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MAESTRÍA EN INGENIERÍA APLICADA

MODALITY: THESIS

“DETERMINATION OF CRITICAL CONDITIONS OF OPERATION OF A SEMI-SUBMERSIBLE PLATFORM UNDER DAMAGE CONDITIONS”

PRESENT:

MARÍA ALEJANDRA RODRÍGUEZ CRUZ

INTERNAL ADVISOR

M.I. JOSÉ HERNÁNDEZ HERNÁNDEZ
(Universidad Veracruzana)

EXTERNAL ADVISOR

DR. RACHEL PAWLING
(University College London)

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Abstract

Following the high-pace growth of offshore platforms constructions and installations, a considerable interest in the evaluation of the global performance of this type of structures has risen. The effects of climate change have transformed the environmental conditions of the operation sites of offshore platforms to which they were designed. This, has caused losses of stability (capsize) of the structures, which has been added to the most common sinister, in this type of structures, collisions with other vessels due to the maneuverability.

Stakeholders involved in all the aspects of offshore business are aware that a latent risk exist, intrinsically associated with the metocean behavior, and would like to understand the dimension of the risk and how to control or minimize it.

This work presents a study, based on numerical simulation, in an offshore structure used as production platforms in the Gulf of Mexico: semi-submersible platform. This will take us to understand its behaviour on the operation site, besides of get to know the performance of the platform under extreme conditions.

Designs of oil platforms are in constant evolution as a result of constant changes in market requirements. This makes previous studies and rules almost obsolete and only applicable partially. The new platforms have different dimensions and geometries compared to the past, the modes of operation have also changed, due to the new demands in the market. Also, the loss of stability or capsize is a complex physical phenomenon, which does not have a complete mathematical description of all the cases that may occur in real operative conditions.

Due to mentioned above, it is of high priority to perform a recent global analysis of the performance of the structure. The evaluation of global performance, for the offshore structure studied in this work, is divided in two principal analyses. The first one is focused upon the stability of the platform, which cover intact stability and damage stability. For the damage stability, an evaluation is done of the structural damage to collisions or meteorological phenomena. The second analysis focused on the hydrodynamic performance of the platforms motions, which was done taking into

account the environmental conditions of the site, such as wind and wave for operating conditions and extreme sea states.

Chapter 1: Introduction

In recent years, following the fast growing of the construction and installation of semisubmersible platforms, there has been a considerable growing interest in the evaluation of stability conditions of this type of structures.

Huse and Nedrelid (1985) relate that the tragic disasters of two semisubmersible platforms, the “Alexander L. Kielland” and the “Ocean Ranger” cost nearly 200 lives. These two accidents lead to a strong focusing on stability and capsizing problems of floating offshore structures in many countries that are involved in offshore activities. Since then, the frequency of worldwide accidents has been significantly reduced, but capsizing of mobile platforms are still reported.

Despite accidents being reduced, the database of accidents of offshore structures, The Worldwide Offshore Accidents Databank (WOAD), shows that the accidents of semisubmersible platforms are the second most common accidents for offshore structures. This dataset shows that about 26% of the semi-submersible offshore platform accidents occurred in the Gulf of Mexico and that this sinister is due to damage to the structure provoked by environmental conditions. (C. Hickey, E. Funnemark y M. Thomas, 2014)

The Gulf of Mexico is exposed to tropical storms (hurricanes) as well to winter storms and northers winds, which causes big gusts of wind. In the case of tropical storms, the Gulf of Mexico has seen an increase in the severity of the hurricanes being now common categories 4 and 5 (A. Fernández, R. Romero and J. Zavala, 2016), which endanger the infrastructure for the oil and gas production at sea. The semi-submersible platform must be sized to support permanent and variable environmental actions over time, which may occur several times through their useful life; providing safety and support to the oil production operations, equipment and facilities on their deck, and most important giving safety to people in it.

Providing a platform design with sufficient stability is still a challenge:

- In first place, the design of oil platforms is in constant evolution as a result of constant changes in marker requirements. This makes the previous concepts partially obsolete and only applicable conditionally. The new platforms have different dimensions and geometries compared to the past, the modes of operation have also changed, due to the new demands in the market, which have an important influence in the platform design.

- In second place, the loss of stability or capsize is a complex physical phenomenon, which does not have a complete mathematical description for all the cases that may occur in real operative conditions. (T. Moan, 2005)

Additionally, the industry's demand for the establishment of rules based on the risk and appropriate regulations has been increased in recent years. Wide circles of professionals involved in all the aspects of marine business are aware that a risk exist which is intrinsically associated with the metocean behavior and would like to understand the dimension of the risk and how to control or minimize it.

In the case of this work, research was based on recent metocean data and was analyzed the critical condition of the operation of a semi-submersible platform (i.e. damage condition). Waves and wind were considered, for different damage cases determined by the most common accidents that causes damage to the structure, such as collisions (P. Glogowski et al., 2017).

There are two methods to evaluated the damage stability (PNA, 2008), by means of either lost buoyancy and trimline added weight, with which the same result is obtained. To understand the damage stability analysis of the platform, the trimline added method was used, which is the method available in MAXSURF software. To review and verify the results, different relevant regulations were used: Stability and Watertight Integrity from DNV (DNV.GL, 2017) and Mobil Offshore Drilling Units from ABS (ABS, 2016).

1.1 Aim

The aim of the present work was to determine the critical operating conditions of a semisubmersible platforms under damage conditions through specialized computational tools, like Maxsurf, considering all the loads that could affect the stability of the structure, whether produced by the same structure or by meteorological and oceanographic conditions.

1.2 Objectives

The objectives of the project were to:

1. Evaluate the hydrodynamic performance of a semi-submersible platform in intact and survival conditions.
2. Make a combination of damage conditions in the semi- submersible platform compartments and obtain the hydrostatic properties using the Maxsurf Software.
3. Evaluate the hydrodynamic behaviour of the semi-submersible platform under extreme conditions.
4. Identify, from the analyses made, the critical parameters that affect the behaviour of the semi-submersible platform.
5. Determine the critical damage condition of the platform for the operation draft.

1.3 Project Road Map

Figure 1-1 describe the process followed in the project.

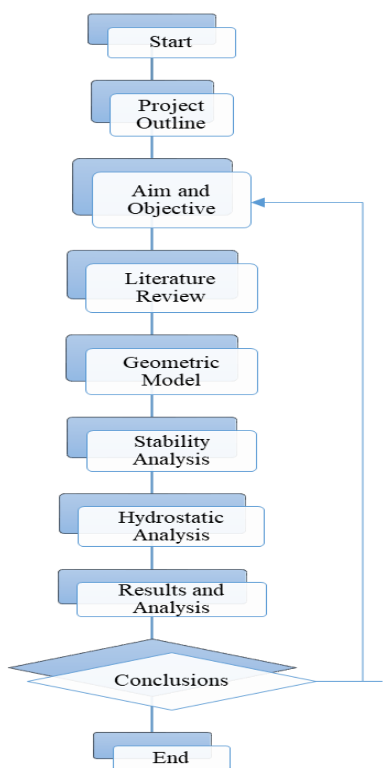

Figure 1-1. Project roadmap

The flowchart indicates the sequence of activities used to elaborate the whole project, including the different models and execute of the analyzes.

Chapter 2: Literature Review

The aim of this review was to assess the state of the art of semisubmersible platform, understand why it has become of significant interest for the naval industry and the importance to evaluate this type of structures.

2.1 Semisubmersible platforms

A semisubmersible platform is a specialized type of vessel used in diverse offshore roles such as MODU (Mobile Offshore Drilling Units) design, like shown in Figure 2-1, oil production platforms, heavy lift cranes and housing. Another type of drilling rig that can drill in ultra-deep waters, drillships are capable of holding more equipment; but semisubmersibles are chosen for their stability. The design concept of partially submerging the rig lessens both rolling and pitching, they are designed with good stability and seakeeping characteristics.

Figure 2.1-1. Semisubmersible platform

2.1.1 Characteristics

Offshore drilling in water depth greater than around 520 meters requires that operations be carried out from a floating vessel, since fixed structures are not practical. Initially in the early 1950s monohull ships were used, but these were found to have significant heave, pitch and yaw motions in large waves, and the industry needed more stable drilling platforms.

A semisubmersible obtains most of its buoyancy from ballasted, watertight pontoons located below the ocean surface and wave action. Structural columns connect the pontoons and operating deck. The operating deck can be located high above the sea level owing to the good stability of the design, and therefore is kept well away from the waves.

With its hull structure submerged at a deep draft, the semi-submersible is less affected by wave loadings than a normal ship. With a small water-plane area, however, the semi-submersible is sensitive to load changes, and therefore must be carefully trimmed to maintain stability.

Semisubmersible platforms are able to transform from a deep to a shallow draft by deballasting (removing ballast water from the hull), thereby becoming surface vessels. Usually they are moved from location to location in this configuration.

2.1.2 Classification

Semisubmersible construction has historically occurred in boom periods and therefore batches of this type of platforms have been built. Semisubmersible platforms have been classified in generations, depending upon the year built and water depth capability.

Table 2.1.2-1. Generation of semisubmersible platform

Generation	Water depth		Dates
First	about 600 ft	200 m	Early 1960s
Second	about 1000 ft	300 m	1969–1974
Third	about 1500 ft	500 m	Early 1980s
Fourth	about 3000 ft	1000 m	1990s
Fifth	about 7500 ft	2500 m	1998–2004
Sixth	about 10000 ft	3000 m	2005–2010

2.2 Stability

The study of the stability of a floating device is a matter of great complexity that should be considered as the design, operation and regulatory aspects at national and international level. In addition, there are numerous factors that have an influence on stability as the design itself, the effects caused by the load, the free surfaces in tanks, the waves, the wind or the density of the water.

2.2.1 Intact Stability

Marine stability can be defined in simple terms as its characteristics or tendency to return to its original state or upright state, when an external force is applied on or removed from the floating structure.

A floating structure is at equilibrium when the weight of the ship acting down through centre of gravity (G) is equal to the up thrust force of water (B) acting through centre of buoyancy and when both of these forces are in same vertical line.

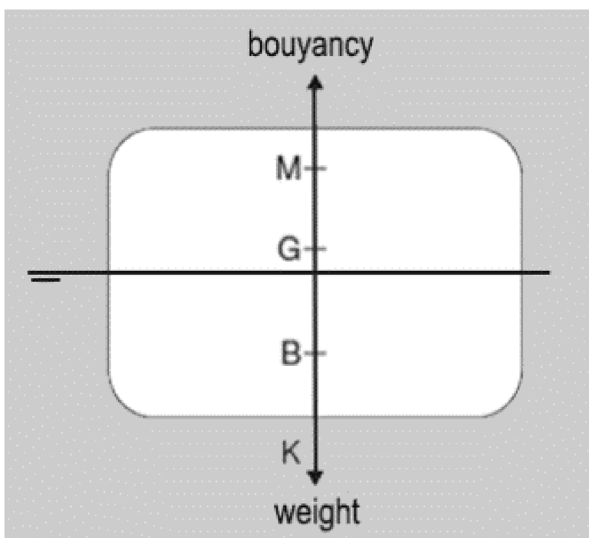

Figure2.2.1-1. Stable equilibrium

A floating structure will come to its upright position or will become stable, when an external force is applied and removed, if the centre of gravity remains in the same position well below height of the structure. When the structure is inclined, centre of buoyancy shifts from B to B1, which creates a movement and the righting lever returns the floating structure to its original position and makes it stable. M is metacenter and GZ is righting lever

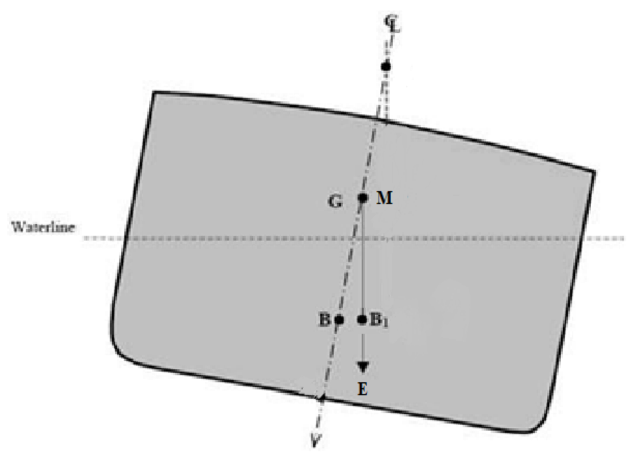

Figure 2.2.1-2. Neutral equilibrium

2.2.2 Damage Stability

The greatest risk related to the stability of the platforms is the risk of capsizes, due to the disastrous consequences that can be derived both from the safety level of personnel on board as well as from economic consequences. Although there is extensive knowledge about stability, the risk of capsizes and the impact of physical phenomena that can influence different situations confer stability and enormous complexity to the study of stability.

Checking the damage stability of a semisubmersible has typically been specified as limited damage to one or two flooded compartments. According to the NPD (Norwegian Petroleum Directorate) this damage should be estimated by a risk analysis. The criterion was formally introduced for all modes of failure of offshore structures in Norway in 1984 (NPD, 1984).

Depending inherently on the fault tolerance ensured by the initial design, the measures that have to be implemented to improve the strength of an existing structure can be much more expensive than those of a new structure. This fact commonly justifies more advanced analyzes of loads, responses, resistances, as well as the use of reliability and risk analysis focused on the initial design (Moan, 2005).

Theoretically the damaged stability is caused when the vertical position of G is higher than the position of transverse metacenter (M). So, when the floating structure heels to an angle (say theta-ϴ), the center of buoyancy (B) now shifts to B1. But the righting lever is now negative, or in other words, the moment created would result in creating further heel until a condition of stable equilibrium is reached. If the condition of stable equilibrium is not reached by the time the deck is not immersed, the structure is said to capsize.

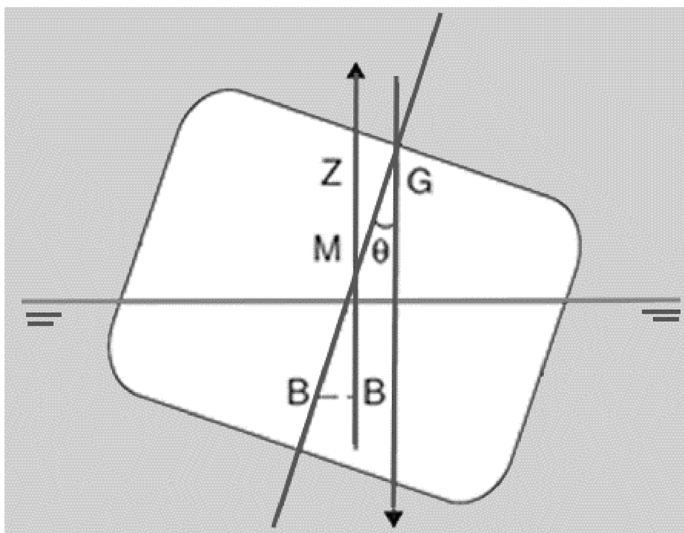

Figure 2.2.2-1. Unstable equilibrium

2.3 Similar Works

Similar studies on the research focus of this work have been made, Vassalos et al. (1985) analysed the intact and damage stability of a platform incorporating to the case of damage stability the effects of waves and winds. They show that considering the effects of wind, waves, damage and combinations thereof has revealed a number of interesting features which have so far been overlooked in judging semisubmersible stability and that a considerable amount of research is still needed about the stability of semi-submersible platforms.

Konovessis et al. (2013) took into consideration different damage cases, loading conditions and damage extents, and their probability of occurrence and potential consequences. This work only covers the theoretical part of the subjects mentioned above, there is not an analysis develop it in a structure.

Hsu et al. (2015) investigated the dynamic motion on a semi-submersible platform considering wind, wave and currents. It is worth mentioning that Hsu's research was done with a 1:50 model of the platform, which was tested under different scenarios, which helped them realize that by doing tests combining wind, waves and current gave very similar responses when testing them separately.

Jin Ma et al. (2017) analysed the wind and waves induced dynamic effects on a semi-submersible platform, the main topic of Jin Ma et al. work is the structural response of which, one of the conclusion makes it as of high relevance for the research focus on this work, since it speaks of the relation that exists between the wind and the waves, conditions that will be used to carry out the analysis of this work. This conclusion said that the combined relationship of wind and wave field reveals the energy transferring relationship between them based on the physical mechanism of wind generating wave. The relationship between wind and wave could be found that the significant wave height increases with the wind speed regularly.

Chapter 3. Critical Review

Offshore platforms work in the complicated sea conditions, where vessels passing by may collide to the platform due to navigational operation errors, and the vessels may be disturbed by winds, waves or current when docking. As the deep water semisubmersible offshore platform work in even worse sea conditions, the collision accidents are even harder to avoid. Collisions between ships and marine structures often result in disastrous consequences such as structural damage, casualties and cargo leakage.

Therefore, it is of great importance to improve the resistibility of structure, no matter what consider economy, safety and protecting environment. The marine structures collision is a high energy process with a powerful impact loading dynamic response and has obvious non-linear dynamic properties. The column structure exposed to the waterline of a semisubmersible offshore platform is the most vulnerable part during a ship collision process.

The literature review however has not provided a clear and a recent conclusion in this subject even less with analysis made with environmental conditions of Gulf of Mexico.

3.1 Problem Statement

It is true that knowledge is very limited as to how a semisubmersible response in a realistic environment when damage occurs when it is heeled. In fact, it is surprising to note that, apart from some work in the Norwegian Hydrodynamics Laboratory and the University of Strathclyde, the problem of the behaviour of a semisubmersible has always been overlooked in spite of its importance. Therefore, there is an urgent need for research in this area and a new look at the stability criteria in the average of semisubmersible platforms as a whole.

This translates into the need to rethink the problem of the stability of the semisubmersible and the rest of the work addresses this same issue, starting with the most fundamental concepts and progressively involving the most complicated.

Chapter 4. Model

4.1 Software

For the development of this work was used the MAXSURF software, which includes tools for hull modelling, stability, motions and resistance prediction, structural modelling, structural analysis, and export to vessel detailing.

The modules used were:

- MAXSURF Modeller for generated geometry.
- MAXSURF Stability for Stability Analysis.
- MAXURF Motions for Hydrodynamic Analysis.

4.2 Model Characteristics

The selected semi-submersible platform is a unit with four columns of square section, supported by ring shaped pontoons with a rectangular cross section. The principal dimensions are shown in Table 4.2-1.

Table 4.2-1. Principal dimensions

DWT	58079 ton
Length	81.2 m
Beam	81.2 m
Depth	43.36 m
Draft	28.8 m

The geometry dimensions are shown in Table 4.2-2.

Table 4.2-2. Geometry dimensions

Element	Quantity	Transversal Secc.	Height
Columns	4	17.2 m X 17.2 m	43.36 m
Pontoons	4	12.4 m X 10.54 m	/

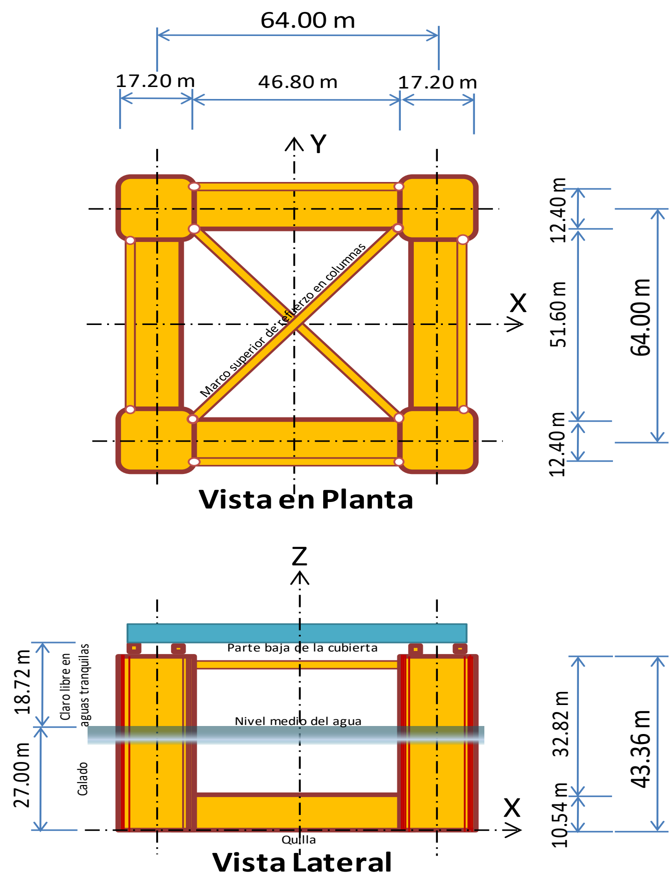

Figure 4.2-1. Plantform geometry and dimentions

4.3 Geometrical Model

The platform was modeled in the Maxsurf software with the Modeler Advanced module, having the model of the hull, the topside was modeled, including cranes and burner.

The model used to perform the respective analyzes to determine the critical operating conditions in damage conditions, is of a semisubmersible platform with a dimension of 81.2 meters of length and beam, with a depth of 43.36 meters. We must remember that the semisubmersible platforms remain positioned with anchors or dynamic positioning, they are used to drill in water depths greater than 100 meters, for which they use submarine connections.

The configuration of the structure is shown in Figure 4.3-1, as well as the wind areas.

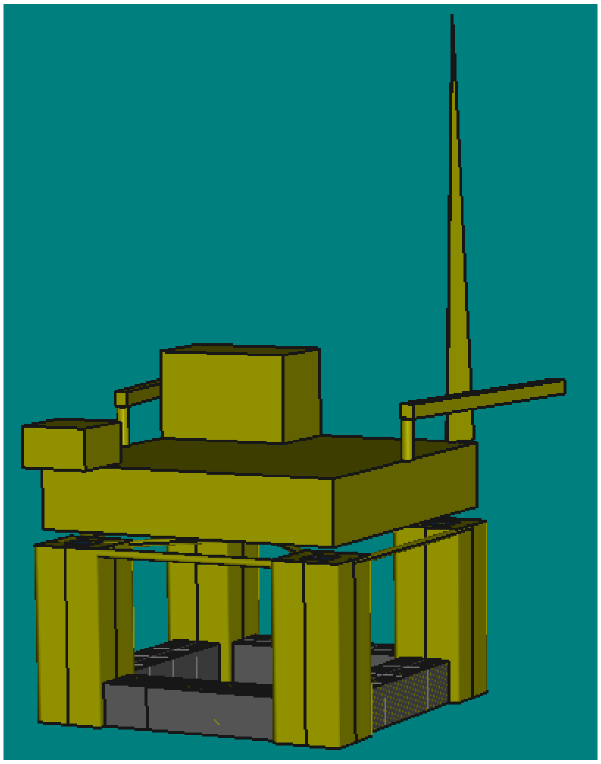

Figure 4.3-1. Geometry model of semisubmersible platform

From the model already generated, the hydrostatic data can be calculated and thus obtain the shape coefficients at the design draft of 28.8 m. The hydrostatic data and the shape coefficients are shown in Tables 4.3-1 and 4.3-2.

Table 4.3-1. Hydrostatic data

Concept	Value		Concept	Value
Displacement t	58079		**MTc tonne.m**	21.259
Draft m	28.8		**BMt m**	20.792
WL Length m	81.2		**BML m**	21.289
Beam max extents on WL	81.2		**GMt m**	2.475
KB m	10.483		**GML m**	2.972
Waterplane Area m^2	12038.826		**KMt m**	31.275
LCB from zero pt. (+ve fwd	0		**KML m**	31.772
LCF from zero pt. (+ve fwd	0		**TPc tonne/cm**	11.515

Table 4.3-2. Shape Coefficients

Coefficiente	Valor
Prismatic coeff. (Cp)	0.47
Block coeff. (Cb)	0.298
Max Sect. area coeff. (Cm)	0.635
Waterpl. area coeff. (Cwp)	0.17

4.4 Tanks

The compartments play a great role in the stability of a platform. Great care must be taken with the dimensions and location of the tanks, accesses and other spaces that may be flooded, because, by regulation, a vertical damage extension of 3 meters in a range of 8 meters, and in addition, all tanks are considered flooded one by one if they are partially or totally below the water line.

For the platform of this document, the compartments were made in reference to existing hulls and following the typical configuration of a semi-submersible platform.

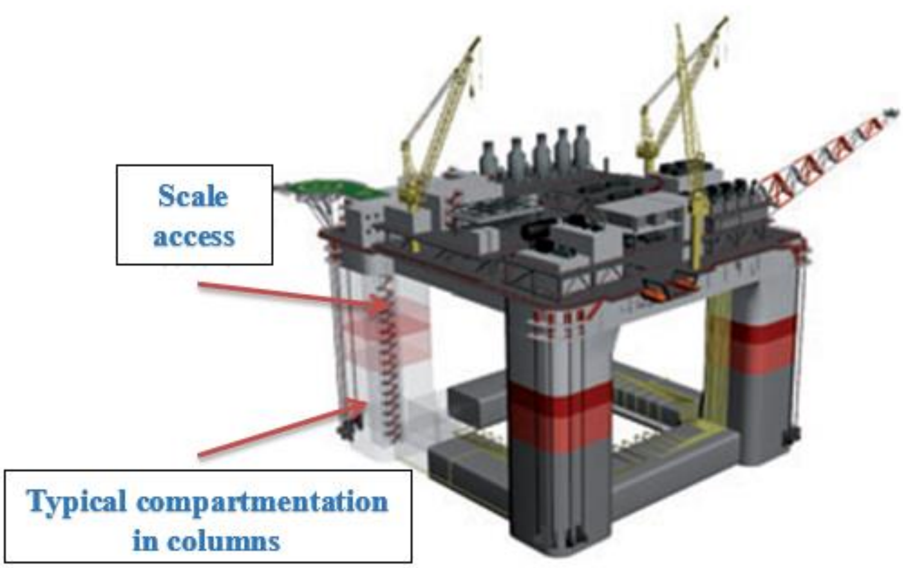

Figure 4.4-1. Typical compartmentation of a semisubmersible platform

The configuration of the tanks on the platform is as shown in Figure 4.4-2, the tanks cover the area of the pontoons and columns.

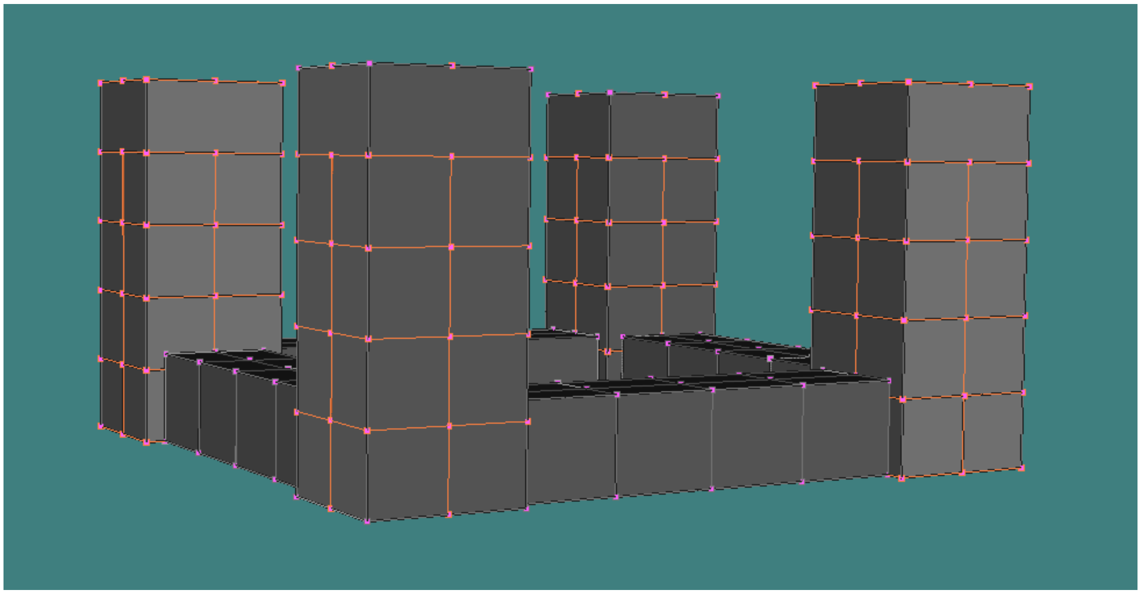

Figure 4.4-2. Tanks' Configuration

Table 4.4-1 specifies the fluids that contain the tanks, as well as their density. The platform has ballast tanks, diesel, fresh water, sea water and insurance, which were used in the program to perform the stability analyzes.

Table 4.4-1. Tanks fluid

Fluid (content) Name	Specific Gravity
SeaWater	1.025
FAW_OIL	0.880
FAD_OIL	0.870
Diesel	0.850
Methanol	0.790
FreshWater	1.000
NoContent	0.000

Table 4.4-2 shows the characteristics of the tanks, as well as their content and density of the fluid that contains.

Table 4.4-2. Tanks Characteristics

Tank Category	Tank Name	Fluid Volume m^3	Fluid Name	SG	Fluid Capacity kg	Fluid Capacity mT	Center of Gravity X m	Y m	Z m		Physical Dimensions Length /X/ m	Width /Y/ m	Height /Z/ m
Pontoon Ballast	NPW_B	717	SeaWater	1.025	7.35E+05	734.9	-15.6	29	5.8		15.6	4.49	10.54
	NPM_B	717	SeaWater	1.025	7.35E+05	734.9	0	29	5.8		15.6	4.49	10.54
	NPE_B	717	SeaWater	1.025	7.35E+05	734.9	15.6	29	5.8		15.6	4.49	10.54
	EPS_B	717	SeaWater	1.025	7.35E+05	734.9	29	-15.6	5.8		4.49	15.6	10.54
	EPM_B	717	SeaWater	1.025	7.35E+05	734.9	29	0	5.8		4.49	15.6	10.54
	EPN_B	717	SeaWater	1.025	7.35E+05	734.9	29	15.6	5.8		4.49	15.6	10.54
	SPW_B	717	SeaWater	1.025	7.35E+05	734.9	-15.6	-29	5.8		15.6	4.49	10.54
	SPM_B	717	SeaWater	1.025	7.35E+05	734.9	0	-29	5.8		15.6	4.49	10.54
	SPE_B	717	SeaWater	1.025	7.35E+05	734.9	15.6	-29	5.8		15.6	4.49	10.54
	WPS_B	717	SeaWater	1.025	7.35E+05	734.9	-29	-15.6	5.8		4.49	15.6	10.54
	WPM_B	717	SeaWater	1.025	7.35E+05	734.9	-29	0	5.8		4.49	15.6	10.54
	WPN_B	717	SeaWater	1.025	7.35E+05	734.9	-29	15.6	5.8		4.49	15.6	10.54
Column Ballast	NE0_BNE	1461.5	SeaWater	1.025	1.50E+06	1498	34.7	34.7	4.8		11.17	11.17	10.54
	SW0_BSW	1461.5	SeaWater	1.025	1.50E+06	1498	-34.7	-34.7	4.8		11.17	11.17	10.54
	NE1_BNE	724	SeaWater	1.025	7.42E+05	742.1	36.8	36.8	16.54		7.9	7.9	12
	NE1_BNW	724	SeaWater	1.025	7.42E+05	742.1	27.3	36.8	16.54		7.9	7.9	12
	SE1_BNE	724	SeaWater	1.025	7.42E+05	742.1	36.8	-27.3	16.54		7.9	7.9	12
	SE1_BSE	724	SeaWater	1.025	7.42E+05	742.1	36.8	-36.8	16.54		7.9	7.9	12
	SE1_BSW	724	SeaWater	1.025	7.42E+05	742.1	27.3	-36.8	16.54		7.9	7.9	12
	SE1_BNW	724	SeaWater	1.025	7.42E+05	742.1	27.3	-27.3	16.54		7.9	7.9	12
	SW1_BNE	724	SeaWater	1.025	7.42E+05	742.1	-27.3	-27.3	16.54		7.9	7.9	12
	SW1_BSE	724	SeaWater	1.025	7.42E+05	742.1	-27.3	-36.8	16.54		7.9	7.9	12
	SW1_BSW	724	SeaWater	1.025	7.42E+05	742.1	-36.8	-36.8	16.54		7.9	7.9	12
	SW1_BNW	724	SeaWater	1.025	7.42E+05	742.1	-36.8	-27.3	16.54		7.9	7.9	12
	NW1_BNE	724	SeaWater	1.025	7.42E+05	742.1	-27.3	36.8	16.54		7.9	7.9	12
	NW1_BSE	724	SeaWater	1.025	7.42E+05	742.1	-27.3	27.3	16.54		7.9	7.9	12
	NW1_BSW	724	SeaWater	1.025	7.42E+05	742.1	-36.8	27.3	16.54		7.9	7.9	12
	NW1_BNW	724	SeaWater	1.025	7.42E+05	742.1	-36.8	36.8	16.54		7.9	7.9	12
	NE2_BNE	640	SeaWater	1.025	6.56E+05	656	36.8	36.8	27.84		7.9	7.9	10.6
	SE2_BSE	640	SeaWater	1.025	6.56E+05	656	36.8	-36.8	27.84		7.9	7.9	10.6
Flow Assurance	NPW_FAW	690	FAW_OIL	0.88	6.07E+05	607.2	-15.6	31.7	5.3		15.6	8.06	5.58
	NPM_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	0	31.7	5.3		15.6	8.06	5.58
	NPE_FAW	690	FAW_OIL	0.88	6.07E+05	607.2	15.6	31.7	5.3		15.6	8.06	5.58
	EPS_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	31.7	-15.6	5.3		8.06	15.6	5.58
	EPM_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	31.7	0	5.3		8.06	15.6	5.58
	EPN_FAW	690	FAW_OIL	0.88	6.07E+05	607.2	31.7	15.6	5.3		8.06	15.6	5.58
	SPW_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	-15.6	-31.7	5.3		15.6	8.06	5.58
	SPM_FAW	690	FAW_OIL	0.88	6.07E+05	607.2	0	-31.7	5.3		15.6	8.06	5.58
	SPE_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	15.6	-31.7	5.3		15.6	8.06	5.58
	WPS_FAD	690	FAD_OIL	0.87	6.00E+05	600.3	-31.7	-15.6	5.3		8.06	15.6	5.58
	WPM_FAS	690	FAD_OIL	0.87	6.00E+05	600.3	-31.7	0	5.3		8.06	15.6	5.58
	WPN_FAW	690	FAW_OIL	0.88	6.07E+05	607.2	-31.7	15.6	5.3		8.06	15.6	5.58
Diesel	SE2_DSW	640	Diesel	0.85	5.44E+05	544	27.3	-36.8	27.84		7.9	7.9	10.6
Methanol	NE1_MSE	724	Methanol	0.79	5.72E+05	572	36.8	27.3	16.54		7.9	7.9	12
	NE1_MSW	724	Methanol	0.79	5.72E+05	572	27.3	27.3	16.54		7.9	7.9	12
Potable Water	**SE2_PNE**	213	FreshWater	1	2.13E+05	213	33.9	-26.3	27.84		3.4	5.2	10.6

Tanks listed below are NOT Fluid tanks. Their structural and equipment weights are included in the lightship weight. If they will be damaged, they will be filled with seawater													
Equipment Spaces	NE0_ESW	1180	NoContent	1.025	1.21E+06	1209.5	29	29	5.3		11.17	11.17	10.54
	NE3_E	2515	NoContent	1.025	2.58E+06	2577.9	32	32	38.25		17.2	17.2	10.22
	SE0_ENW	1180	NoContent	1.025	1.21E+06	1209.5	29	-29	5.3		11.17	11.17	10.54
	SE0_ESE	1267.6	NoContent	1.025	1.30E+06	1299.3	34.7	-34.7	4.8		11.17	11.17	10.54
	SE2_ENW	572	NoContent	1.025	5.86E+05	586.3	27.3	-27.3	27.84		7.9	7.9	10.6
	SE3_E	2515	NoContent	1.025	2.58E+06	2577.9	32	-32	38.25		17.2	17.2	10.22
	SW0_ENE	1180	NoContent	1.025	1.21E+06	1209.5	-29	-29	5.3		11.17	11.17	10.54
	SW3_E	2515	NoContent	1.025	2.58E+06	2577.9	-32	-32	38.25		17.2	17.2	10.22
	NW0_ENW	1267.6	NoContent	1.025	1.30E+06	1299.3	-34.7	34.7	4.8		11.17	11.17	10.54
	NW0_ESE	1180	NoContent	1.025	1.21E+06	1209.5	-29	29	5.3		11.17	11.17	10.54
	NW2_ESE	572	NoContent	1.025	5.86E+05	586.3	-27.3	27.3	27.84		7.9	7.9	10.6
	NW3_E	2515	NoContent	1.025	2.58E+06	2577.9	-32	32	38.25		17.2	17.2	10.22
Access Spaces	NP_A	1618	NoContent	1.025	1.66E+06	1658.5	0	36.1	4.6		46.8	3.65	10.54
	EP_A	1618	NoContent	1.025	1.66E+06	1658.5	36.1	0	4.6		3.65	46.8	10.54
	SP_A	1618	NoContent	1.025	1.66E+06	1658.5	0	-36.1	4.6		46.8	3.65	10.54
	WP_A	1618	NoContent	1.025	1.66E+06	1658.5	-36.1	0	4.6		3.65	46.8	10.54
	NEA_AC	1065.7	NoContent	1.025	1.09E+06	1092.3	32	32	24.8		6.8	6.8	37.18
	SEA_AC	1065.7	NoContent	1.025	1.09E+06	1092.3	32	-32	24.8		6.8	6.8	37.18
	SWA_AC	1065.7	NoContent	1.025	1.09E+06	1092.3	-32	-32	24.8		6.8	6.8	37.18
	NWA_AC	1065.7	NoContent	1.025	1.09E+06	1092.3	-32	32	24.8		6.8	6.8	37.18
Void Spaces	NE2_VNW	640	NoContent	1.025	6.56E+05	656	27.3	36.8	27.84		7.9	7.9	10.6
	NE2_VSE	640	NoContent	1.025	6.56E+05	656	36.8	27.3	27.84		7.9	7.9	10.6
	NE2_VSW	640	NoContent	1.025	6.56E+05	656	27.3	27.3	27.84		7.9	7.9	10.6
	SE2_VNE	640	NoContent	1.025	6.56E+05	656	38.1	-27.8	27.84		5.2	8.6	10.6
	SW2_VNE	640	NoContent	1.025	6.56E+05	656	-27.3	-27.3	27.84		7.9	7.9	10.6
	SW2_VSE	640	NoContent	1.025	6.56E+05	656	-27.3	-36.8	27.84		7.9	7.9	10.6
	SW2_VSW	640	NoContent	1.025	6.56E+05	656	-36.8	-36.8	27.84		7.9	7.9	10.6
	SW2_VNW	640	NoContent	1.025	6.56E+05	656	-36.8	-27.3	27.84		7.9	7.9	10.6
	NW2_VNE	640	NoContent	1.025	6.56E+05	656	-27.3	36.8	27.84		7.9	7.9	10.6
	NW2_VSW	640	NoContent	1.025	6.56E+05	656	-36.8	27.3	27.84		7.9	7.9	10.6
	NW2_VNW	640	NoContent	1.025	6.56E+05	656	-36.8	36.8	27.84		7.9	7.9	10.6

Chapter 5. Applicable regulations

For the stability analysis of a semisubmersible platform, we must mainly follow the guidelines of IMO Code for the Construction and Equipment of Mobile Offshore Drilling Units.

IMO is the main organization that regulates the guidelines for semisubmersible platforms, so we must satisfy its rules so that the platform can be operable. In addition, units of this type are commonly classified, so DNV (Det Norske Veritas) is the classification house used in this work, and must comply with the guidelines that this establishes.

The base documents used in the project are the following:

- IMO "Code for the Construction and Equipment of Mobile Offshore Drilling Units"
- DNV-OS-C301 "Stability and Watertight Integrity"
- MSC.267(85) Adoption of the International code on Intact Stability

Chapter 6. Meteorological and Oceanographic conditions

The most important meteorological and oceanic conditions for floating structures are: wind and wave, which contribute to structural damage, operational disturbances or navigation failures.

• In the presence of wind, the topside of a floating structure behaves like a sail. By means of this the wind provides a force to the structure that modifies its original trajectory. Excessive balances are harmful to the internal system of the platform, produce breakages of fittings that are not properly lashed, cause great fatigue to the crew, increases the risk of cargo shifting, limits operations processing equipment and operation of the cranes.

The wind spectrum is used to define the variable wind speeds that cause dynamic loads on the platform. Wind data measured in the field is necessary to develop an appropriate wind spectrum for a specific site. The spectrum thus defined is used to calculate the fluctuating forces of wind.

• The wave or movement of the waves comes from the incidence of wind on the sea. The wind blowing on the surface of the water sinks the mass on which it falls. Since the water is incompressible, this results in other adjacent bodies of water rising above the horizontal. When the gust of wind ceases, the high water tends to fall and the one that sank rises. Both masses of water due to inertia exceed the horizontal and an oscillatory movement is initiated that would be damped if the gusts do not continue.

Waves generated mainly by the wind are an important source of environmental forces acting on offshore platforms. These waves are irregular in shape, can vary in height and length, and can approach a platform from one or more directions simultaneously.

6.1 Generalities and Applications

Extreme environmental considerations are those that produce the extreme response and which have a low probability of being exceeded in the life of the structure.

Environmental phenomena are generally defined by physical variables of a statistical nature. The statistical definition should take into account extreme conditions such as variations in long and short terms. If a reliable database exists, the phenomena can be described by joint probabilities. The environmental data for the design should represent the geographic areas where the structure will be located, or where the operation will take place.

6.2 Wind parameters used for stability verification

The intact and damaged stability requirements including the wind parameters are given by classification houses such as DNV, and based on IMO (IMO, 1989). Next, the requirements related to the design wind parameters are described to preserve their stability and structural integrity for a semi-submersible platform.

The heeling moment curves produced by the wind will be plotted with respect to the wind forces calculated according to the following formula:

$$F = 0.5\ C_s\ C_h\ \rho\ V^2\ A \qquad \textbf{Equation 1}$$

Where:

F = Wind force (Newton)

$\mathbf{C_s}$ = The shape coefficient depending on the shape of the structural member exposed to the wind indicated in Table 8

$\mathbf{C_h}$ = The height coefficient depending on the height above sea level of the structural member exposed to wind indicated in Table 9

$\boldsymbol{\rho}$ = The air mass density (1.222 kg/m^3)

V = The wind velocity (metres per second)

A = Projected area of all exposed surfaces in the upright or heeled condition (m^2)

Wind forces shall be considered from any direction relative to the unit and the value of the wind velocity. In general, a minimum wind velocity of 36 m/s (70 knots) for offshore service shall be used for normal operating and transit conditions and a minimum wind velocity of 51.5 m/s (100 knots) shall be used for the severe storm conditions.

In calculating the wind heeling moments, the lever of the wind overturning force shall be taken vertically from the centre of pressure of all surfaces exposed to the wind to the centre of lateral resistance of the underwater body of the unit. The unit is assumed floating free of mooring restraint.

Table 6.2-1. Values of the coefficient Cs

Shape	C_s
Spherical	0.4
Cylindrical	0.5
Large flat surface (hull, deckhouse, smooth under-deck areas)	1.0
Drilling derrick	1.25
Wires	1.2
Exposed beams and girders under deck	1.3
Small parts	1.4
Isolated shapes (crane, beam, etc.)	1.5
Clustered deckhouses or similar structures	1.1

Table 6.2-2. Values of the coefficient C_h

Height above sea level (metres)	C_h	*Height above sea level (metres)*	C_h
0 – 15.3	1.00	137.0 – 152.5	1.60
15.3 – 30.5	1.10	152.5 – 167.5	1.63
30.5 – 46.0	1.20	167.5 – 183.0	1.67
46.0 – 61.0	1.30	183.0 – 198.0	1.70
61.0 – 76.0	1.37	198.0 – 213.5	1.72
76.0 – 91.5	1.43	213.5 – 228.5	1.75
91.5 – 106.5	1.48	228.5 – 244.0	1.77
106.5 – 122.0	1.52	244.0 – 256.0	1.79
122.0 – 137.0	1.56	Above 256	1.80

6.3 Wave parameters used for stability verification

The first-order wave forces acting on a structure can be calculated by the Morison Equation or by the Diffraction Theory. To know when it is convenient to use one or the other, the relationship between the dimension of the structural element and the wave length can be used in a simplified manner. For the case in which the dimension of the structural element is less than one fifth of the length of the wave, the Morison equation is used, otherwise the wave diffraction theory should be used.

6.3.1 Wave spectrum

For mathematical and application purposes, waves are often analyzed representing with a sinusoidal function, but in reality, the waves are represented by irregular curves, which obey a pattern, but do not have any sinusoidal function. That is usually the superposition of several sinusoidal waves.

To calculate the wave spectrum according to the conditions and parameters such as peak periods, the highest significant wave crest and frequency of wave encounters. Should follow the following equation recommended by the *International Towing Tank Conference* to calculate the wave spectrum for sea areas where there is no data available on the waves:

$$S(\omega_w) = \frac{A}{\omega_w^5} e^{-B/\omega_w^4}$$

Equation 2

Where:

$\boldsymbol{S(\omega_w)}$ the standard wave spectrum;

$\boldsymbol{\omega_w}$ the circular frequency in radians per second;

$\boldsymbol{A} = 173\,(H)_{1/3}^2/T_1^4$;

$\boldsymbol{B} = 691/T_1^4$.

In which $\boldsymbol{(H)_{1/3}}$ is the significant wave height

$\boldsymbol{T_1}$ the significant wave period

This equation is solved in the Maxsurf Motions Advanced software.

6.4 Metocean Parameters

Due to the need to have information on the reference metocean parameters to carry out the hydrodynamic analysis, the data shown in the document *"API 2INT-MET: Interim Guidance on Hurricane Conditions in the Gulf of Mexico"* and *"Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-Working Stress Design"* both of the *"American Petroleum Institute"*.

Where meteocean conditions driven by hurricanes are provided for most areas of the Gulf of Mexico north of 26 ° N, deep water (WO) greater than or equal to 10 m (33 feet) means a low water level (MLLW). The conditions are presented for four approximate regions of different hurricane climatologist, as shown in Figure 10. Regions have been selected based on trends in (1) population size and intensity, (2) regional wind extremes and swell, (3) frequency of loop currents and swirls, and (4) road storms take in the Gulf.

Regions are:

West, between 97.5 ° W and 95 ° W

Central West, between 94 ° W and 90.5 ° W

Central, between 89.5 ° W and 86.5 ° W

East, between 85.5 ° W and 82.5 °W

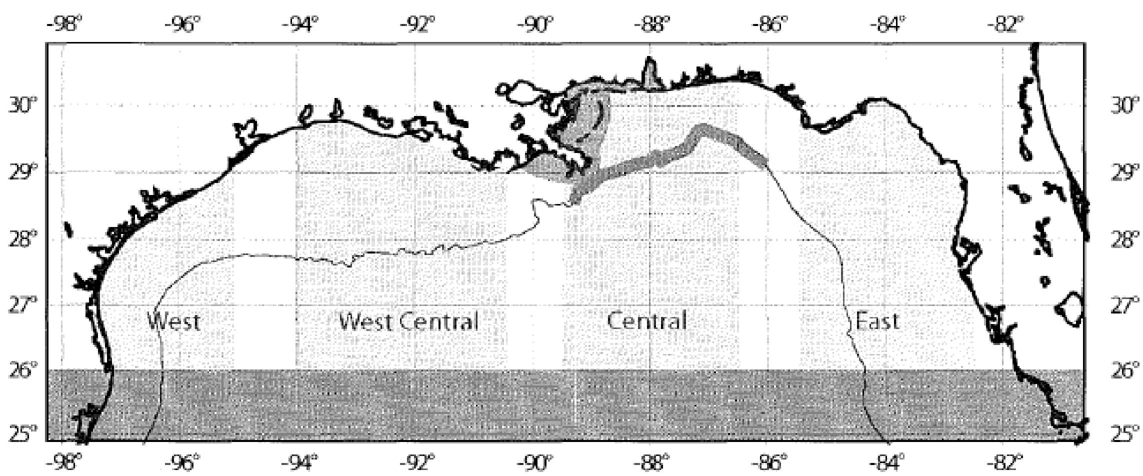

Figure 6.4-1. Gulf regions and areas of application.

The data corresponding to the Central North area of the Gulf of Mexico, "Central" (89.5 ° W and 86.5 ° W), will be used for water depth greater than 100 m.

The metocean data for the Central North Zone of the Gulf of Mexico are shown in Table 6.4-1.

Table 6.4-1. Values of hurricane winds, waves, currents and tides of the Central North of the Gulf of Mexico.

RETURN PERIOD (YEARS)	10	25	50	100	200	1000	2000	10000
WIND (10 M ELEVATION)								
1-HOUR MEAN WIND SPEED (M/S)	33	40.1	44.4	48	51	60	62.4	67.2
10-MIN MEAN WIND SPEED (M/S)	36.5	44.9	50.1	54.5	58.2	69.5	72.5	78.7
1-MIN MEAN WIND SPEED (M/S)	41	51.1	57.4	62.8	67.4	81.6	85.6	93.5
3-SEC GUST (M/S)	46.9	59.2	66.9	73.7	79.4	97.5	102.5	112.8
WAVES, WD > = 1000 M								
SIGNIFICANT WAVE HEIGHT (M)	10	13.3	14.8	15.8	16.5	19.8	20.5	22.1
MAXIMUM WAVE HEIGHT (M)	17.7	23.5	26.1	27.9	29.1	34.9	36.3	39.1
MAXIMUM CREST ELEVATION (M)	11.8	15.7	17.4	18.6	19.4	23	23.8	25.6
PEAK SPECTRAL PERIOD (5)	13	14.4	15	15.4	15.7	17.2	17.5	18.2
PERIOD OF MAXIMUM WAVE (S)	11.7	13	13.5	13.9	14.1	15.5	15.8	16.4
CURRENTS, WD > = 150 M								
SURFACE SPEED (M/S)	1.65	2	2.22	2.4	2.55	3	3.12	3.36
SPEED AT MID-PROFILE (M/S)	1.24	1.5	1.67	1.8	1.91	2.25	2.34	2.52
O-SPEED DEPTH (M)	69.3	84.2	93.2	100.8	107.1	126	131	141.1

Next, the data corresponding to the runs carried out for which the responses to the waves generated by wind currents in the translation movements are analyzed: heave, sway and surge; and in the oscillating movements: roll, pitch and yaw. See Table 6.4-2.

Velocity [kn]	Incidence angle [°]	Wind Velocity [kn]
0	0° a 180°, Δ° = 15°	de 10 a 48, ΔV = 10

Table 6.4-2. Range to aplaied in the hydrodynamic analysis

For the analysis, the Panel Method was used for the analysis of zero velocity. Since the platform is in operation. For the wave spectrum, the Pierson Moskowitz model was used for waves generated by wind.

6.5 Response to meteorological and oceanic conditions

The so-called Response Operator Amplitude (RAOs) or also known as transfer functions describe the response of a component or structure subject to wave amplitude unit, in the frequency domain. Obtaining it allows estimating the response of an element to waves of any height, based on the assumptions of linearity of the structural system and the effects of the waves themselves. It also allows the superposition of effects in the frequency domain, which computationally is a great benefit. To calculate the RAOs, the starting point is to determine the response of the structural system to the waves that represent the energy, in the frequency domain, of a sea state.

The MAXSURF MOTIONS program determines the RAOs for the six degrees of freedom, in the center of gravity of the floating structure. This simulates the movement of the platform over an initial heeling angle (in this project, the initial heeling angle is product of the wind load).

6.5.1 Response Spectrum

The response of a floating structure in an irregular wave meets the same statistical laws of the waves. Wave response records show similar behavior to that same wave record. Therefore, instead of having a graph for the square of each component of the wave amplitude as a function of frequency, we can obtain a graph of the square of the amplitude of any motion that the particular component of wave at an amplitude and Frequency could produce.

The resulting spectrum is known as the response spectrum, which will give us similar statistical properties, when the correct factors are applied, to those obtained in the case of the wave spectrum. It should be noted that the total energy and significant wave height will not change if the analysis is made from a static point of the vessel, that is, at zero speed, as is our case, in other words, the spectrum of encounter of the waves will be the same wave spectrum.

From the above, the response spectrum satisfies the following equation:

$$S_{\emptyset}(\omega_e) = S_{\zeta}(\omega_e) \cdot |H(\omega_e)|^2$$

Equation 3

Where:

$S_{\emptyset}(\omega_e)$ spectrum of response to a specific movement;

$S_{\zeta}(\omega_e)$ wave spectrum;

$H(\omega_e)$ the response amplitude operator, RAO.

Chapter 7. Analysis and Results

7.1 Load condition

To perform the intact stability calculation, the operation condition was taken into account.

1. 100% of the draft whose distribution on deck and filling of tanks are shown in Tables 7.1-1 and 7.1-2.

Table 7.1-1. Weight ratio on deck.

Item	Ton	LCG m	TCG m	VCG m
Lightship	31905.24	-0.97	1.22	33.15
Process Module	5028.580	-1.650	32.440	57.750
Brige	591.490	6.430	-0.370	60.430
Power/quarters	3344.820	-0.070	-36.100	54.170
Mooring Equipment	798.330	0.000	0.000	20.430
East Receiving Module	1746.350	33.950	0.690	53.810
West Receiving Module	2494.780	-34.050	-2.210	55.730

Table 7.1-2. Filling of tanks for condition 1

Tank	%Full	Full ton	Peso ton	LGC m	TCG m	VCG m
C_FS_1_set1	100%	641.158	641.158	36.3	36.3	4.335
C_FS_2_set1	100%	641.159	641.159	36.3	27.7	4.335
C_FS_4_set1	100%	641.159	641.159	27.7	27.7	4.335
C_FS_3_set1	100%	641.159	641.159	27.7	36.3	4.335
C_FS_1_set2	50%	641.158	320.579	36.3	36.3	10.838
C_FS_2_set2	50%	641.159	320.579	36.3	27.7	10.838
C_FS_3_set2	50%	641.159	320.579	27.7	36.3	10.838
C_FS_4_set2	50%	641.159	320.579	27.7	27.7	10.838
C_FS_4_set3	0%	641.159	0	27.7	27.7	17.34
C_FS_1_set3	0%	641.158	0	36.3	36.3	17.34
C_FS_2_set3	0%	641.159	0	36.3	27.7	17.34
C_FS_3_set3	0%	641.159	0	27.7	36.3	17.34
C_FS_1_set4	0%	641.158	0	36.3	36.3	26.01
C_FS_2_set4	0%	656.565	0	36.276	27.7	26.01
C_FS_3_set4	0%	641.159	0	27.7	36.3	26.01
C_FS_4_set4	0%	641.159	0	27.7	27.7	26.01

C_FP_3_set1	100%	641.159	641.159	27.7	-27.7	4.335
C_FP_2_set1	100%	641.158	641.158	36.3	-36.3	4.335
C_FP_4_set1	100%	641.159	641.159	27.7	-36.3	4.335
C_FP_1_set1	100%	641.159	641.159	36.3	-27.7	4.335
C_FP_2_set2	25%	641.158	160.29	36.3	-36.3	9.754
C_FP_4_set2	25%	641.159	160.29	27.7	-36.3	9.754
C_FP_1_set2	25%	641.159	160.29	36.3	-27.7	9.754
C_FP_3_set2	25%	641.159	160.29	27.7	-27.7	9.754
C_FP_2_set3	0%	641.158	0	36.3	-36.3	17.34
C_FP_4_set3	0%	641.159	0	27.7	-36.3	17.34
C_FP_3_set3	0%	641.159	0	27.7	-27.7	17.34
C_FP_1_set3	0%	641.159	0	36.3	-27.7	17.34
C_FP_4_set4	0%	641.159	0	27.7	-36.3	26.01
C_FP_2_set4	0%	641.158	0	36.3	-36.3	26.01
C_FP_3_set4	0%	641.159	0	27.7	-27.7	26.01
C_FP_1_set4	0%	641.159	0	36.3	-27.7	26.01
C_AS_3_set1	100%	641.158	641.158	-36.3	36.3	4.335
C_AS_2_set1	100%	641.159	641.159	-27.7	27.7	4.335
C_AS_1_set1	100%	641.159	641.159	-27.7	36.3	4.335
C_AS_4_set1	100%	641.159	641.159	-36.3	27.7	4.335
C_AS_2_set2	50%	641.159	320.579	-27.7	27.7	10.838
C_AS_3_set2	50%	641.158	320.579	-36.3	36.3	10.838
C_AS_1_set2	50%	641.159	320.579	-27.7	36.3	10.838
C_AS_4_set2	50%	641.159	320.579	-36.3	27.7	10.838
C_AS_2_set3	0%	641.159	0	-27.7	27.7	17.34
C_AS_3_set3	0%	641.158	0	-36.3	36.3	17.34
C_AS_1_set3	0%	641.159	0	-27.7	36.3	17.34
C_AS_4_set3	0%	641.159	0	-36.3	27.7	17.34
C_AS_2_set4	0%	641.159	0	-27.7	27.7	26.01
C_AS_3_set4	0%	641.158	0	-36.3	36.3	26.01
C_AS_1_set4	0%	641.159	0	-27.7	36.3	26.01
C_AS_4_set4	0%	641.159	0	-36.3	27.7	26.01
C_AP_4_set1	100%	641.158	641.158	-36.3	-36.3	4.335
C_AP_3_set1	100%	641.159	641.159	-36.3	-27.7	4.335
C_AP_2_set1	100%	641.159	641.159	-27.7	-36.3	4.335
C_AP_1_set1	100%	641.159	641.159	-27.7	-27.7	4.335
C_AP_4_set2	25%	641.158	160.29	-36.3	-36.3	9.754
C_AP_3_set2	25%	641.159	160.29	-36.3	-27.7	9.754
C_AP_2_set2	25%	641.159	160.29	-27.7	-36.3	9.754
C_AP_1_set2	25%	641.159	160.29	-27.7	-27.7	9.754

C_AP_1_set3	0%	641.159	0	-27.7	-27.7	17.34
C_AP_4_set3	0%	641.158	0	-36.3	-36.3	17.34
C_AP_3_set3	0%	641.159	0	-36.3	-27.7	17.34
C_AP_2_set3	0%	641.159	0	-27.7	-36.3	17.34
C_AP_4_set4	0%	641.158	0	-36.3	-36.3	26.01
C_AP_3_set4	0%	641.159	0	-36.3	-27.7	26.01
C_AP_2_set4	0%	641.159	0	-27.7	-36.3	26.01
C_AP_1_set4	0%	641.159	0	-27.7	-27.7	26.01
P_Fwd_out_set1	100%	481.606	481.606	35.647	17.545	5.27
P_Fwd_in_set1	80%	491.252	393.002	28.201	17.55	4.122
P_Fwd_out_set2	100%	482.018	482.018	35.647	5.85	5.27
P_Fwd_in_set2	100%	492.452	492.452	28.34	5.855	5.27
P_Fwd_out_set3	100%	482.018	482.018	35.647	-5.85	5.27
P_Fwd_out_set4	100%	482.018	482.018	35.647	-17.55	5.27
P_Fwd_in_set4	80%	491.256	393.005	28.201	-17.55	4.122
P_Port_out_set1	100%	481.189	481.189	17.55	-35.648	5.27
P_Port_in_set2	100%	481.017	481.017	5.847	-28.352	5.27
P_Port_in_set1	0%	481.189	0	17.55	-28.9	0
P_Port_out_set2	100%	481.189	481.189	5.85	-35.648	5.27
P_Port_in_set3	100%	478.318	478.318	-5.815	-28.352	5.27
P_Port_out_set3	100%	481.189	481.189	-5.85	-35.648	5.27
P_Port_in_set4	0%	481.189	0	-17.55	-28.9	0
P_Port_out_set4	100%	481.189	481.189	-17.55	-35.648	5.27
P_Aft_in_set1	70%	482.769	337.938	-28.116	-17.55	3.44
P_Aft_out_set1	100%	490.103	490.103	-35.658	-17.545	5.27
P_Aft_in_set2	100%	484.005	484.005	-28.351	-5.855	5.27
P_Aft_out_set2	100%	490.519	490.519	-35.658	-5.85	5.27
P_Aft_out_set3	100%	490.519	490.519	-35.658	5.85	5.27
P_Aft_in_set4	70%	483.179	338.225	-28.116	17.545	3.44
P_Aft_out_se4	100%	490.519	490.519	-35.658	17.55	5.27
P_Stbd_in_set1	0%	481.189	0	-17.55	28.9	0
P_Stbd_out_set1	100%	481.189	481.189	-17.55	35.648	5.27
P_Stbd_out_set2	100%	481.189	481.189	-5.85	35.648	5.27
P_Stbd_in_set2	100%	478.339	478.339	-5.815	28.352	5.27
P_Stbd_out_set3	100%	481.189	481.189	5.85	35.648	5.27
P_Stbd_in_set3	100%	480.996	480.996	5.848	28.352	5.27
P_Stbd_in_set4	0%	481.189	0	17.55	28.9	0
P_Stbd_out_set4	100%	481.189	481.189	17.55	35.648	5.27
P_Fwd_in_set3	100%	764.443	764.443	28.9	-5.85	5.27
P_Aft_in_set3	100%	1026.67	1026.67	-22.555	-4.109	5.27

C_FS_1_set5	0%	522.124	0	36.3	36.3	34.68
C_FS_2_set5	0%	641.158	0	36.3	27.7	34.68
C_FS_3_set5	0%	618.348	0	27.7	36.3	34.68
C_FS_4_set5	0%	613.825	0	27.7	27.7	34.68
C_FP_2_set5	0%	641.158	0	36.3	-36.3	34.68
C_FP_4_set5	0%	618.348	0	27.7	-36.3	34.68
C_FP_1_set5	0%	641.158	0	36.3	-27.7	34.68
C_FP_3_set5	0%	613.825	0	27.7	-27.7	34.68
C_AS_3_set5	0%	622.636	0	-36.494	36.3	34.68
C_AS_1_set5	0%	634.215	0	-27.661	36.3	34.68
C_AS_4_set5	0%	640.074	0	-36.3	27.7	34.68
C_AS_2_set5	0%	611.052	0	-27.7	27.7	34.68
C_AP_4_set5	0%	639.334	0	-36.3	-36.3	34.68
C_AP_3_set5	0%	640.074	0	-36.3	-27.7	34.68
C_AP_2_set5	0%	617.271	0	-27.7	-36.3	34.68
C_AP_1_set5	0%	611.052	0	-27.7	-27.7	34.68

Remaining with 58079 tons of displacement, LCG = 0.001 m forward, TCG = 0.006 m to starboard and VCG = 28.160 m for the condition at 100% of draft.

Once the simulation was performed in the Sorfware Maxsurf Stability Enterprise, the following results shown in Table 7.1-3 were obtained, which will be used to determine if it meets the conditions described in Appendix I.

Table 7.1-3. Results for the analysis for condition 1

Heel to starboard, degrees	**-180**	**-170**	**-160**	**-150**	**-140**
GZ, m	-5.44	-2.512	-1.53	-1.837	-3.027
Area under GZ curve from zero heel m.rad	16.9619	16.2872	15.9609	15.682	15.2654
Displacement t	57391	57393	57392	57390	57391
Draft Amidships m	-58.406	-58.557	-59.317	-59.507	-60.754
WL Length m	77.75	77.75	77.75	81.2	81.2
GMt corrected m	18.902	4.922	-0.027	-5.115	-7.676
Lat.proj. Windage area m^2	2929.801	4271.969	4946.111	4996.551	4985.251
Lat.proj. Windage VCA (world) m	-28.674	-24.833	-21.948	-17.74	-12.322
Lat.proj. Underwater area m^2	1219.491	1244.84	1444.405	1891.861	2221.627
Lat.proj. Underwater VCA (world) m	-66.507	-66.049	-65.455	-63.697	-60.524
Continuation					
Heel to starboard, degrees	**-130**	**-120**	**-110**	**-100**	**-90**
GZ, m	-4.139	-4.005	-2.904	-2.729	-5.478

Area under GZ curve from zero heel m.rad	14.6288	13.8979	13.2908	12.834	12.1495
Displacement t	57394	57394	57393	57393	57397
Draft Amidships m	-63.746	-71.357	-93.054	-155.986	n/a
WL Length m	81.2	81.2	81.2	81.2	81.2
GMt corrected m	-3.935	7.792	3.426	-1.813	-20.929
Lat.proj. Windage area m^2	5211.943	5409.266	5576.661	5335.46	4901.755
Lat.proj. Windage VCA (world) m	-6.747	-1.509	2.522	5.778	10.417
Lat.proj. Underwater area m^2	2415.586	2413.266	2134.104	1796.524	1691.685
Lat.proj. Underwater VCA (world) m	-56.017	-50.617	-44.993	-38.152	-30.183
Continuation					
Heel to starboard, degrees	**-80**	**-70**	**-60**	**-50**	**-40**
GZ, m	-9.002	-12.082	-14.293	-15.228	-11.445
Area under GZ curve from zero heel m.rad	10.8843	9.0335	6.7203	4.1084	1.6758
Displacement t	57394	57388	57393	57393	57392
Draft Amidships m	-65.122	-7.332	12.96	23.759	29.351
WL Length m	81.2	81.2	81.2	81.2	81.2
GMt corrected m	-19.2	-15.803	-9.257	-0.682	55.635
Lat.proj. Windage area m^2	4914.192	4911.541	4750.637	4459.879	4271.97
Lat.proj. Windage VCA (world) m	18.953	27.745	35.758	42.791	48.911
Lat.proj. Underwater area m^2	2217.793	2788.726	3038.348	3124.845	3031.877
Lat.proj. Underwater VCA (world) m	-24.99	-19.698	-13.762	-7.53	-1.974
Continuation					
Heel to starboard, degrees	**-30**	**-20**	**-10**	**0**	**10**
GZ, m	-2.628	-1.388	-0.494	-0.006	0.481
Area under GZ curve from zero heel m.rad	0.4812	0.2118	0.0328	-0.0002	0.0307
Displacement t	57395	57393	57393	57393	57393
Draft Amidships m	29.487	28.137	28.204	28.204	28.204
WL Length m	81.2	81.2	81.2	81.2	81.2
GMt corrected m	27.15	9.214	3.428	2.48	3.43
Lat.proj. Windage area m^2	4258.18	4038.77	3533.695	2685.796	3212.139
Lat.proj. Windage VCA (world) m	51.958	53.85	54.986	55.415	52.971
Lat.proj. Underwater area m^2	2885.528	2758.534	2304.669	1463.497	2304.669
Lat.proj. Underwater VCA (world) m	2.527	5.978	7.879	11.125	7.879
Continuation					
Heel to starboard, degrees	**20**	**30**	**40**	**50**	**60**
GZ, m	1.36	2.546	11.391	15.205	14.2
Area under GZ curve from zero heel m.rad	0.2068	0.4663	1.6478	4.0757	6.6751
Displacement t	57393	57393	57394	57395	57394
Draft Amidships m	28.156	29.556	29.398	23.854	13.259

WL Length m	81.2	81.2	81.2	81.2	81.2
GMt corrected m	8.446	27.248	55.974	-0.869	-9
Lat.proj. Windage area m^2	3630.47	3998.055	4172.07	4497.736	4772.033
Lat.proj. Windage VCA (world) m	51.39	50.457	48.372	43.118	36.054
Lat.proj. Underwater area m^2	2760.046	2890.357	3034.808	3129.794	3050.5
Lat.proj. Underwater VCA (world) m	5.989	2.565	-1.95	-7.494	-13.681
Continuation					
Heel to starboard, degrees	**70**	**80**	**90**	**100**	**110**
GZ, m	12.436	10.176	7.364	7.979	10.036
Area under GZ curve from zero heel m.rad	9.0006	10.9908	12.498	13.7891	15.3652
Displacement t	57391	57393	57394	57393	57394
Draft Amidships m	-9.035	-76.289	n/a	-172.371	-103.702
WL Length m	81.2	81.2	81.2	81.2	81.2
GMt corrected m	-10.661	-14.864	-17.061	9.791	14.6
Lat.proj. Windage area m^2	4969.323	5071.651	5164.538	5566.496	5872.363
Lat.proj. Windage VCA (world) m	27.52	17.983	8.799	4.354	0.7
Lat.proj. Underwater area m^2	2741.443	2060.334	1428.901	1565.489	1827.903
Lat.proj. Underwater VCA (world) m	-19.989	-25.961	-31.801	-39.575	-46.748
Continuation					
Heel to starboard, degrees	**120**	**130**	**140**	**150**	**160**
GZ, m	10.447	7.823	3.695	-1.197	-5.793
Area under GZ curve from zero heel m.rad	17.1935	18.8231	19.8428	20.0654	19.4429
Displacement t	57393	57397	57394	57394	57394
Draft Amidships m	-81.79	-72.427	-66.988	-63.237	-60.562
WL Length m	81.2	81.2	81.2	81.2	77.75
GMt corrected m	-9.964	-19.615	-26.499	-29.636	-21.322
Lat.proj. Windage area m^2	5832.863	5665.046	5372.993	5258.852	5037.03
Lat.proj. Windage VCA (world) m	-4.18	-9.708	-14.964	-19.506	-22.569
Lat.proj. Underwater area m^2	1956.122	1919.678	1930.854	1884.856	1760.274
Lat.proj. Underwater VCA (world) m	-53.001	-58.507	-63.473	-66.826	-68.342
Continuation					
Heel to starboard, degrees	**170**	**180**			
GZ, m	-8.173	-5.44			
Area under GZ curve from zero heel m.rad	18.1611	16.9204			
Displacement t	57392	57393			
Draft Amidships m	-58.557	-58.406			
WL Length m	77.75	77.75			
GMt corrected m	-1.217	18.9			
Lat.proj. Windage area m^2	4271.945	2929.779			
Lat.proj. Windage VCA (world) m	-24.833	-28.674			

Lat.proj. Underwater area m^2	1566.42	1219.513			
Lat.proj. Underwater VCA (world) m	-67.911	-66.507			

7.2 Calculation of stability Heeling Arm by wind in the condition.

For this calculation we will need to determine the force of the wind, which equation is described in section 6.2, and the heeling arm by means of the formula described in the book Principles of Naval Architecture, VOL I.

According to the formula of the book Principles of Naval Architecture, VOL I, the heeling arm for wind, H.A. it is determined with the following expression:

$$H.A. = 0.0195V^2 Alcos^2\theta/1000\Delta$$ **Equation 4**

Where:

0.0195 V^2 A = F

ℓ = the vertical distance from the center of the projected area submerged to the center of the projected area exposed to the wind.

Δ = Displacement of the vessel.

Therefore, $H.A. = Flcos^2\theta/1000\Delta$.

Once the pertinent operations have been carried out, the data obtained from wind heeling arms are shown in the Table 7.2-1.

Table 3.2-1. Wind heeling arms for condition 1.

Ángulo, °	HA, m	Ángulo, °	HA, m	Ángulo, °	HA, m	Ángulo, °	HA, m
-180	0	**-90**	0.211	**0**	9.974	**90**	0
-170	0	**-80**	1.156	**10**	8.503	**100**	0
-160	0	**-70**	2.726	**20**	6.587	**110**	0
-150	0	**-60**	4.694	**30**	4.506	**120**	0
-140	0	**-50**	6.772	**40**	2.563	**130**	0
-130	0	**-40**	8.503	**50**	1.041	**140**	0
-120	0	**-30**	10.078	**60**	0.161	**150**	0
-110	0	**-20**	10.824	**70**	0	**160**	0
-100	0	**-10**	10.787	**80**	0	**170**	0

7.3 Result of the analysis of Intact Stability

After doing the analysis, the following results were obtained, which are shown in Table 7.3-1 with heeling ranging from -180 ° to 180 ° in steps of 10 °.

Table 7.3-1. Results of the criteria

Code	Criteria	Value	Units	Actual	Status
2.2 Pontoons	2.2.4.1 GZ area: to Max GZ	0.0800	m.rad	4.3172	Pass
2.2 Pontoons	2.2.4.2 Angle of equilibrium ratio	50.00	%	24.09	Pass
2.2 Pontoons	2.2.4.3 Angle of vanishing stability <=100m in length	130.0	deg	147.6	Pass
2.6 MODUs	2.6.3.1.2 Ratio of areas type 3	130.000	%	5256.890	Pass
2.6 MODUs	2.6.3.1.3 Range of positive stability	96.0	deg	112.6	Pass

Being the stability curve GZ generated by the data of the model and the heeling moment curve by wind the shown in the Figure 7.3-1.

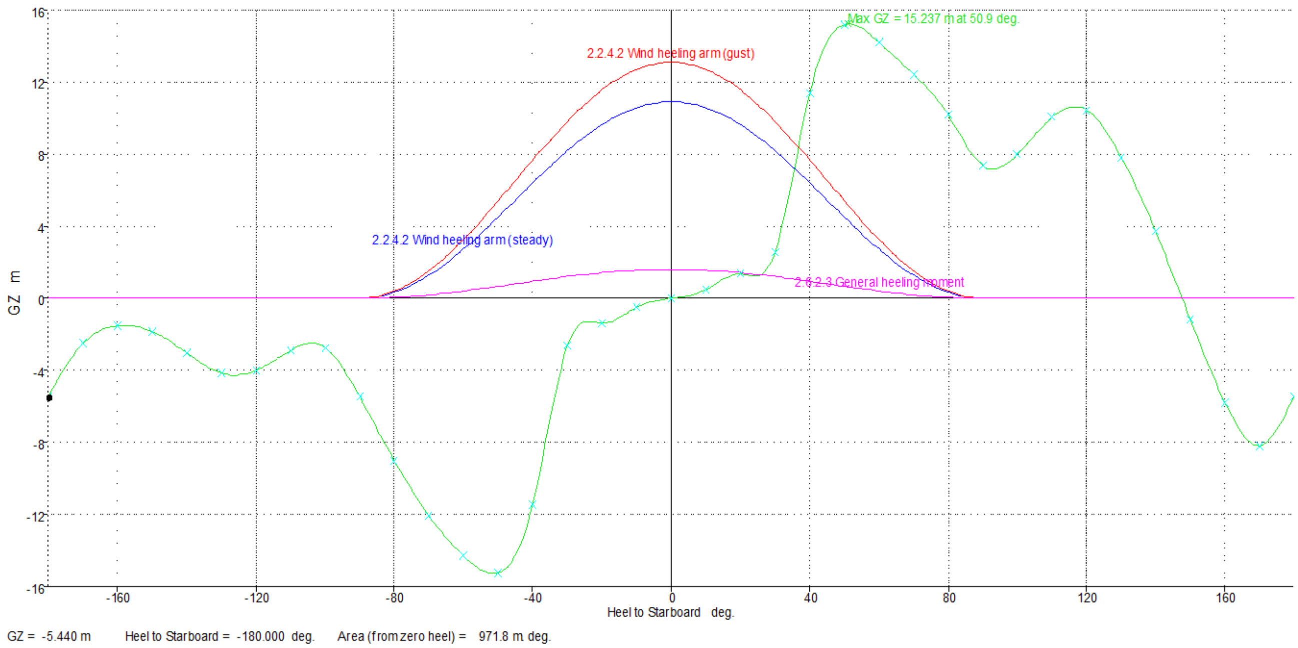

Figure 7.3-1. Righting arm and heeling arm curves for condition 1.

7.4 Result of the analysis of Damage Stability

For the analysis of condition 1 of damage stability, two tanks in port were damaged, P_Port_out_set2 and P_Port_out _set3, which are shown in figure 7.4-1.

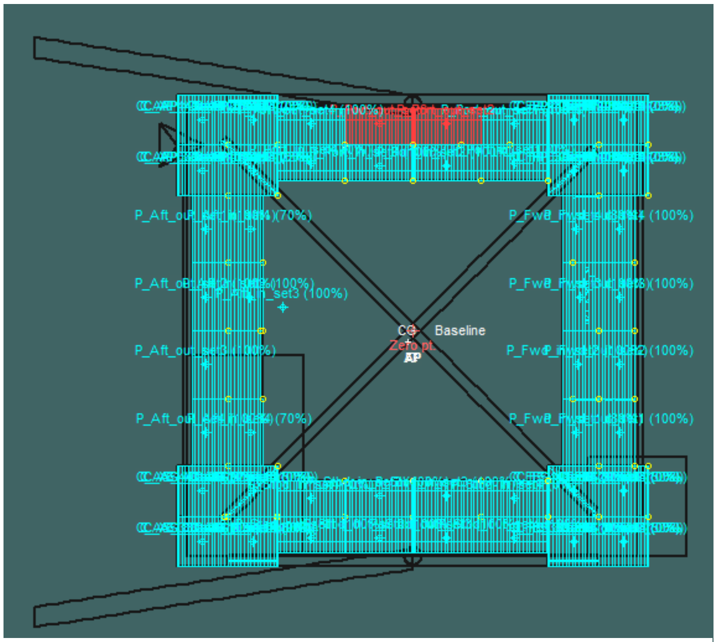

Figure 7.4-1. Damage tanks in port

Once the simulation has been performed in the Maxsurf Stability Software, the results obtained are shown in the following Table 7.4-1.

Table 7.4-1, Result of the criteria for Semi-submersible damage.

CRITERIA	VALUE	UNIT
-Initial Draft	28.8	m
-KG	29.505	m
-Projected area on the water line	2681.91	m^2
-Displacement	55758	ton
-First Intercession	10.664	grados
-Initial inclination angle	9.625	grados
-Minimum required angle (PASS)	17	grados
-Second intersection	148.33	grados
-Main range righting moment about heeling moment	137.666	grados
-Minimum required range (PASS)	7	grados
-Relative magnitude righting moment for heeling moment	8.284	
-Minimum Required (PASS)	2	

The stability curve generated with condition 1 and the damaged tanks on port is the one shown in Figure 7.4-2.

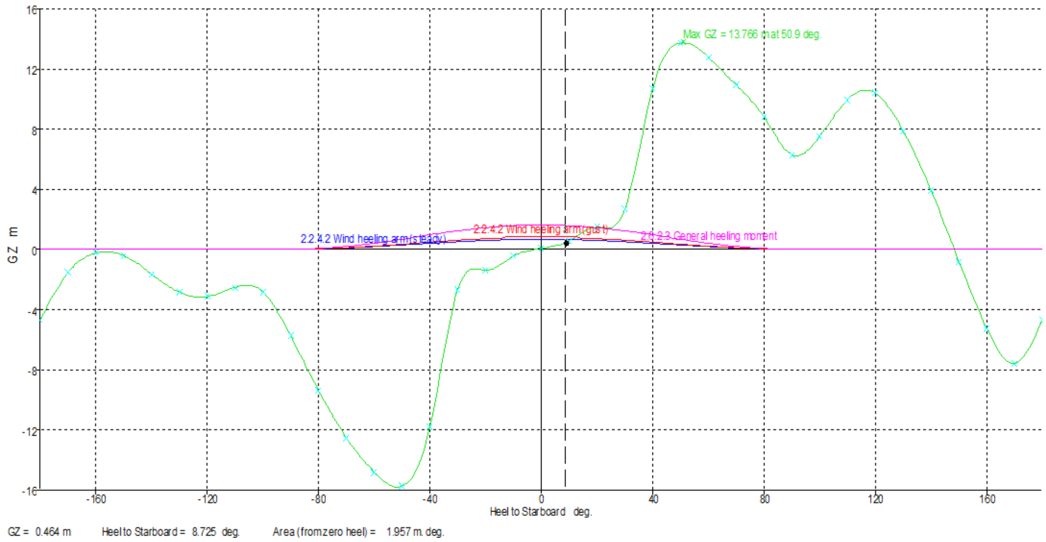

Figure 7.4-24. Stability and Wind curve for damage.

7.5 Results of Hydrodynamic Analysis

The Maxsurf Motion module is a program for diffraction analysis based on linear potential theory or Airy theory. The code is able to solve the problem of diffraction - radiation in the first and second order range. The forces associated with the solution of the equations up to first order, are those that regularly represent the forces of greater magnitudes, while the solution until second order allows to calculate the drift forces, which are relatively of smaller magnitude.

According to this theory the waves have the shape of a sinusoidal curve described in 2 dimensions (horizontal axis x and vertical axis z) that propagates in a constant x direction. This theory considers that the wave height is small compared to the wave length and the water depth.

7.5.1 Wave spectrum, RAO and CG response spectrum

For this section the response on the Centre of Gravity is show, which is a critical point on the platform. The coordinates of the centre of gravity of the semi-submersible are: VCGr = 28.828 m, TCGr = 0.06 m and LCGr = 0.01m.

The standard wave spectrum of Pierson Moskowitz generated by winds of 10 kn, 30 kn and 48 kn, are shown in Figures 7.5.1-1, 7.5.1-2 and 7.5.1-3, respectively.

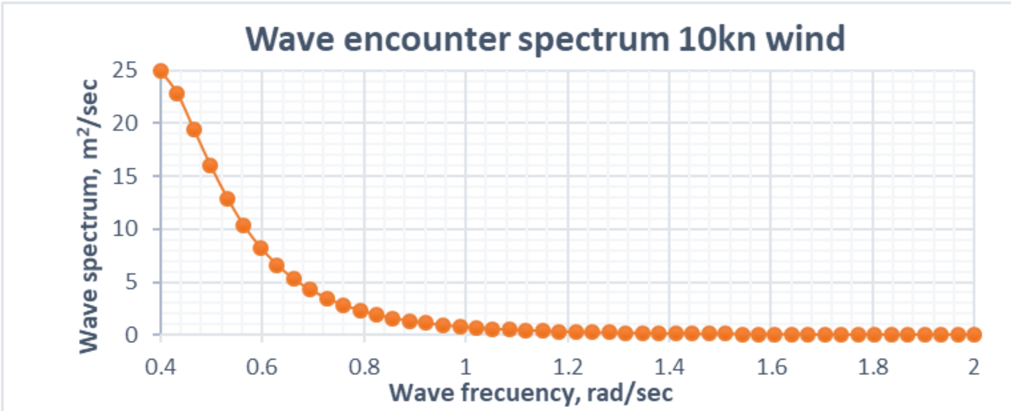

Figure 7.5.1-1. Wave spectrum at 10kn wind

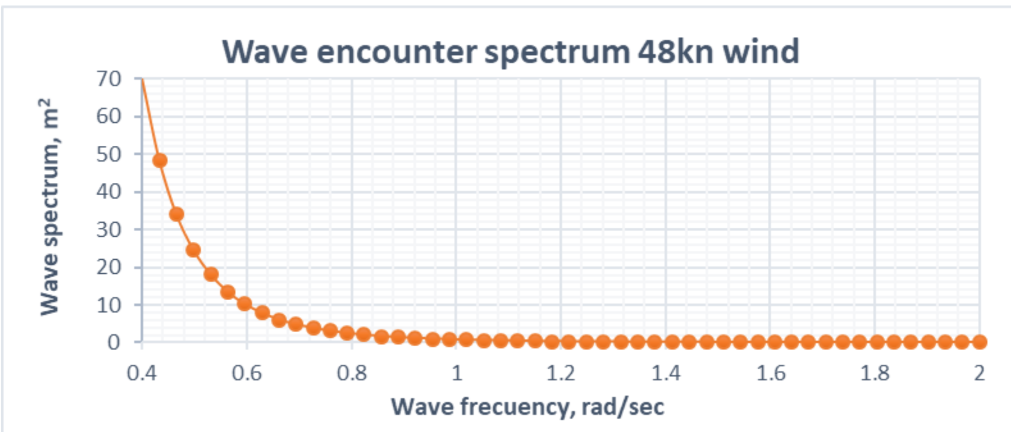

Figure 7.5.1-2. Wave spectrum at 48kn wind

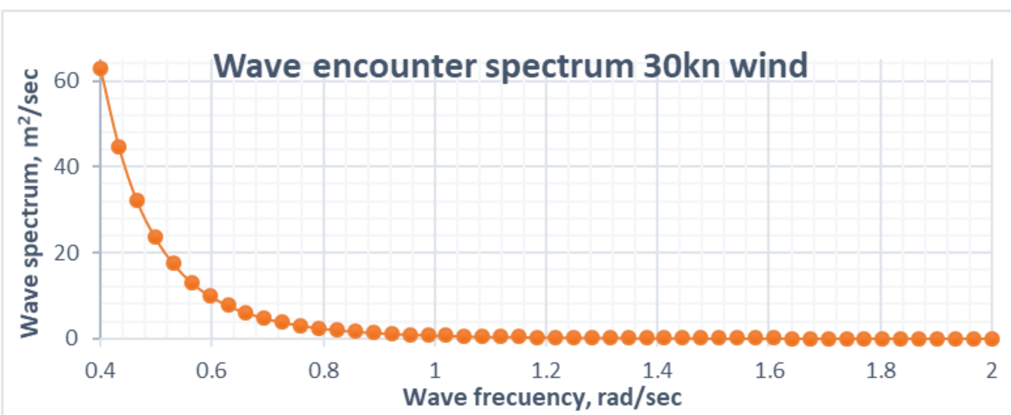

Figure 7.5.1-3. Wave spectrum at 30kn wind

7.5.2 Natural Periods

In order to avoid resonance effects leading to large amplitude motions, the platforms are designed to obtain their natural periods of motion far from the characteristic wave frequencies present at the site of operation. Generally, semi-submersible platforms have natural motion periods in Surge, Sway and Yaw longer than 100 s, greater than 20 s in the degrees of freedom of Heave, Roll and Pitch for the semi-submersible platform, according with Faltisen (1990).

In Figure 7.5.2-1, 7.5.2-2 and 7.5.2-3 are shown the RAOs for heave, roll and pitch movements generated at the center of gravity of the Semi-submersible.

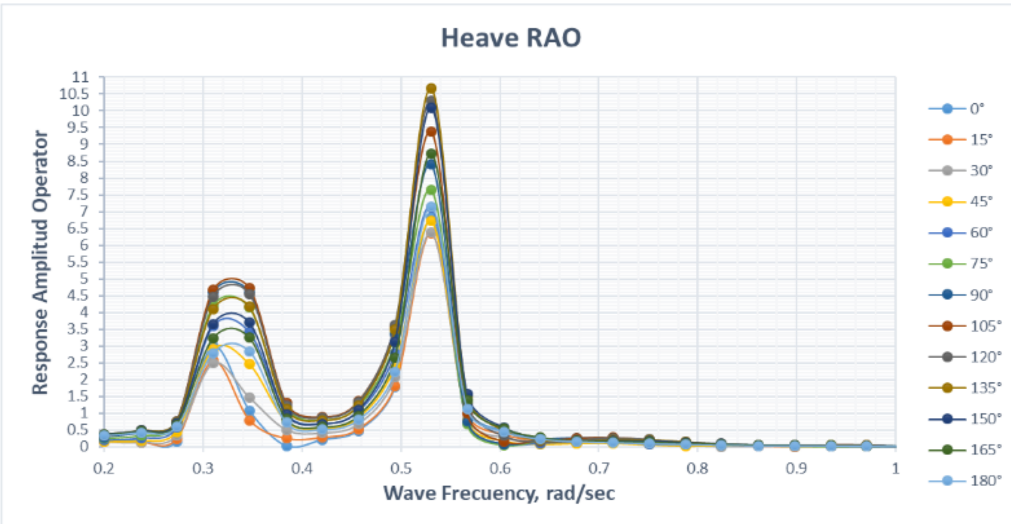

Figure 7.5.2-16. Heave RAO's in CG in different wave incidence angles.

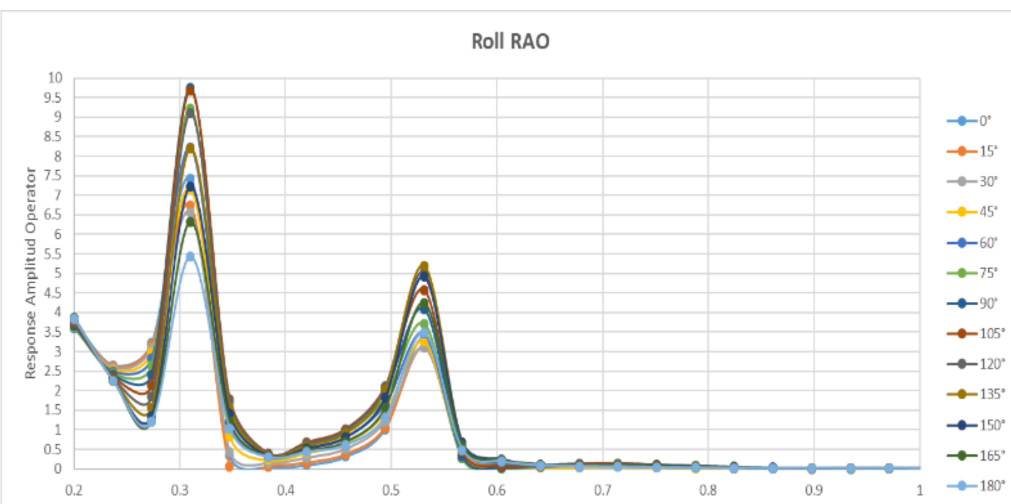

Figure 7.5.2-2. Roll RAO's in CG in different wave incidence angles.

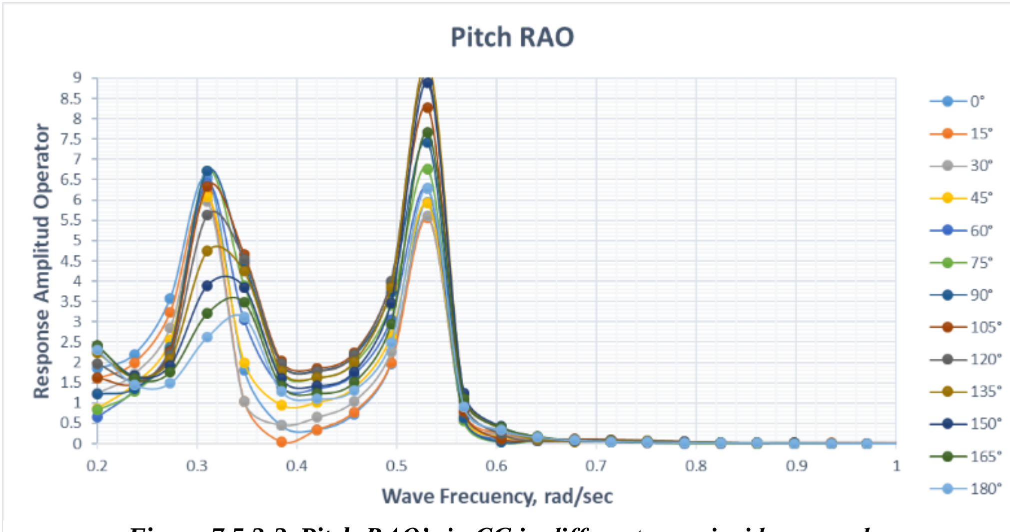

Figure 7.5.2-3. Pitch RAO's in CG in different wave incidence angles.

Table 7.5.2-1 shows the results of the natural periods with respect to those recommended to avoid resonance to Semi- Submersible.

Concept	Required	Calculated
Natural Period of Heave	>20 s	21.18s
Natural Period of Roll	>20s	26.76s
Natural Period of Pitch	>20s	25.75s

Table 7.5.2-1. Natural Periods

Chapter 8. Conclusions and future works

In summary, it is important to highlight that the wind and the sea are the main modifying causes of the equilibrium position of a floating structure.

According to the data obtained in the stability analysis it was obtained that the semi-submersible platform are GM = 2.475 m and GZ = 50.9 deg, which satisfy the criteria established by the IMO and the class clasification, in this case DNVGL, as shown in tables 17 and 18.

The hydrodynamic part should be noted that the semi-submersible platform has favorable natural periods, meets with the established requirements to avoid coming into resonance with the wave period of said site, according with Faltisen (1990).

This kind of platforms have not been installed yet in the Region of Mexico for deep waters, so this work shows that the semi-submersible platform of this work has a highest performance in deep waters of the Region of Mexico which has better behavior in both stability approach as hydrodynamic for the environmental conditions in that region.

8.1 Recommendations for future works

Future works could be focused in carry out a coupled analyzes of the platform in which the mooring system is included to obtain more accurate results, as well, performing an analysis with irregular waves, since it is well known that the waves in the ocean are irregular, they can vary in height and length, and can approach a platform from one or several directions simultaneously, for which it would be necessary to have access to a database with the meteorological and environmental conditions of a return period of at least 100 years.

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Appendix I

Intact Stability Criteria

The area under the righting moment curve to the second intercept or downflooding angle, whichever is less, shall be not less than 30% in excess of the area under the wind heeling moment curve to the same limiting angle. As shown in Figure 20.

The righting moment curve shall be positive over the entire range of angles from upright to the second intercept.

During severe weather conditions, the metacentric height, GM_0 shall not be less than 0.3 m.

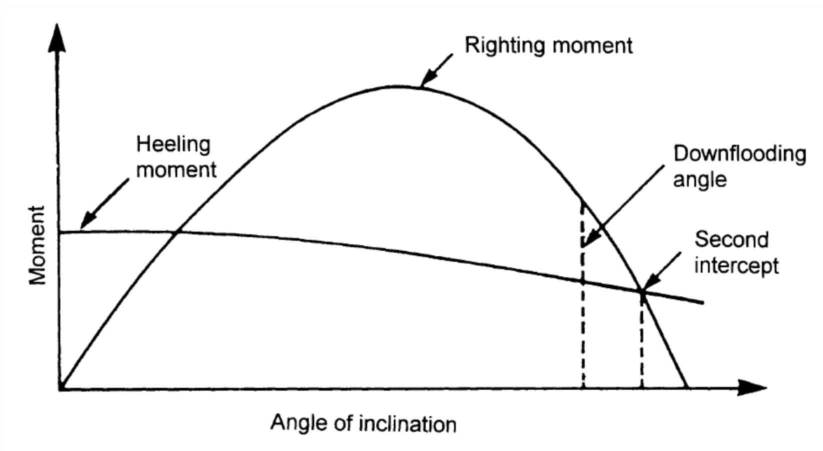

Figure I-1. Helling moment and righting momento curves

Damage Stability Criteria

The calculation of damage stability, as its concept rightly says, is the ability of a vessel to stay afloat after damaged to its structural integrity for example collision, damage caused internally or due to weather phenomena. Such damages cause the leak of the liquid stored inside the damaged tank or the water flooding the tanks, which ends in the loss of buoyancy and / or stability.

The unit shall have sufficient freeboard and be subdivided by means of watertight decks and bulkheads to provide sufficient buoyancy and stability to withstand a wind heeling moment induced by a wind velocity of 25.8 m/s (50 knots) superimposed from any direction in any operating or transit condition, taking the following considerations in table 19 into account.

Table I-1. Damage stability requirements for semi-submersible units.

Requirements	**IMO/DNVGL**
For waterline damage:	
-Static heel	-
-Steady heel	≤17°
-Opening within 4 m above final waterline to be weathertight	Yes
-Range of positive stability, to lesser of the upper extent of weathertight integrity or second intercept, to be at least	7°
Extent of weathertight integrity:	
-Within above range, righting moment at least twice of windheeling moment, at same angle	Yes
-Area ratio ≥1.0	-

Appendix II

Conference Paper

A Holistic Examination of the Survivability of Offshore Platforms for the Gulf of Mexico Region

María Alejandra Rodríguez-Cruz[1], Adrian Isidro Colorado-Moreno[1], Santiago Suárez-de la Fuente[2], José Hernández-Hernández[1]*

[1] Maestría en Ingeniería Aplicada, Facultad de Ingeniería de la Construcción y el Habitat, Universidad Veracruzana (UV)
Boca del Río, Veracruz-Llave, Mexico
[2] University College London, (UCL)
London, England

ABSTRACT

Periods of growth in the offshore industry have involved considerable interest in and investigation of the survivability of offshore structures against various hazards. The potential for changes in the frequency and intensity of severe weather events due to climate change, and increasing public awareness of environmental damage from accidents only increases this concern. These exogenous and industry-driven changes and areas of uncertainty point towards a need for a holistic assessment of the survivability of future ocean platforms. This paper presents a comparative analytical study of different types of offshore structures used as production platforms in the Gulf of Mexico including a semi-submersible platform and a Floating Production, Storage and Offloading (FPSO). The holistic evaluation of platform describe in this paper involves two numerical analyses. The first focuses upon the stability and the second examine the hydrodynamic performance.

KEY WORDS: Stability; Hydrodynamic performance; Floating Production Storage and Offloading; Semi-submersible.

INTRODUCTION

Huse and Nedrelid (1985) relate that the tragic disasters of two semisubmersible platforms, the "Alexander L. Kielland" and the "Ocean Ranger" cost nearly 200 lives, these two accidents lead to a strong focus on the performance of the platforms in the areas of stability and hydrodynamics. Since then, the frequency of worldwide accidents has been significantly reduced, but capsizing of mobile platforms remains a hazard.

The Gulf of Mexico is exposed to tropical storms (hurricanes) as well to winter storms and northern winds, which associated high wind speeds. In the case of tropical storms, the Gulf of Mexico has seen an increase in the severity of the hurricanes being now common categories 4 and 5 (NHC, 2015), which endanger the infrastructure for the oil and gas production at sea.

Additionally, the industry's demand for the establishment of risk-based rules and appropriate regulations have been increased in recent years. Wide circles of professionals involved in all aspects of marine business are aware that risks exist which is intrinsically associated with the metocean behavior and would like to understand the dimension of the risk and how to manage or minimize it.

Changes in weather and wave statistics due to climate change have been noted and various attempts have been made to predict future trends under various emissions scenarios. The outcome of these predictions can sometimes seem contradictory. Considering the Gulf of Mexico, Bruyère et al (2017) predict fewer hurricanes but more storms in category 3-5, with increased precipitation and an estimated 10% extra cyclone damage. Appendini et al (2014) note an increase in extreme wave heights associated with cyclones, however other work such as Eichelberger et al (2008) and Erikson et al (2018) suggests that mean wind speeds and wave heights may actually decrease in the Gulf region. The latter being associated with a reduction in wave period.

The work presented in this paper, utilised recent metocean data and analyzed the critical condition of the operation of both, semi-submersible platform and FPSO. Waves and wind were considered, for different damage cases determined by the most common accidents that causes damage to the structure, such as collisions (Glogowski, Igielski, Orymowska and Pilip, 2017).

METHODOLOGY

In this work, an analysis was carried out to determine the stability and hydrodynamic characteristics of two platforms, a semi-submersible type and an FPSO. Such designs are commonly used in the Gulf of Mexico Region. The analysis was carried out with the Maxsurf software. For the analyzes, a model of each floating structure was used, as well as their respective standards of stability, established by organizations such as the International Maritime Organization and the Classification Houses.

Model Characteristics

A FPSO and the Semi-submersible platform were considered in 2,090 m water depth. The main particulars of the FPSO model are summarized in Table 1 and for the Semi-submersible are shown in Table 2 and 3. In Figure 1 and 2 can see the model geometry of the FPSO and Semi-submersible respectively.

Table 1. Principal dimensions of FPSO

Deadweight Tonnage (DWT)	350 000 ton
Length Overall (LOA)	361 m
Beam (B)	61.54 m
Draught (D)	21 m
Depth (T)	28.64 m

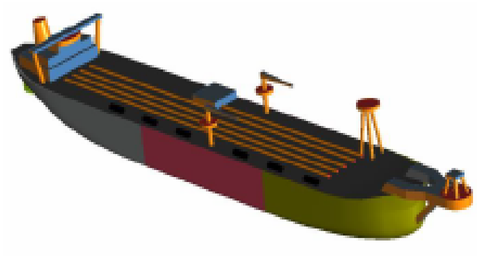

Figure 1. FPSO Geometry.

Table 2. Principal dimensions of Semi-submersible platform.

Deadweight Tonnage (DWT)	45475 ton
Length Overall (LOA)	81.2 m
Beam (B)	81.2 m
Draught (D)	27 m
Depth (T)	43.36 m

Table 3. Dimensions of Columns and Pontoons.

Item	Quantity	Cross section	Total Height
Columns	4	17.2 m X 17.2 m	43.36 m
Pontoons	4	12.4 m X 10.54 m	/

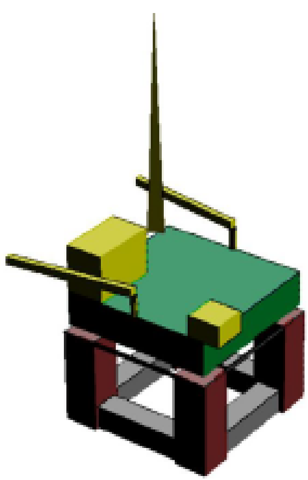

Figure 2. Semi-submersible Geometry.

Intact Stability

Regarding the intact stability calculation for the FPSO the criteria described in the International Code On Intact Stability, IMO (2009) in section 3.2 mentions that for tankers with a capacity of more than 5'000 deadweight tons, regulation 27 of Annex I applies of MARPOL 73/78 which are similar to the documents of the DNVGL classification society used to complement the regulations:

- Rules for classification: Offshore units - DNVGL-RU-OU-0102. Edition January 2017. Floating production, storage and loading units.
- Offshore standards, DNVGL-OS-C301. Edition January 2017. Stability and watertight integrity.
- Rules for classification: Ships - DNVGL-RU-SHIP Pt.3 Ch.15. Edition July 2016, amended January 2017. Stability

And for the calculation of intact stability of the Semi-submersible platform two standards were applied:

- IMO "Code for the Construction and Equipment of Mobile Offshore Drilling Units"
- DNV-OS-C301 "Stability and Watertight Integrity"

Figure 3 shows an example of the intact stability criteria applied for floating offshore structures.

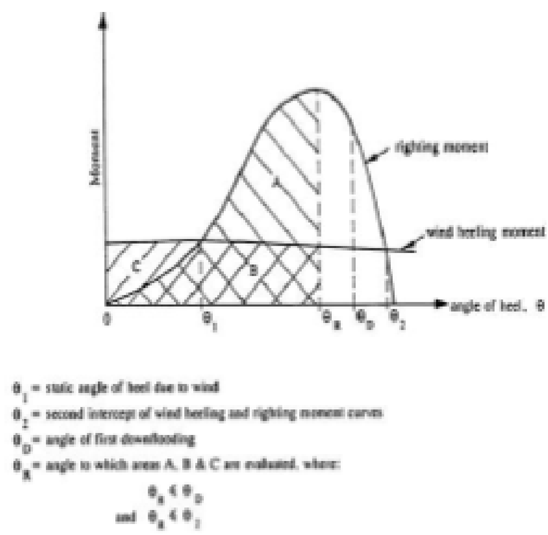

Figure 3. Intact stability criteria for floating offshore structures (Reference taken to DNVGL-OS-C301, 2017).

Table 4 and 5 summarize the respective values from the GZ curve for the specific types of floating offshore structures like FPSO and Semi-submersible as set by IMO and DNVGL.

Table 4. Intact Stability requirements for FPSO.

Requirements IMO/DNVGL
-The area under the righting lever curve (GZ curve) shall not be less than 0.055 metre-radians up to $\theta = 30°$ angle of heel and not less than 0.09 metre-radians up to $\theta = 40°$ or the angle of flooding θf if this angle is less than 40°. Additionally, the area under the righting lever curve between the angles of heel of 30° and 40° or between 30° and θf, if this angle is less than 40°, shall not be less than 0.03 metre-radians
-The righting lever (GZ) shall be at least 0.20 m at an angle of heel equal to or greater than 30°
-The maximum righting level should occur at an angle of heel preferably exceeding 30° but not less than 25°
-The initial metacentric height, GM_0 shall not be less than 0.15 m.
For severe weather conditions, area (b) under the GZ curve should be equal to or greater than area (a) as shown in Figure 2-1.

Table 5. Intact stability requirements for semi-submersible units.

Requirements	IMO	DNVGL
- Steady heel (with wind)	-	-
- Initial GM for operating, transit, survival condition	≥ 0 m	≥ 1.0 m
- Initial GM for temporary condition	≥ 0 m	≥ 0.3 m
-Angle of heel at second intercept	-	-
-GZ ≥ 0.5GMminsinθ		Min. (downflooding angle, angle of maximum GZ, 15•)

Damage Stability

The calculation of damage stability, as its concept rightly says, is the ability of a vessel to stay afloat after damaged to its structural integrity for example collision, damage caused internally or due to weather phenomena. Such damages causes the leak of the liquid stored inside the damaged tank or the water flooding the tanks, which ends in the loss of buoyancy and / or stability. In Tables 6 and 7 shows the requirements for FPSO and Semi-submersible platform for damage stability.

Table 6. Damage Stability requirements for FPSO.

Requirements IMO/DNVGL
-The area under the righting moment (GZ) curve until the second intersection or angle of floating, whichever is less, shall exceed a minimum of 40% of the area under the heeling moment curve. As shown in Figure 2-2.
-The final waterline, taking into account the sink, heel and trim, should be below the lower edge of any opening through which progressive flooding may occur.
-In the final stage of flooding, the angle of heel due to asymmetric flooding should not exceed 25 °, this angle can increase up to 30 ° if there is no immersion of the deck.
-Stability in the final stage of flooding should be investigated and may be considered sufficient if the righting arm curve has at least a 20 degree range beyond the equilibrium position with a maximum residual righting arm of at least 0.1 meter within the 20° distance; the area under the curve within this range must not be less than 0.0175 m-rad.

Table 7. Damage stability requirements for semi-submersible units.

Requirements	IMO/DNVGL
For waterline damage:	
-Static heel	-
-Steady heel	≤17°
-Opening within 4 m above final waterline to be weathertight	Yes
-Range of positive stability, to lesser of the upper extent of weathertight integrity or second intercept, to be at least	7°
Extent of weathertight integrity:	
-Within above range, righting moment at least twice of windheeling moment, at same angle	Yes
-Area ratio ≥1.0	-

In Table 8 is presented a summary comparison of the rule requirements for damage extent for different types of compartments and all types of damage for semi-submersibles.

Table 8. Damage extent assumptions for semi-submersibles.

Damage extent	IMO	DNVGL
Waterline damage:		
-Penetration 1.5 m	Yes	Yes
-Vertical height 3 m	Yes	Yes
-Damaged width 3 m	-	-
-Damage zone -1.5 m to +1.5 m of waterline	Yes	Yes
-Disregard bulkhead within one-eight of the column perimeter	Yes	-
-Waterline damage to any one compartment	-	-
-Waterline damage only below waterline, adjacent to sea or connected to sea (by pipes, etc.)	Yes	Yes

Hydrodynamics

In order to avoid resonance effects leading to large amplitude motions, the platforms are designed to obtain their natural periods of motion far from the characteristic wave frequencies present at the site of operation. Generally, semi-submersible platforms and FPSO have natural motion periods in Surge, Sway and Yaw longer than 100 s, greater than 20 s in the degrees of freedom of Heave, Roll and Pitch for the semi-submersible platform, for the FPSO between 4-16s for Heave and Pitch and 20-25s for Roll, according with Faltisen (1990). while the characteristic periods of a wave with 100 years of return period are in the range of 8 to 18 s, which leads to non-resonant responses of the first order.

ANALYSIS

The analyzes in this work were carried out using the Maxsurf software, the stability analysis was carried out modeling the platforms in the Maxsurf Modeler Advanced module, then the tanks were modeled in the Maxsurf Stability Enterprise, the FPSO with 44 tanks and the Semi-submersible with 112 tanks and both platforms were leveled to their design draft

Through the software the hydrostatic data were obtained, which include: displacement, draft, Length Overall (LOA), Beam max extents on Water

Line, distance between Keel and Buoyancy (KB), waterplane area, Longitudinal Center of Buoyancy (LCB), Longitudinal Center of Flotation (LCF), Moment to Change Trimm (MTc), Height of the metacenter above the centre of buoyancy (BM), Metacentric height (GM), Distance between Keel to Metacenter (KM), Tonnes per cm Immersion (TPc).

Throughout this paper, when dealing with Transverse Stability, BMt, GMt and KMt will be used. When dealing with Longitudinal Stability, then BML, GML and KML will be used. In Tables 9 and 10 are summarized, for each model, the results obtained for the hydrostatic data.

It is important to mention that for this study the mooring system was not considered and both platforms were analyzed in operation.

Table 9. FPSO hydrostatic data.

Parameter	Value	Parameter	Value
-Displacement [t]	393202	-MTc [tonne.m]	5012.073
-Draft [m]	21	-BMt [m]	14.873
-Lenght Overall [m]	360.997	-BML [m]	465.541
-Beam max extents on WL [m]	61.5	-GMt [m]	10.767
-KB [m]	10.894	-GML [m]	461.435
-Waterpl. Area [m^2]	19879.585	-KMt [m]	25.767
-LCB from zero pt. (+ve fwd) [m]	-169.084	-KML [m]	476.435
-LCF from zero pt. (+ve fwd) [m]	-177.237	-TPc [tonne/cm]	203.766

Table 10. Semi-submersible Hydrostatic data.

Parameter	Value	Paramater	Value
-Displacement [t]	58079	-MTc [tonne.m]	21.259
-Draft [m]	27	-BMt m	20.792
-Length Overall [m]	81.2	-BML [m]	21.289
-Beam max extents on WL [m]	81.2	-GMt [m]	2.475
-KB [m]	10.483	-GML [m]	2.972
-Waterplane Area [m^2]	12038.826	-KMt [m]	31.275
-LCB from zero pt. (+ve fwd) [m]	0	-KML [m]	31.772
-LCF from zero pt. (+ve fwd) [m]	0	-TPc [tonne/cm]	11.515

The curve of righting moment and heeling moment produced by the wind were calculated which are plotted with respect to the wind forces calculated according to the following equation 1 according to the previously established rules.

$$F = 0.5 C_s C_h P v^2 A \quad (1)$$

F = the wind force (Newton)
Cs = the shape coefficient depending on the shape of the structural member exposed to the wind.
Ch = the height coefficient depending on the height above sea level of the structural member exposed to Wind.
P = the air mass density (1.222 kg/m3)
V = the wind velocity (metres per second)
A = the projected area of all exposed surfaces in either the upright or the heeled condition (m2)

"In general, a minimum wind velocity of 36 m/s (70 knots) for offshore service shall be used for normal operating and transit conditions and a minimum wind velocity of 51.5 m/s (100 knots) shall be used for the severe storm conditions"

In the hydrodynamic analysis of the platforms, the platforms response to waves was analyzed at zero speed. The Pierson Moskowitz wave spectrum, which takes into account the irregular wave formed by wind forces, was taken into account the highest wind speed recorded in a return period of 100 years, the wave loads of greater magnitude on the offshore structures occur in the wave frequencies, generating movements in the wave frequency of the platform.

RESULTS

Results of Intact Stability of FPSO

Tables 11,12,13 and Figure 4 show the results of the intact stability analysis of the FPSO with heels ranging from -50 ° to 90 ° in steps of 10 °

Table 11. Results of the stability analysis of the FPSO.

Criteria	Ref	Unit	Calculated	Status
Initial GMo in port	0.15	m	10.77	Pass
Area 0 to 30	0.06	m.rad	1.17	Pass
Area 0 to 40	0.09	m.rad	1.83	Pass
Area 30 to 40	0.03	m.rad	0.66	Pass
Max GZ to 30 or higher	0.2	m	4.07	Pass
Maximum angle GZ	25	deg	46.4	Pass
Initial Gmo in sea	0.15	m	10.77	Pass

Table 12. Results which takes into account weather conditions.

Criteria	a	b	status
Area b => a, m.rad	1.32	1.59	Pass

Table 13. Results for severe storm winds.

Criteria	Ref	Calculated	status
GZ Area 40% greater than Area HA	40.00%	640%	Pass
Righting moment curve		See Figure 4	Pass

Since the stability curve GZ was plotted by the data generated by the stability analysis in each heel angle, which are shown in Figure 4.

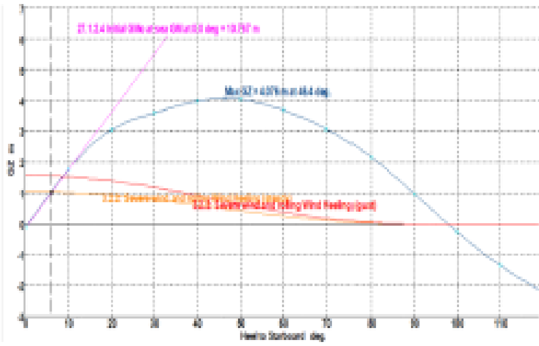

Figure 4. Righting arm and heeling arm curves.

Results of Damage Stability of FPSO

Tables 14 and Figure 5 show the results of the damage stability analysis of the FPSO

Table 14. Result of the criteria for FPSO damage.

Description	Required	Calculated	Satisfy
-Area 1 > Area 2	40%	5215.01%	Yes
-Bottom waterline to some opening, after the flood	< 100% opened	40.45%	Yes
-Final angle due to flood	< 25°	5.05°	Yes
-Positive stability range after equilibrium	> = 20°	103.8°	Yes
-Residual GZ in the range of 20 °	> 0.1 m	3.33 m	Yes
-Area within the range of 20°	> 0.0175 m-rad	0.6171 m-rad	yes

In Figure 5 is shown the stability curve GZ which was plotted using the data generated in each heel angle.

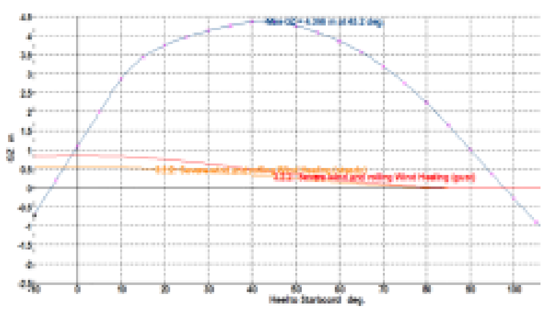

Figure 5. Stability and Wind curve for damage.

Results of Intact Stability of Semi-Submersible Platform

Tables 15 and Figure 6 show the results of the intact stability analysis of the Semi-Submersible Platform with heels ranging from -180 ° to 180 ° in steps of 10 °

Table 15. Results of the stability analysis of the Semi-submersible.

Criteria	Value	Units	Calculated	Status
-GZ area: to Max GZ	22.9	deg	50.9	Pass
-Angle of equilibrium ratio	50	%	24.09	Pass
-Angle of vanishing stability <=100m in length	130	deg	147.6	Pass
-Ratio of areas type 3	130	%	5256.9	Pass
-Range of positive stability	96	deg	112.6	Pass

In Figure 6 is shown the stability curve for the damage case of the FPSO, which was generated with the data obtained by the damage stability analysis.

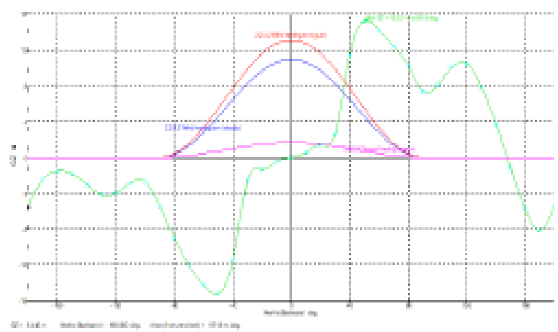

Figure 6. GZ stability curve generated by the model data and the wind moment curve. .

Results of Damage Stability of Semi-submersible platform

Tables 16 and Figure 7 show the results of the damage stability analysis of the Semi-submersible platform.

Table 16. Result of the criteria for Semi-submersible damage.

Criteria	Value	Unit
-Initial Draft	27	m
-KG	29.505	m
-Projected area on the water line	2681.91	m^2
-Displacement	55758	ton
-First Intercession	10.664	degree
-Initial inclination angle	9.625	degree
-Minimum required angle (PASS)	17	degree
-Second intersection	148.33	degree
-Main range righting moment about heeling moment	137.666	degree
-Minimum required range (PASS)	7	degree
-Relative magnitude righting moment for heeling moment	8.284	
-Minimum Required (PASS)	2	

In Figure 7 is shown the stability curve for the damage case of the Semi-submersible platform, which was generated with the data obtained by the damage stability analysis for each angle.

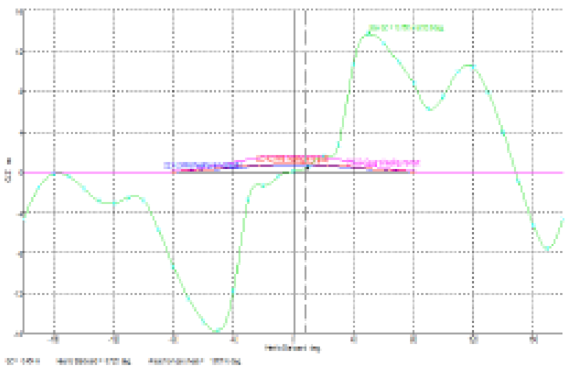

Figure 7. Stability and Wind curve for damage.

Results of Hydrodynamic Analysis of FPSO

In Figure 8 and 9 are shown the RAOs for roll and pitch movements generated at the center of gravity of the FPSO.

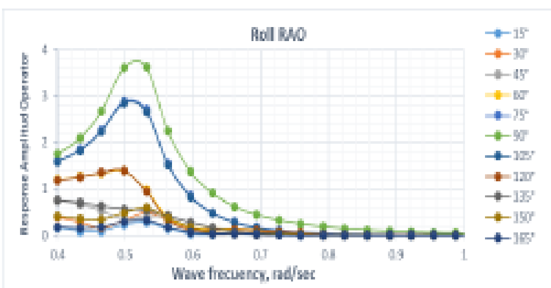

Figure 8. Roll RAO's in CG in different incidence angles.

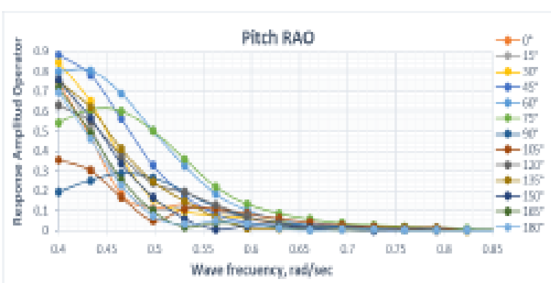

Figure 9. Pitch RAO's in CG in different wave incidence angles.

Table 17 shows the results of the natural periods with respect to those recommended to avoid resonance to FPSO.

Table 17. Natural periods.

Concept	Required	Calculated
Natural Period of Heave	4-16 s	23.89 s
Natural Period of Roll	>20s	25.78s
Natural Period of Pitch	4-16s	23.89s

Results of Hydrodynamic Analysis of Semi-submersible platform

In Figure 10, 11 and 12 are shown the RAOs for heave, roll and pitch movements generated at the center of gravity of the Semi-submersible.

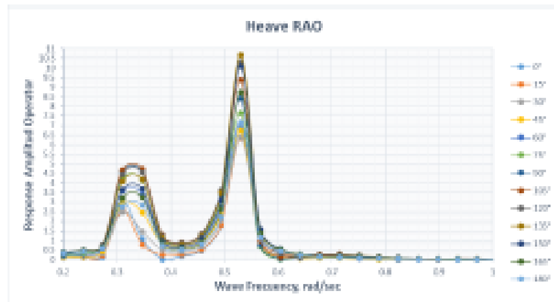

Figure 10. Heave RAO's in CG in different wave incidence angles.

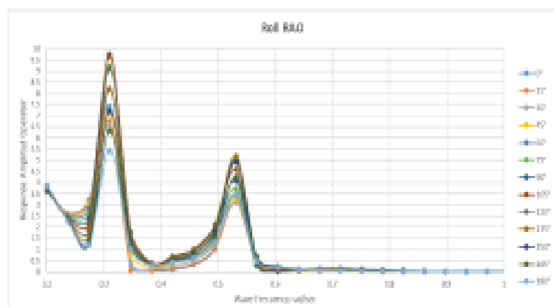

Figure 11. Roll RAO's in CG in different wave incidence angles.

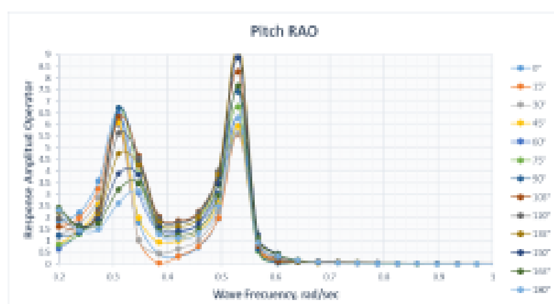

Figure 12. Pitch RAO's in CG in different wave incidence angles.

Table 18 shows the results of the natural periods with respect to those recommended to avoid resonance to Semi- Submersible.

Table 18. Natural Periods.

Concept	Required	Calculated
Natural Period of Heave	>20 s	21.18s
Natural Period of Roll	>20s	26.76s
Natural Period of Pitch	>20s	25.75s

CONCLUSIONS

According to the data obtained in the stability analysis it was obtained that for the FPSO were GM = 10.767 m and GZ = 46.4 deg and for the semi-submersible were GM = 2.475 m and GZ = 50.9 deg, which satisfy the criteria established by the IMO and the class clasification, in this case DNVGL, the hydrodynamic part should be noted that the FPSO has a lower amplitude in the RAO of Heave, Roll and Pitch, besides that the semi-submersible platform has favorable natural periods, meets with the established requirements to avoid coming into resonance with the wave period of said site.

These platforms have not been installed in the Region of Mexico for deep waters, so this study shows that the platform with the highest performance in deep waters of the Region of Mexico is the semi-submersible platform of this study, which has better behavior in both stability approach as hydrodynamic for the environmental conditions in the said region.

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