PETROBRAS	**TECHNICAL REPORT**	Nº:	I-RL-3010.2B-1350-960-P4X-001		
	CLIENT:	SRGE	SHEET	1 of	15
	JOB:	PROD1000			
	AREA:	BÚZIOS			
SRGE	TITLE:	**REFERENCE RAO**	INTERNAL		
			ESUP		

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A	ROLL VISCOUS DAMPING UPDATE

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1 LIST OF ACRONYMS

FPSO : Floating Production Storage and Offloading

DOF : Degrees of Freedom

RAO : Response Amplitude Operators

2 INTRODUCTION

This report presents RAO data for motion and acceleration predictions, when definitive data is not available yet.

FPSO's hull considered to generate the RAO curves is the PETROBRAS Reference Hull (barge-shaped type). Thus, results presented in this report shall not be used for other FPSOs with different hull shapes.

3 FPSO MAIN PARTICULARS AND COORDINATE SYSTEM

Table 3-1 summarizes FPSO main particulars.

Table 3-1 Reference Hull main particulars

Main Characteristics			
Item	**Acronym or Symbol**	**Value**	**Unit**
Length Between Perpendiculars	LBP	345.3	meters
Molded Depth	D	33.80	meters
Hull Breadth Moulded	B	60.00	meters
Draft, Max Operational	T	23.78	meters
Maximum Displacement	Δ	469779	metric tons

The FPSO reference system origin is located along the baseline at the intersection point with hull stern. The sign conventions are given as follows:

X: Origin at Hull stern (Aft Perpendicular) - Positive Forward;

Y: Origin at Centerline - Positive Portside;

Z: Origin at Baseline - Positive Upward;

Figure 3-1 through Figure 3-4 illustrates the coordinate system and its signs convention.

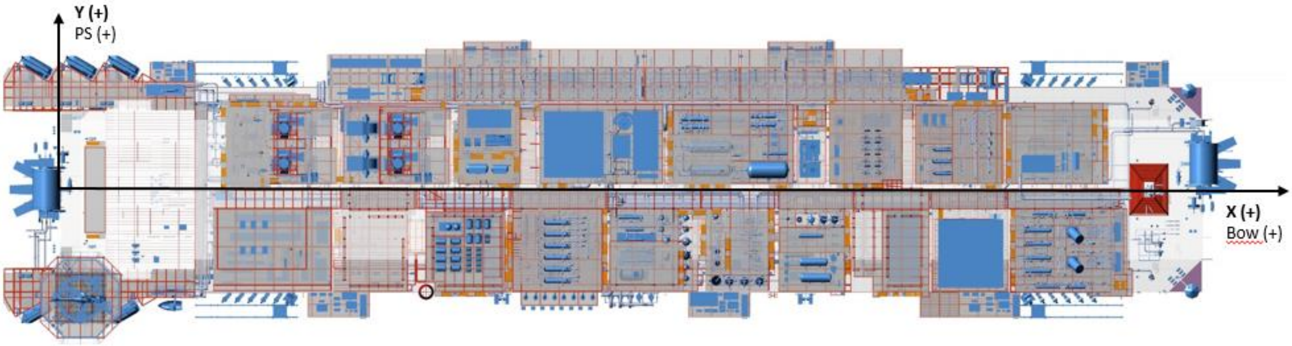

Figure 3-1 Top View

Figure 3-2 Front View

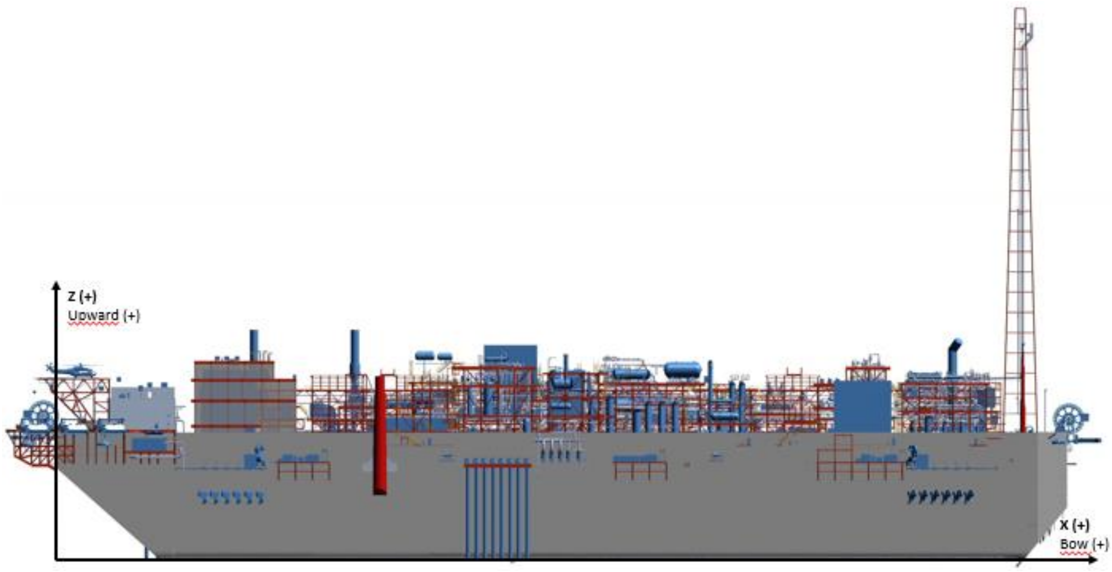

Figure 3-3 Starboard View

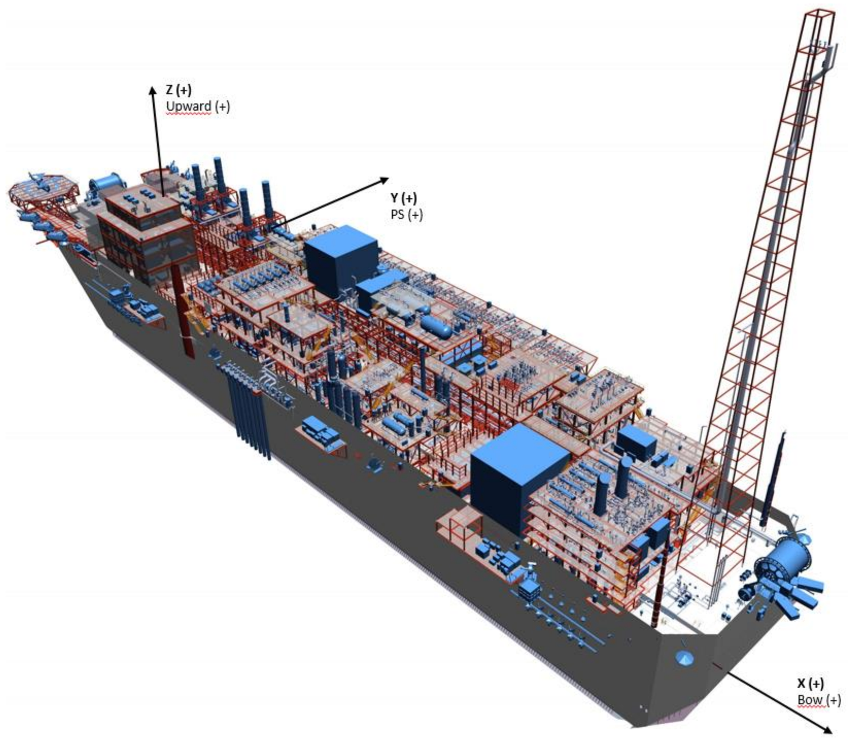

Figure 3-4 Starboard View

Center of Gravities for each draft brought out throughout this report are given in the described coordinate system.

4 FPSO 6-DOF

Figure 4-1 illustrates the six degrees of freedom (DOF) of a rigid floating structure, where:

Surge : linear motion along floating structure's longitudinal axis.

Sway : linear motion along floating structure's transversal axis.

Heave : linear motion along floating structure's vertical axis.

Roll : rotational motion about floating structure's longitudinal axis.

Pitch : rotational motion about floating structure's transversal axis.

Yaw : rotational motion about floating structure's vertical axis.

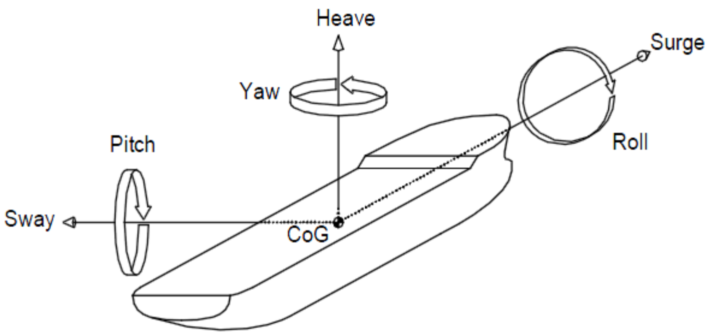

Figure 4-1 Floating body 6-DOF description

5 WAMIT & FPSO REFERENCE SYSTEMS

Figure 5-1 shows the hydrodynamic model set up in WAMIT for the RAOs calculation. One can notice the coordinate axes in red that are the same ones described in item 3.

Additionally, the figure also shows another reference system, in green, which is positioned at the FPSO center of gravity. The RAOs amplitude are obtained in the green reference system.

The blue coordinate axes, in turn, are positioned on the free surface. They are utilized to reference the unit amplitude regular waves. For example, as one can notice in Figure 5-1, the incoming wave at 180 degrees corresponds to a head sea, while the incoming waves at 0 degree is a following sea. Usually, in a single-body analysis, the green and blue coordinate axes are positioned along the same vertical line.

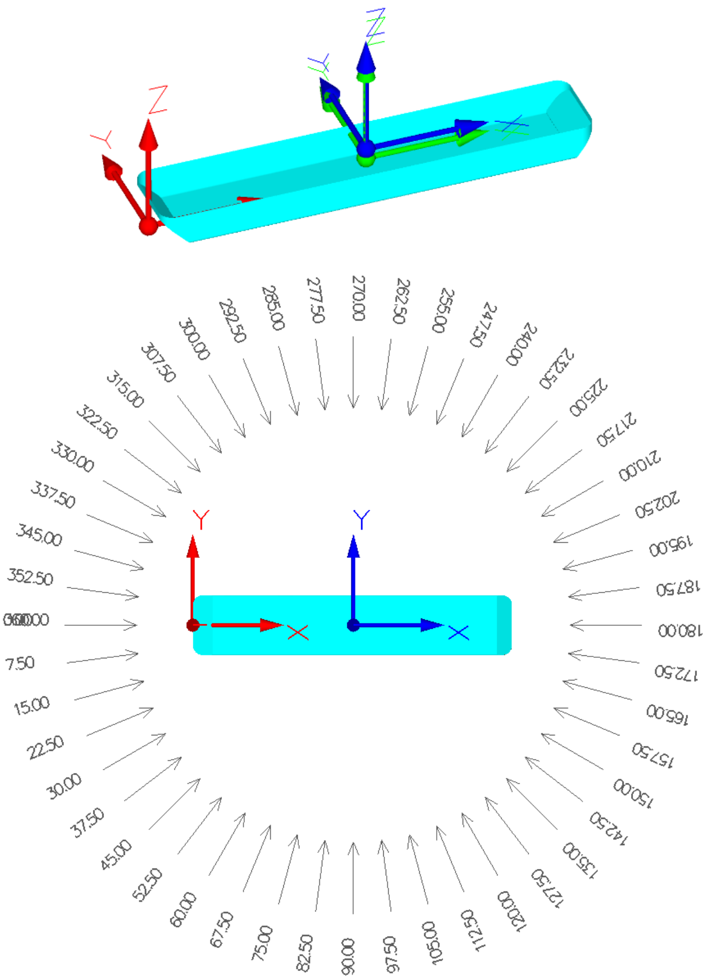

Figure 5-1 Hydrodynamic model

The relation between the incoming wave and the RAO is given as follows:

$$\eta = A\, e^{-ik(x\cos\beta + y sin\beta)}\; e^{i\omega t}$$

$$x = 0, y = 0$$

$$\eta = A\, e^{i\omega t}$$

$$X_n = |X_n|\; e^{i(\omega t + \varphi_n)} \quad \mathrm{n} = 1,\ldots,6$$

$$\mathrm{Re}(X_n) = |X_n|\; \cos(\omega t + \varphi_n)$$

Where,

η wave elevation
A wave amplitude
β wave incidence angle
ω wave angular frequency
$x = 0, y = 0$ positions in the horizontal plane
X_n platform motion
n degree of freedom
$\mathrm{Re}(X_n)$ real part of the motion
φ phase angle

6 FPSO LOADING CONDITIONS

Table 6-1 shows the loading conditions adopted in this report to generate the RAOs for the FPSO 6-DOF.

One shall note that, 24P states for a draft corresponding to 24% of the maximum oil storage capacity, 47P, 47%, and so on.

Table 6-1 loading conditions

Propoerties	Unit	Loading Conditions				
		MinLoaded	24P	47P	69P	100P
Draft	(m)	10.8	13.2	16.1	19	23.8
Mass	(ton)	2.05E+05	2.53E+05	3.12E+05	3.83E+05	4.70E+05
Center of Gravity	X (m)	176.65	179.78	179.58	179.24	178.61
Center of Gravity	Y (m)	0	0	0	0	0
Center of Gravity	Z (m)	22.27	18.43	16.76	16.36	17.32
Center of Gravity	Z*(m)	22.52	19.58	17.83	17.24	18.04
KB	(m)	5.47	6.71	8.2	10	12.16
KM - Transv.	(m)	34.32	30.3	27.61	25.97	25.35
GM - Transv.	(m)	12.05	11.87	10.85	9.61	8.03

**due to free surface effect on tanks*

Table 6-2 describes the Heave, Roll and Pitch natural periods for each loading condition.

Table 6-2 Natural Periods

Properties	Unit	Loading Conditions				
		MinLoaded	24P	47P	69P	100P
Natural Period	Heave (s)	11.12	1.57	12.1	12.71	13.27
Natural Period	Roll (s)	18.5	18.14	17.66	17.42	17.67
Natural Period	Pitch(s)	11.41	11.58	12.16	12.43	12.74

6.1 Inertia Matrices

In this report, the inertia matrices are given in the following units:

	1 2 3	4 5 6
1 2 3	t	t m
4 5 6	t m	t m^2

6.1.1 Minimum Loading Condition

	1	2	3	4	5	6
1	2.05E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	2.05E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	2.05E+05	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	0.00E+00	0.00E+00	1.37E+08	9.20E+06	-4.27E+06
5	0.00E+00	0.00E+00	0.00E+00	9.20E+06	2.38E+09	3.86E+05
6	0.00E+00	0.00E+00	0.00E+00	-4.27E+06	3.86E+05	2.37E+09

6.1.2 Loading Condition 24P

	1	2	3	4	5	6
1	2.53E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	2.53E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	2.53E+05	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	0.00E+00	0.00E+00	1.56E+08	1.61E+07	9.74E+06
5	0.00E+00	0.00E+00	0.00E+00	1.61E+07	2.63E+09	-2.20E+06
6	0.00E+00	0.00E+00	0.00E+00	9.74E+06	-2.20E+06	2.61E+09

6.1.3 Loading Condition 47P

	1	2	3	4	5	6
1	3.12E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	3.12E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	3.12E+05	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	0.00E+00	0.00E+00	1.70E+08	1.61E+07	3.91E+06
5	0.00E+00	0.00E+00	0.00E+00	1.61E+07	3.33E+09	-1.14E+06
6	0.00E+00	0.00E+00	0.00E+00	3.91E+06	-1.14E+06	3.32E+09

6.1.4 Loading Condition 69P

	1	2	3	4	5	6
1	3.83E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	3.83E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	3.83E+05	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	0.00E+00	0.00E+00	1.86E+08	2.33E+07	1.53E+06
5	0.00E+00	0.00E+00	0.00E+00	2.33E+07	3.78E+09	4.05E+05
6	0.00E+00	0.00E+00	0.00E+00	1.53E+06	4.05E+05	3.78E+09

6.1.5 Loading Condition 100P

	1	2	3	4	5	6
1	4.70E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.00E+00	4.70E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	0.00E+00	0.00E+00	4.70E+05	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	0.00E+00	0.00E+00	2.07E+08	1.61E+07	4.73E+06
5	0.00E+00	0.00E+00	0.00E+00	1.61E+07	4.31E+09	2.04E+06
6	0.00E+00	0.00E+00	0.00E+00	4.73E+06	2.04E+06	4.32E+09

6.2 Stiffness Matrices

In this report, the stiffness matrices are given in the following units:

	1 2 3	4 5 6
1 2 3		
4 5 6		t m

The main role of the stiffness matrices in the analyses brought out in this report is to account for the free surface effects in Roll motion. The term C_{44} is given by:

$$C_{44} = \Delta(GM_{FS} - GM_{s})$$

Where,

Δ: FPSO displacement at a certain draft.

GM_{FS}: metacentric height corrected due to free surface effects.

GM_S: solid metacentric height (no free surface effect correction).

6.2.1 Minimum Loading Condition

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	-5.23E+05	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

6.2.2 Loading Condition 24P

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	-2.86E+06	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

6.2.3 Loading Condition 47P

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	-3.30E+06	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

6.2.4 Loading Condition 69P

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	-3.31E+06	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

6.2.5 Loading Condition 100P

	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	-3.27E+06	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0

7 ROLL VISCOUS DAMPING

As mentioned before, the RAOs for all FPSO degrees of freedom are generated in the same way, except Roll, which is dependent on the viscous damping parameter that must be tuned for the correct assessment. Table 7-1 shows the environmental condition category, while Table 7-2 shows how the Roll viscous damping parameter has been set according to the category.

Table 7-1 environmental condition category

Hs	RAO
Hs <=2.5	Fatigue
2.5m < Hs <= 4.5m	1-year return period
Hs > 4.5m	100-year return period

Table 7-2 Roll viscous damping defined in terms of critical damping percentage for the corresponding return-periods or categories

		Roll Motion	
Loading Condition ID	RAO	(%Critical Damping)	Viscous Damping (t.m2/s)
MinLoad	Fatigue waves/ green water long-term	1.0	1.39E+06
	1-year return period waves	1.0	1.39E+06
	100-year return period waves	2.0	2.78E+06
24P	Fatigue waves/ green water long-term	1.0	1.54E+06
	1-year return period waves	1.0	1.54E+06
	100-year return period waves	2.5	3.85E+06
47P	Fatigue waves/ green water long-term	1.0	1.68E+06
	1-year return period waves	1.0	1.68E+06
	100-year return period waves	2.5	4.20E+06
69P	Fatigue waves/ green water long-term	1.0	1.82E+06
	1-year return period waves	1.0	1.82E+06
	100-year return period waves	2.5	4.55E+06
100P	Fatigue waves/ green water long-term	1.0	1.90E+06
	1-year return period waves	1.0	1.90E+06
	100-year return period waves	3.0	5.69E+06

One came up with this approach, since it is understood that the level of viscous damping varies according to the response amplitudes, which in turn is dependent on the significant wave height. As a result, the higher the return period, the higher the roll viscous damping coefficient to be applied.

8 RAOs FOR THE 6-DOF

The following values were used on WAMIT to create the nondimensional form of the RAO curves:

Table 8-1 RAO curves WAMIT parameters

Parameter	Value
ULEN (dimensional length characterizing the body dimension)	1.000
GRAV (acceleration of gravity)	9.806

Table 8-2 RAO DATA

WAMIT RAO Files (*.4 & *.out)	PROD1000_RAO&OUT_Rev_A.zip

9 CONCLUSION

This report presented RAO data for motion and acceleration predictions, when definitive data is not available yet.

Data provided in this report are preliminary, and shall be updated as soon as detailed information are provided.