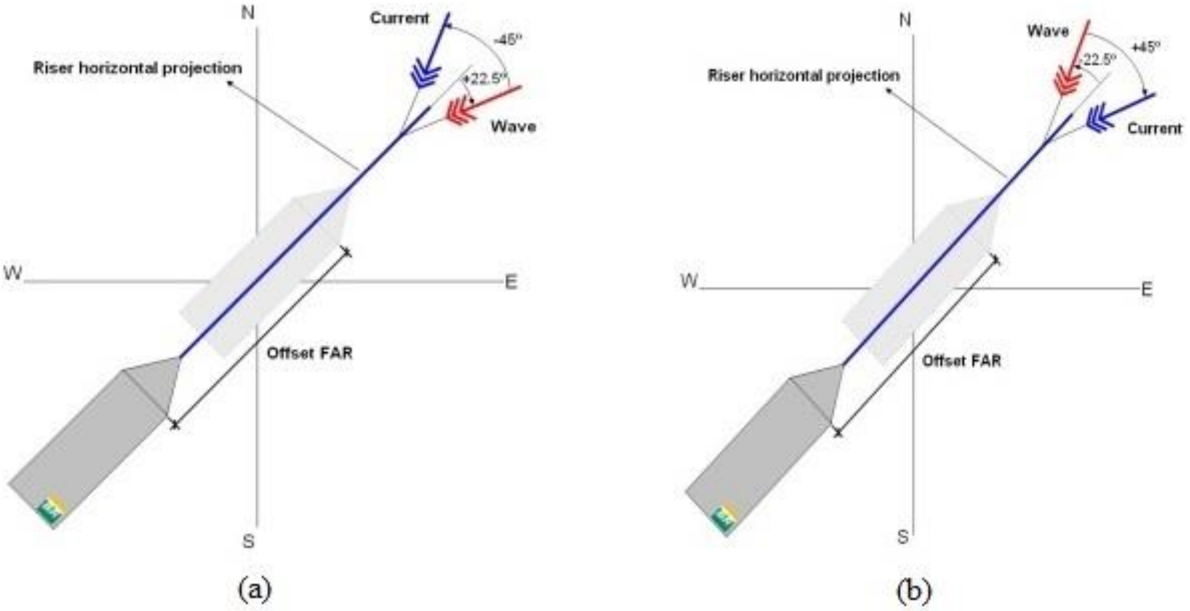

Figure 8 - Crossed environmental loads and offsets: (a), (b) Far

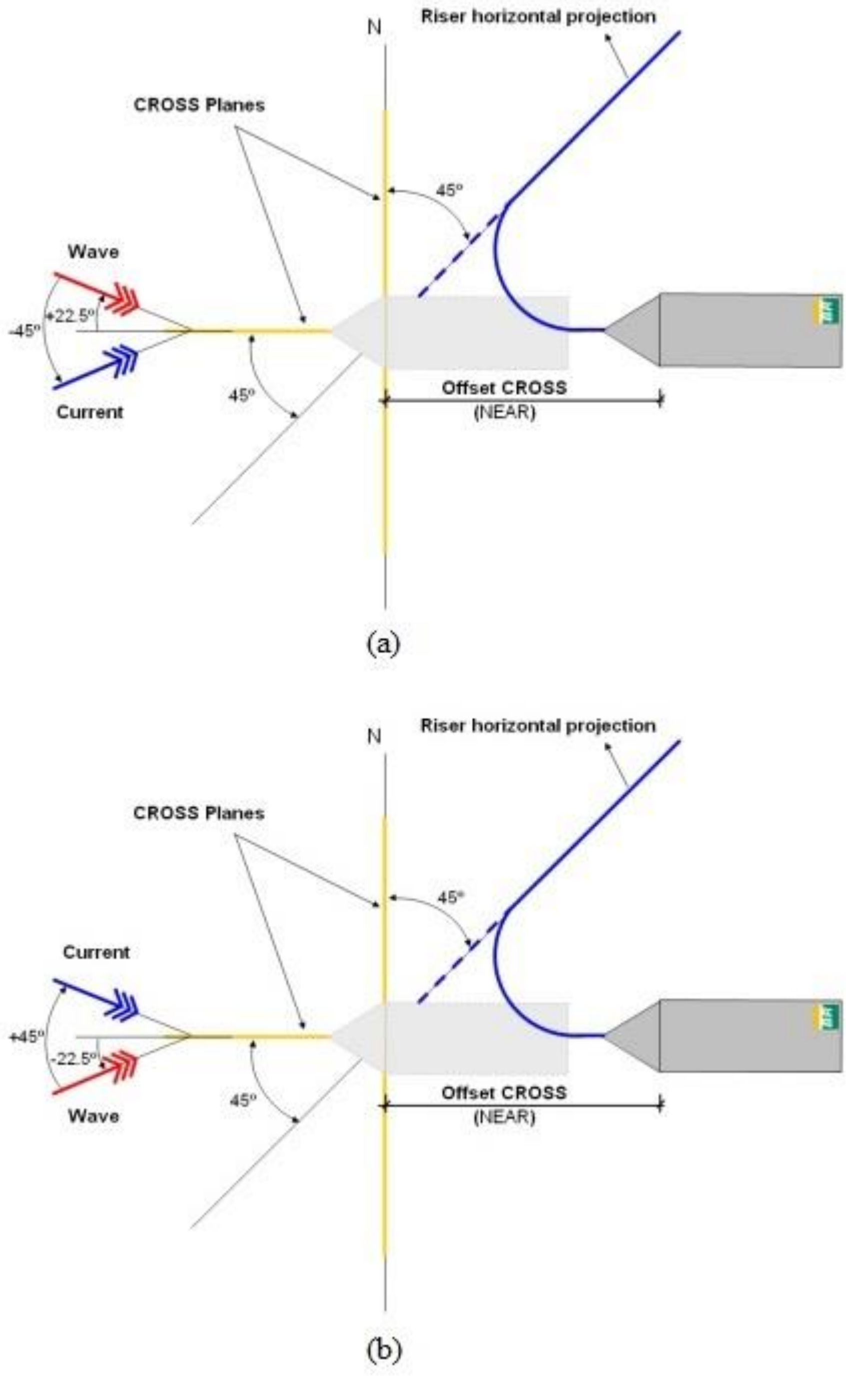

Figure 9 - Crossed environmental loads and offsets: (a), (b) Crossed Near

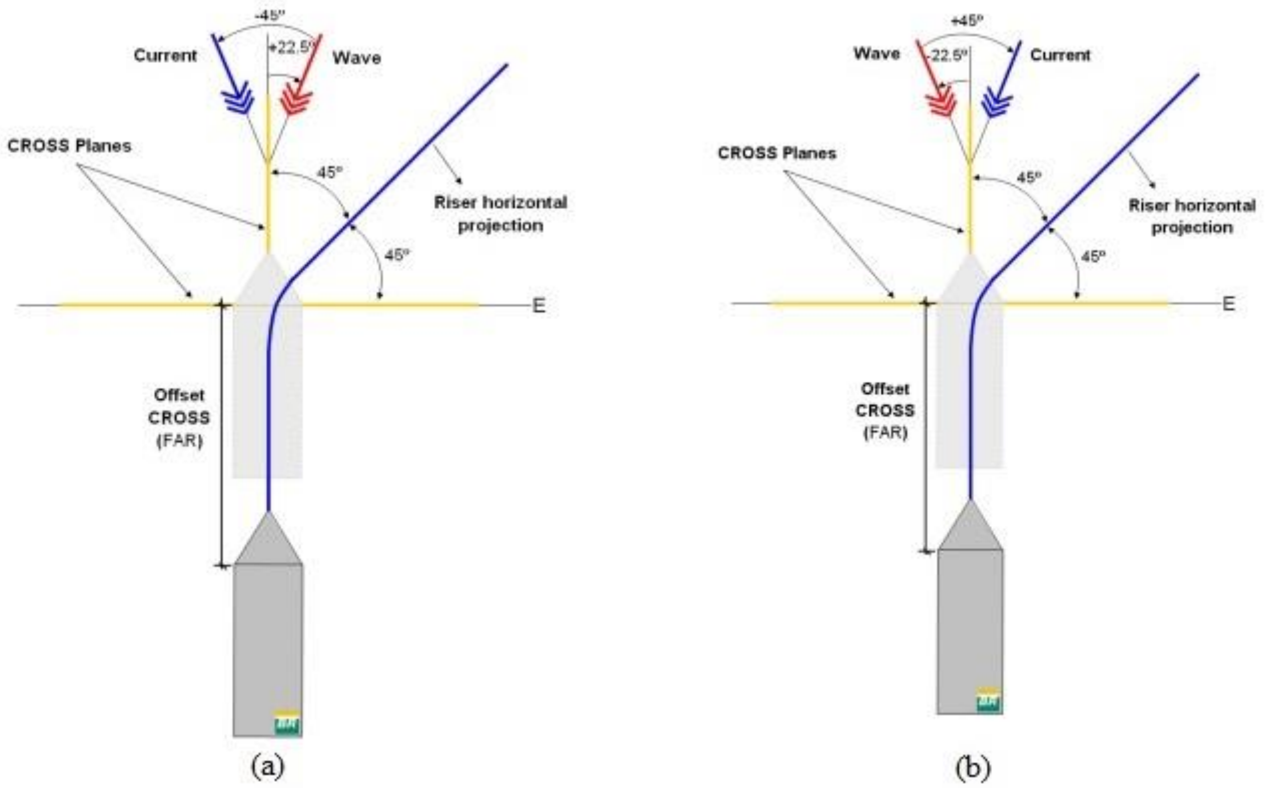

Figure 10 - Crossed environmental loads and offsets: (a), (b) Crossed Far

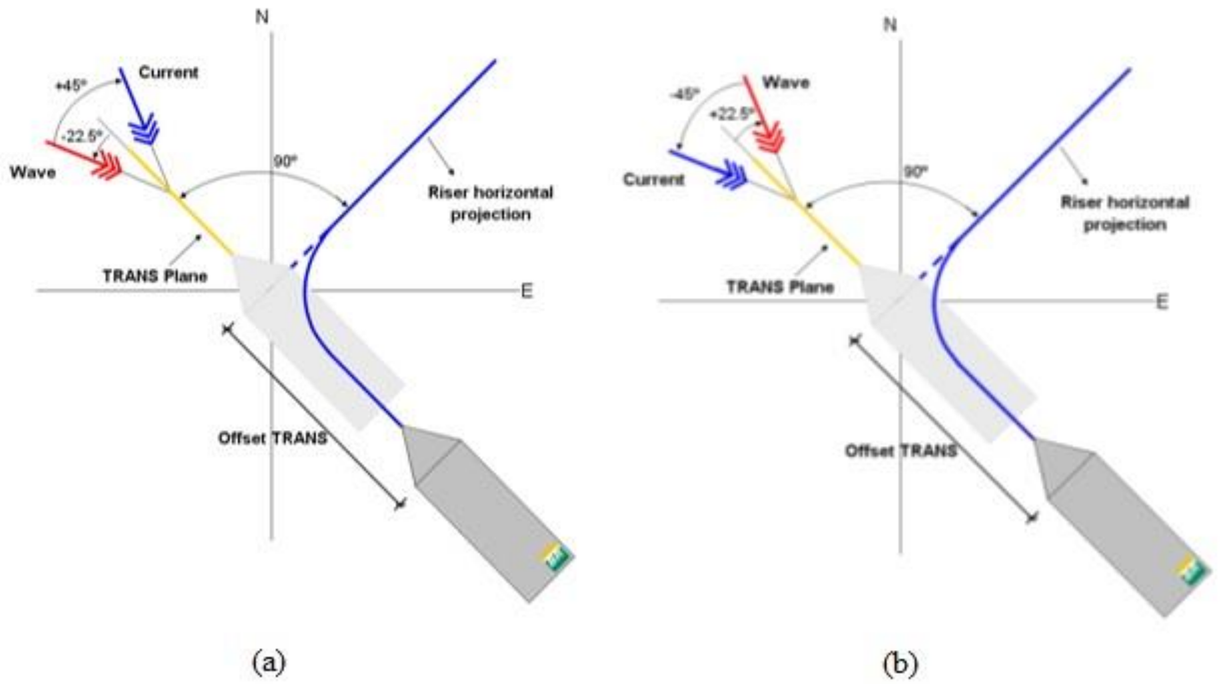

Figure 11 - Crossed environmental loads and offsets: (a), (b) Transverse

Table 4 - Global analysis matrix for Design Case B

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which presents:
		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 on Table 4 will become two different load cases

Table 5 - Global analysis matrix for Design Case C

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which presents:
		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 modules 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 on Table 4 will become two different load cases

Table 6 - Global analysis matrix for Design Case D

Load Case	Position	Functional Load: FPU Draft	Functional Load: FPU Heading	FPU offset: RP	FPU offset: Direction	Environmental Load – Wave: RP	Wave: Direction	Current: RP	Current: Direction	Accidental Load	From Table 3, select the load case which presents:
GD-01	Near	Draft with the worst vertical acceleration and angular motion for each load case(1)	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(2)
GD-02	Far										Maximum tension and angle on the top region among far cases(2)
GD-03	Crossed										Maximum tension and angle on the top region among crossed cases(2)
GD-04	Transverse										Maximum tension and angle on the top region among transverse cases(2)

(1) For selection of the FPU draft and waves for each load case, a motion analysis shall be performed

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

Table 7 - Global analysis matrix for Design Case E

Load Case	Position	Functional Load: PLSV Draft	Functional Load: PLSV Heading	Functional Load: Offset	Environmental Load – Wave: H (m)	Wave: T (s)	Wave: Direction	Current: RP	Current: Direction
GE-01					8.55		Head seas		
GE-02	Neutral	Draft with the worst vertical acceleration and angular motion for each load case(1)	Not applicable	None	7.60	(1)	45º from bow	1-year	Collinear
GE-03					6.08		Beam seas		

(1) For each load case, a screening analysis shall be performed to choose the PLSV draft and wave period (between 6 to 15 s)

Table 8 - Global analysis matrix for Design Case F

Load Case	Position	Functional Load: PLSV Draft	Functional Load: PLSV Heading	Functional Load: Offset	Environmental Load – Wave: H (m)	Wave: T (s)	Wave: Direction	Current: RP	Current: Direction
GF-01					8.55		Head seas		
GF-02	(1)	Draft with the worst vertical acceleration and angular motion for each load case(1)	Same as the FPU	(1)	7.60	(2)	45º from bow	1-year	(3)
GF-03					6.08		Beam seas		

(1) Please refer to Design Case F description on the beginning of this section

(2) For each load case, a screening analysis shall be performed to choose the PLSV draft and wave period (between 6 to 15 s)

(3) Current direction shall be the same of the offset direction

Table 9 - Global analysis matrix for Design Case G

Load Case	Position	Functional Load					Environmental Load				
			FPU Heading		FPU Offset		Wave			Current	
		FPU Draft	FPU Turret (Fig. 4)	Others	RP	Direction	H (m)	T (s)	Direction	RP	Direction
GG-01	Near	Draft with the worst vertical acceleration and angular motion for each load case[1]	Head seas	Actual Heading	1-year, intact mooring	0° from the riser plane	3.80	(1)	Collinear	1-year	Collinear
GG-02	Far					180° from the riser plane	3.80				
GG-03	Crossed					± 45° (cross near) and ± 135° (cross far) from the riser plane	3.80				
GG-04	Transverse					± 90° from the riser plane	3.80				
GG-05	Near		22.5° from bow			0° from the riser plane	3.80		Crossed ± 22.5 of the offset direction		Crossed ± 45 of the wave
GG-06	Far					180° from the riser plane	3.80				
GG-07	Crossed					± 45° (cross near) and ± 135° (cross far) from the riser plane	3.80				
GG-08	Transverse					± 90° from the riser plane	3.80				
GG-09	Near		Beam seas (90°)	(2)		0° from the riser plane	3.80		(3)		(4)
GG-10	Far					180° from the riser plane	3.80				
GG-11	Crossed					± 45° (cross near) and ± 135° (cross far) from the riser plane	3.80				
GG-12	Transverse					± 90° from the riser plane	3.80				

(1) For each load case, a screening analysis shall be performed to choose the FPU draft and wave period (between 6 to 15 s)

(2) These load cases are applicable for turret mooring systems only

(3) Wave direction shall be ± 90° relative to the offset direction. There are two possible wave directions for each load case

(4) Current direction shall be the same of the offset direction, and the FPU shall be considered aligned with the current, running from bow to stern

Table 10 - Global analysis matrix for Verification Case H

Load Case	Position	Functional Load				Environmental Load				
		FPU Draft	FPU Heading	FPU offset		Wave			Current	
				Value	Direction	H (m)	T (s)	Direction	RP	Direction
GH-01	Near	Same as GG-01		14.5% of WD (and, eventually, 12.5%)	Same as GG-01					
GH-02	Far	Same as GG-02			Same as GG-02					
GH-03	Crossed	Same as GG-03			Same as GG-03					
GH-04	Transverse	Same as GG-04			Same as GG-04					
GH-05	Near	Same as GG-05			Same as GG-05					
GH-06	Far	Same as GG-06			Same as GG-06					
GH-07	Crossed	Same as GG-07			Same as GG-07					
GH-08	Transverse	Same as GG-08			Same as GG-08					
GH-09[1]	Near	Same as GG-09			Same as GG-09					
GH-10[1]	Far	Same as GG-10			Same as GG-10					
GH-11[1]	Crossed	Same as GG-11			Same as GG-11					
GH-12[1]	Transverse	Same as GG-12			Same as GG-12					

(1) These load cases are applicable for turret mooring systems only

Table 11 - Offset values for First oil with temporary mooring condition

Case	Environmental RP	Mooring condition	Total FPU Offset(1) (% of the 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

Table 12 - Global analysis matrix for Verification Case I

<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>GI-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 3is 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>GI-02</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2) (3)</td></tr>
<tr><td>GI-03</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2) (3)</td></tr>
<tr><td>GI-04</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2) (3)</td></tr>
<tr><td>GI-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>GI-06</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2)</td></tr>
<tr><td>GI-07</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2)</td></tr>
<tr><td>GI-08</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2)</td></tr>
<tr><td>GI-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>GI-10</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases(3)</td></tr>
<tr><td>GI-11</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases(3)</td></tr>
<tr><td>GI-12</td><td>Transverse</td><td>Maximum TDP, sag or hog curvature among transverse cases(3)</td></tr>
<tr><td>GI-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>GI-14</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases</td></tr>
<tr><td>GI-15</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases</td></tr>
<tr><td>GI-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 on 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

Table 13 - Global analysis matrix for Verification Case J

<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">Accidental Load</th><th rowspan="3">From Table 3, select the load case which presents:</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>GJ-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), damaged 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 rowspan="16">One mooring line broken</td><td>Maximum tension and angle on the top region among near cases(2) (3)</td></tr>
<tr><td>GJ-02</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2) (3)</td></tr>
<tr><td>GJ-03</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2) (3)</td></tr>
<tr><td>GJ-04</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2) (3)</td></tr>
<tr><td>GJ-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>GJ-06</td><td>Far</td><td>Maximum tension and angle on the top region among far cases(2)</td></tr>
<tr><td>GJ-07</td><td>Crossed</td><td>Maximum tension and angle on the top region among crossed cases(2)</td></tr>
<tr><td>GJ-08</td><td>Transverse</td><td>Maximum tension and angle on the top region among transverse cases(2)</td></tr>
<tr><td>GJ-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>GJ-10</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases(3)</td></tr>
<tr><td>GJ-11</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases(3)</td></tr>
<tr><td>GJ-12</td><td>Transverse</td><td>Maximum TDP, sag or hog curvature among transverse cases(3)</td></tr>
<tr><td>GJ-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>GJ-14</td><td>Far</td><td>Maximum TDP, sag or hog curvature among far cases</td></tr>
<tr><td>GJ-15</td><td>Crossed</td><td>Maximum TDP, sag or hog curvature among cross cases</td></tr>
<tr><td>GJ-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 on Table 13 will become two different load cases

(3) For GJ-01, GJ-02, GJ-03, GJ-04, GJ-09. GJ-10, GJ-11 and GJ-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 GJ-05, GJ-06, GJ-07, GJ-08, GJ-13, GJ-14, GJ-15 and GJ-16

Table 14 - Global analysis matrix for Verification Case K

Load Case	Position	Functional Load				Environmental Load				Accidental Load	From Table 3, select the load case which presents:
		FPU Draft	FPU Heading	FPU offset		Wave		Current			
				RP	Direction	RP	Direction	RP	Direction		
GK-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), intact 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)
GK-02	Far										Maximum tension and angle on the top region among far cases(2) (3)
GK-03	Crossed										Maximum tension and angle on the top region among crossed cases(2) (3)
GK-04	Transverse										Maximum tension and angle on the top region among transverse cases(2) (3)
GK-05	Near					1-year		(1)			Maximum tension and angle on the top region among near cases(2)
GK-06	Far										Maximum tension and angle on the top region among far cases(2)
GK-07	Crossed										Maximum tension and angle on the top region among crossed cases(2)
GK-08	Transverse										Maximum tension and angle on the top region among transverse cases(2)
GK-09	Near					(1)		1-year			Maximum TDP, sag or hog curvature among near cases(3)
GK-10	Far										Maximum TDP, sag or hog curvature among far cases(3)
GK-11	Crossed										Maximum TDP, sag or hog curvature among cross cases(3)
GK-12	Transverse										Maximum TDP, sag or hog curvature among transverse cases(3)
GK-13	Near					1-year		(1)			Maximum TDP, sag or hog curvature among near cases
GK-14	Far										Maximum TDP, sag or hog curvature among far cases
GK-15	Crossed										Maximum TDP, sag or hog curvature among cross cases
GK-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 on Table 14 will become two different load cases

(3) For GK-01, GK-02, GK-03, GK-04, GK-09. GK-10, GK-11 and GK-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 GK-05, GK-06, GK-07, GK-08, GK-13, GK-14, GK-15 and GK-16

4.2.3 Input and output data tables

SUPPLIER shall present tables containing the input and output data of the performed global analysis, for both the design cases (specified on Table 1) and verification cases (specified on Table 2). The input data tables shall have at least the information presented on the template on Table 15. The output data tables shall have at least the information presented on the template on Table 16 and Table 17.

These tables shall be preferably included as attachments to the report file to not oversize the body text content. However, for each design case (and verification case when applicable) these results must be summarized on the body text according to the templates on Table 18 (for GA, GB, GC, GD, GG, GH, GI, GJ and GK) and Table 19 (for GE and GF) to fully comply with the minimum information for the Design Report as required in [4].

Table 15 - Minimum content for extreme-load global analysis input data table

Load Case	Wave								Current				Offset		Draft
	Hs (m)	Tp (s)	Gamma	H(1) (m)	T(1) (s)	Compass Direction (N, NE...)	Direction(2) (deg.)	RP (years)	Value at the surface (m/s)	Compass Direction (N, NE...)	Direction(2) (deg.)	RP (years)	Value (m)	Direction(2) (deg.)	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

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

(2) Clockwise relative to true north

Table 16 - Minimum content for extreme-load global analysis output data table (BSR Region)

Load Case	BSR Region(1)																
	F_{Max} with assoc. BR and TA			F_{Min} with assoc. BR and TA			BR_{Min} with assoc. F and TA			TA_{Max} with assoc. F		TA_{Min} with assoc. F		Max ShF & assoc. BM(2)		Max BM & assoc. ShF(2)	
	F_{Max} (kN)	BR (m)	TA (deg.)	F_{Min} (kN)	BR (m)	TA (deg.)	BR_{Min} (m)	F (kN)	TA (deg.)	TA_{Max} (deg.)	F (kN)	TA_{Min} (deg.)	F (kN)	ShF_{Max} (kN)	BM (kN.m)	BM_{Max} (kN.m)	ShF (kN)
...	...	...		...	...		...	...		...	...	...	...	...	...	...	...

(1) For global analysis design cases GE and GF these results must be taken at the PLSV laying system exit and winch bottom connection respectively

(2) Not applicable for design cases GE and GF

Table 17 - Minimum content for extreme-load global analysis output data table (Sag/Hog, TDP Region and Anchoring)

Load Case	Sag/Hog(1)										TDP region						Anchoring	
	Sag distance to seabed		Hog distance to seabed		F_{Max} & Associated BR		F_{Min} & Associated BR		BR_{Min} & Associated F		F_{Max} & Associated BR		F_{Min} & Associated BR		BR_{Min} & Associated F		F_{Max} (kN)	F_{Min} (kN)
	Max (m)	Min (m)	Max (m)	Min (m)	F_{Max} (kN)	BR (m)	F_{Min} (kN)	BR (m)	BR_{Min} (m)	F (kN)	F_{Max} (kN)	BR (m)	F_{Min} (kN)	BR (m)	BR_{Min} (m)	F (kN)		
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

(1) Applicable only when SUPPLIER proposes a lazy wave configuration

Table 18 - Minimum content (except GE and GF) for extreme-load global analysis summary output data table

Design or Verification Global Analysis Case	Umbilical Region	Main Load	Associated Load	FPU Riser Balcony Limits(1)	Load Case
GA, GB, GC, GD, GG, GH, GI, GJ or GK	BSR	Max Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Bending Radius (m)	Tension (kN)	N/A	(2)
		Max Shear Force (kN)	Bending Moment (kN.m)	*Allowable Shear Force (kN)*	(2)
		Max Bending Moment (kN.m)	Shear Force (kN)	*Allowable Bending Moment (kN.m)*	(2)
	Sag/Hog(3)	Max Sag distance to seabed (m)	N/A	N/A	(2)
		Min Sag distance to seabed (m)	N/A	N/A	(2)
		Max Hog distance to seabed (m)	N/A	N/A	(2)
		Min Hog distance to seabed (m)	N/A	N/A	(2)
		Max Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Bending Radius (m)	Tension (kN)	N/A	(2)
	TDP	Max Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Tension (kN)	Bending Radius (m)	N/A	(2)
		Min Bending Radius (m)	Tension (kN)	N/A	(2)
	Anchoring	Max Tension (kN)	N/A	N/A	(2)
		Min Tension (kN)	N/A	N/A	(2)

(1) To be informed by PETROBRAS

(2) GA-01 to GA-20 or GB-01 to GB-08 or GC-01 to GC-08 or GD-01 to GD-04 or GG-01 to GG-12 or GH-01 to GH-12 or GI-01 to GI-16 or GJ-01 to GJ-16 or GK-01 to GK-16

(3) Applicable only when SUPPLIER proposes a lazy wave configuration

Table 19 - Minimum content for GE and GF summary output data table

Design Global Analysis Case	Umbilical Region	Main Load	Associated Load	Load Case
GE or GF	Top connection	Max Tension (kN)	Angle (deg.)	(1)
		Min Tension (kN)	Angle (deg.)	(1)
		Max Angle (deg.)	Tension (kN)	(1)
		Min Angle (deg.)	Tension (kN)	(1)
	Sag/Hog(2)	Max Sag distance to seabed (m)	N/A	(1)
		Min Sag distance to seabed (m)	N/A	(1)
		Max Hog distance to seabed (m)	N/A	(1)
		Min Hog distance to seabed (m)	N/A	(1)
		Max Tension (kN)	Bending Radius (m)	(1)
		Min Tension (kN)	Bending Radius (m)	(1)
		Min Bending Radius (m)	Tension (kN)	(1)
	TDP	Max Tension (kN)	Bending Radius (m)	(1)
		Min Tension (kN)	Bending Radius (m)	(1)
		Min Bending Radius (m)	Tension (kN)	(1)

(1) GE-01 to GE-03 or GF-01 to GF-03

(2) Applicable only for GF global analysis cases when SUPPLIER proposes a lazy wave configuration

4.3 Structural analysis

The load cases for structural analysis presented herein shall be performed to determine stresses and/or strains on the subsea umbilical components and the respective utilization factors relative to the considered structural capacities.

4.3.1 General notes

The following notes shall be observed for all load cases stated in section 4.3.2:

- The load cases shall consider the fluid conduits under the internal pressures defined on Table 1 and on 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 umbilical section is under effective compression, then "minimum effective tension" means "maximum effective compression".

4.3.2 Load cases

Structural analysis of design cases A to G shall include at least the load cases from Table 20 to Table 26. Structural analysis of verification cases H to K shall include at least the load cases from Table 27 to Table 30.

Table 20 - Structural analysis matrix for Design Case A

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LA-01	BSR	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	BSR	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 21 - Structural analysis matrix for Design Case B

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LB-01	BSR	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	BSR	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 22 - Structural analysis matrix for Design Case C

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LC-01	BSR	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	BSR	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 23 - Structural analysis matrix for Design Case D

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LD-01	BSR	Maximum from GD-01 to GD-04	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LD-02	BSR	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-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 24 - Structural analysis matrix for Design Case E

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LE-01	Top	Maximum from GE-01 to GE-03	---	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LE-02(1)	Top	Minimum from GE-01 to GE-03	---	---	Buckling 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	Maximum from GE-01 to GE-03	---	External pressure relative to the water depth	Excessive ovalization or collapse of fluid conduits
LE-05	TDP	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	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

Table 25 - Structural analysis matrix for Design Case F

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

Table 26 - Structural analysis matrix for Design Case G

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LG-01	BSR	Maximum from GG-01 to GG-12	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LG-02	BSR	Associated to the bending radius	Minimum from GG-01 to GG-12	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers

Table 27 - Structural analysis matrix for Verification Case H

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LH-01	BSR	Maximum from GH-01 to GH-12	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LH-02	BSR	Associated to the bending radius	Minimum from GH-01 to GH-12	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers

Table 28 - Structural analysis matrix for Verification Case I

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LI-01	BSR	Maximum from GI-01 to GI-16	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LI-02	BSR	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-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

Table 29 - Structural analysis matrix for Verification Case J

Load Case	Umbilical Region	Tension	Bending Radius	Other Loads	Potential Failure Mechanism
LJ-01	BSR	Maximum from GJ-01 to GJ-16	Associated to the effective tension	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LJ-02	BSR	Associated to the bending radius	Minimum from GJ-01 to GJ-16	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LJ-03	TDP, Sag or Hog	Associated to the bending radius	Minimum from GJ-01 to GJ-16	---	Yielding of structural components Deformation of copper conductors Deformation of optical fibers
LJ-04(1)	TDP, Sag or Hog	Minimum from GJ-01 to GJ-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 30 - Structural analysis matrix for Verification Case K

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

4.3.3 Input and output data table

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

The data table shall have at least the information presented on Table 31.

Table 31 - Minimum content for extreme-load structural analysis data table

Load Case	Global Analysis Load Case	Effective Tension (kN)	Bending Radius (m)	Other Loads	Component	Criterion	Structural Capacity	Result	UF
(1)	(2)				(3)	(4)	(5)	(6)	

(1) Structural analysis load case

(2) Global analysis load case where the loads are taken from

(3) Umbilical structural or functional component under evaluation (e.g., armor wires, metallic tubes, electrical cable copper conductors etc.)

(4) Acceptance criterion relative to the evaluated component (e.g, SMYS, strain, maximum axial compression etc.)

(5) Value (in MPa, kN, % etc.) relative to the established acceptance criterion

(6) Result obtained (in MPa, kN, % etc.) to be compared to the 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 performing the structural analysis and presenting its results as required above.

5 Fatigue analysis

SUPPLIER shall refer to the project-specific documentation that informs which technical specification – regarding fatigue analysis – must be considered. Fatigue analysis technical specification defines the applicable metocean data, load cases, global and structural analyses minimum requirements, umbilical and ancillary equipment design rules and how the results must be presented.

6 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].

7 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 lines (umbilicals, flexible pipes, rigid pipes and/or anchoring lines) shall be available to SUPPLIER at the applicable project-specific documentation.

APPENDIX A – MOTION ANALYSIS

The selection of wave spectrum properties per direction and FPU/PLSV 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 is available (Hs x Tp contour curves), the following procedure shall be adopted for the load cases analyzed:

a) first, for each draft that a RAO table is available (at least full and ballasted), the movements of the FPU/PLSV shall be transferred from its CoM to the umbilical's connection point, thus obtaining the RAO at that 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, the most probable maximum amplitudes for roll (R_{max}), pitch (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 must 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 a RAO table is available (at least full and ballasted), the movements of the FPU/PLSV shall be transferred from its CoM to the umbilical'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, the most probable maximum amplitudes for roll, pitch 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 PLSV the connection points are defined by the position of the wheel or the vertical laying system.

APPENDIX B – WAVE MODELLING PROCEDURES

Unless otherwise stated, 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).

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

When considering an irregular wave, a minimum of 100 (one hundred) harmonic components shall be considered to describe the wave spectra.

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

i) to perform a 3-hour simulation;

ii) 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;

iii) to perform at least 10 (ten) 5-minute windows considering at least 5 (five) different random seeds; for each different seed, two 5-minute windows shall be selected: one containing the highest vertical acceleration and the other containing the highest angular motion. If it happens to have the highest vertical acceleration and the highest angular motion at the same 5-minute window, another seed shall be evaluated and other windows shall be selected until the minimum of 10 (ten) is reached.

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

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;

B.2 Regular Wave Procedure

The following steps shall be considered:

a) transfer the RAO from the vessel CoM to the umbilical top connection coordinates;

b) obtain the response spectrum for the movements of the top connection by crossing the wave spectrum and RAOs for the umbilical 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 maximum from Hs 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 umbilical top 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 umbilical top connection:

1. For a given wave direction relative to the FPU/PLSV, the RAO for displacements and vertical acceleration at the umbilical top connection shall be determined for each draft of the FPU/PLSV;

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 displacements 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/PLSV 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/PLSV 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 (six) degrees of freedom at the umbilical top 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 umbilical top 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 umbilical top connection point and a regular wave with maximum height (H_{max}) determined according to item 4 and period (T) defined in item 6.