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SEAKEEPING EVALUATION OF SHIPS FOR OPERATIONAL PLANNING IN THE GULF OF GUINEA

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Abstract—**This paper evaluates the sea-keeping characteristics of a Platform Supply Vessel (PSV) for operational planning in the Gulf of Guinea according to the respective international requirements or standard criteria. The ship's design and operation characteristics were examined, the characteristics of the specified sea environment in which the ship should perform its mission were assessed, the impact of the specified sea environment on the design and operation of the ship was evaluated and ultimately, the operational criteria that should not be exceeded, so that the ship can perform its mission effectively was determined. Structural Analysis and Design Computer-Aided Design (SACS CAD) Software was employed to model the ship design and it was subjected to the environment in which it is to operate. The Joint North Sea Wave Project (JONSWAP) spectrum was used to model the local wind sea wave with Orca Finite Element Analysis of Flexible Systems (ORCAFLEX). This analysis showed the dynamic movement of the Platform Supply Vessel (PSV) in the various degrees of freedom (heave, surge, sway, yaw, roll, and pitch). Broad-based results showed that the PSV is fit to be operational. This was because of the various tests that were conducted for normal conditions. The various degrees of freedom offset exerted by the PSV were below the tolerance limit of platform supply vessels (10% of water depth of 100m=10m). The results obtained were for the south, the heave offset of 1.6032m and surge offset of 2.1507m. For the southwest, the heave offset of 1.5033m, the surge offset of 1.0712m, and the sway offset of 1.0753m. For the west, the heave offset of 1.068m, and the sway offset of 1.2114m. Local Sea wind wave in the south direction (180°) exerts the most environmental loading on the designed PSV. This was because of the result obtained for the extreme condition (heave offset of 1.9571m and surge offset of 1.4107m. The PSV stability parameters were also obtained as summarized in Appendix C and known to be within the limit of acceptability and validated by comparing the righting lever, GZ, of the designed PSV in Figure 16 with that obtained by marine.info (2021). Both righting levers, GZs were above the 30 degrees requirement of UKMCA (2008) criteria for PSVs. The GZ obtained was 62.8 degrees which should not be exceeded to prevent the PSV from capsizing. The study contributes to the body of knowledge surrounding seakeeping evaluations of PSVs and serves as a foundation for evaluating the design and performance of these vessels in the demanding offshore environment**

Keywords—**Platform, Seakeeping, Evaluation, supply**

I. INTRODUCTION

The operability of a ship or vessel in a sea environment is the capability of the vessel to accomplish its mission in that environment [1]. Ship operability is a major performance indicator of the ship for operational planning. It is well known that adverse sea conditions induce significant dynamic motions, velocities, accelerations, and loads, which deteriorate the performance of both the crew and the various subsystems on board, including the ship hull form [2] [3]. The success of a ship's design depends ultimately on its performance in a seaway and not in calm water since the sea is mostly not calm [4].

Seakeeping analysis is a possibility to predict the behavior of ships at sea, to evaluate their motions, accelerations as well as their impact on the comfort of crew and passengers, the load demand on hull structures, and the operations on-board [5]. Prediction of the seakeeping performance of a ship in the earlier ship's design step is necessary to ensure the safety of navigation during sailing [6] [7]. For the ship's performance at sea, many parameters play an important role such as the sea conditions, the ship's speed, the relationship of the ship length to significant wavelength, and the course of the ship with respect to the waves [8]. In considering the performance of a ship at sea, the ship designer is primarily concerned with three qualities: habitability, operability, and survivability [9]. Habitability deals with human comfort and performance on board ships. The requirements depend on the ship type and its mission. For example, a much higher degree of habitability is required for a passenger ship than for ordinary merchant vessels [10]. Operability is concerned with the ability of the ship, with all mechanical equipment and instrumentation systems on board, and its crew to carry out the assigned tasks at sea. Survivability is concerned with the safety of the ship, its crew, and cargo when sea conditions become so rough that the ship, its crew, and cargo, are in danger of damage or destruction. Even though these three qualities are quite different in their nature, they may be affected by the following quantities or aspects: ship motions like heave, pitch, and roll, accelerations, particularly in vertical and transverse directions, course keeping including tendency to broaching, increased in required power to attain the speed, global hull girder loads, local sea loads, deck wetness and water ingress, slamming (bow flare, bottom), propeller emergence and racing [11] [12]. The importance of these quantities or aspects depends mainly on the type and mission of the ship.

Furthermore, the interpretation of seakeeping behavior is relatively difficult since the sea environment in which the ship operates is hydrodynamic, and hence the ship's performance can only be quantified in terms of statistics. The ship designer evaluates the ship's performance with probabilities that a certain critical level will be exceeded, which makes his task not easier. The results of the seakeeping performance analysis may also be used to supply the ship master and operators with information that may help them take the necessary measures to avoid dangerous situations in rough sea conditions. To accommodate such a demand, this research proposed to evaluate the seakeeping performance of a PSV operating in the Gulf of Guinea. The vertical motion of the PSV including the heave and pitch motions was quantified by her response to the amplitude operator (RAO). Computational Fluid Dynamic software was used to analyze the behavior, where several effects of various Froude numbers, hull lateral separation ratios and wavelengths on the heave, and pitch motions of the PSV are considered.

The consequence of having dynamic offsets in its stability, speed, motion, and structural stress due to hydrodynamic forces propagated by extreme conditions of the marine environment that leads to crew discomfort, structural damages, and fatigue failures of the ship hull is the major concern of this research since it adversely affects operations in terms of efficiency, cost, and time.

For a successful vessel design, good seakeeping characteristics should be incorporated into the design in the initial design phases. At this stage, it is still possible to vary the geometry of the hull or structure or to change other design parameters that are critical with respect to wave forces and/or vessel motions [6] [7]. Hence, it is important to have a reliable prediction tool at the t design stage. However, after more than 40 years of intensive and extensive seakeeping research, both experimental and computational tools have been sufficiently developed to judge and optimize the seakeeping performance of ships, at least in the early stages of the design process [13] [14] [15].

In many cases, model testing is preceded by computer calculations. The computations are performed to optimize a design and/or to determine the most critical combination of operational and environmental parameters to define a cost-effective model test program. To provide the ultimate validation of both computational and physical models full-scale measurements are needed. Full-scale trials are also carried out to determine whether a ship fulfills its design specifications, to collect data on the actual sea performance of the ship, or to monitor continuously specific operations such as heavy transport or offshore installations.

In this dissertation, the theoretical background, and the seakeeping tools available to the designer and the operator to carry out seakeeping calculations were presented. The designer equipped with these tools will be able to assess the dynamic response of any ship in a specific seaway. To evaluate the operability of a ship in a seaway, a set of seakeeping criteria was specified which depend on the mission of the ship. The ship is considered as operable in any sea state where all set criteria are satisfied. The emphasis of this study was on supply ships operating in the Gulf of Guinea, Southern Nigeria.

II. EXTENT OF PAST WORK

Sea-keeping ability is a measure of how well-suited a vessel is to condition when underway. It also refers to analyzing the behavior of a vessel in regular waves, represented through the RAOs. RAO is a linear operator that represents the input (wave) – output (movement) transfer, it being of key relevance to determining vessel design parameters [16]. Sea-keeping performance is expressed as the weighted sum of the peak values of ship responses in regular waves, for various ship speeds and headings [17] [18] [19]. Optimum performance corresponds to the minimum value of this sum, which is the objective function of the study. The main purpose of this work is to analyze the behavior at sea of support vessels that adapt to the wave conditions of a specific location from the Gulf of Guinea Sea.

Recent literature shows that a lot of attention has been paid to the problem of evaluating the sea-keeping characteristics of ships for operational planning in a specified sea environment. Many authors are professionally engaged in a sea-keeping assessment of fishing vessels in the conceptual design stage, sea-keeping of a fast displacement catamaran, and sea-keeping analysis of small displacement high-speed vessels [7] [18] [19] [20]. Ahmad (2008) studied the development of fast craft seakeeping design methodology [20], while Fang and Chan (2004) investigated the seakeeping characteristics of high-speed catamarans in waves[21]. Sariöz and Narli in, 2005, examined the effect of criteria on seakeeping performance assessment[17]. Castiglione et al.in, 2011, carried out the numerical investigation of the seakeeping behavior of a catamaran advancing in regular head waves[16], while Ozumet al,in 2011, presented a parametric study on seakeeping assessment of fast ships in the conceptual design stage[6], and Bruzzone et al, in, 2008, assessed nonlinear seakeeping analysis of catamarans with central bulb[21]. These studies, however, addressed the problem of evaluating the sea-keeping characteristics of ships for operational planning, but in a superficial manner.

According to Gregory (2006) in the seakeeping operability of naval ships, the operability of a vessel in the sea environment, i.e., the capability to accomplish its mission is a major performance indicator of the vessel[1]. He stated that it is well known that adverse sea conditions induce significant dynamic motions, velocities, accelerations, and loads, which deteriorate the performance of both the crew and the various subsystems on board, including the hull form itself. He cited that, for example, the operation of medium and large naval ships e.g., destroyers, frigates, and corvettes depend highly on the capability of the helicopters on board to take off and, more important land. Otherwise, they are vulnerable to the attack of submarines. His study also put forward that in severe wind and sea conditions and to ensure a convenient air wake field operation of helicopters, the captains use to maneuver their vessels so that they sail in quartering to following sea conditions. Furthermore, he maintained that the specifications of the helicopters operating on board ships provide maximum acceptable values (criteria) which should not be violated for the take-off and landing procedures to be safe. Thus, the operation of the aircraft, and especially the helicopters depends on the motions of the vessels in a seaway.

The current practice in the design and operation of naval ships to ensure their operational availability in specified sea conditions was analyzed and the pertinent existing criteria were reviewed. Additional information contained in NATO STANAG 4154 was discussed and a framework of procedures to satisfy all involved subsystems was proposed. Available methods to improve the performance of existing vessels or new designs were presented and discussed. Mohsen and Hassan (2013) examined the effect of hull form coefficients on the vessel sea-keeping performance[22]. Their study investigated the hull form of a high-speed engine vessel based on a smart model, to observe the effect of variations in some geometrical parameters and hull form coefficients, such as Cwpand Cp, on sea-keeping response by means of numerical and experimental methods. For modeling, neural networks, and polynomial fitting methods were combined to achieve enough accuracy in modeling

The effect of variations in Cwpand Cp on the hydrodynamic response, which is calculated by the modified strip theory method and Pierson-Moskowitz (PM) wave spectrum, was illustrated. The main assumption of the study was that variations in hull form parameters are so slight that each variable can be assumed independent of other variables. Displacement, speed, and angle of wave approach were considered constant for the vessel and the model in their study. All geometrical parameters and vessel hull form coefficients affect the vessel hydrodynamic coefficients differently. Two of these mentioned parameters were the water plane area coefficient and prismatic coefficient whose effects on the vessel seakeeping were studied. Simulation results indicated that the present modeling can be applied to vessel hull form design, considering geometrical limits and the desired optimal conditions.

Fitriadhyet al. (2017) studied the seakeeping performance of a rounded hull catamaran in waves using CFD approach[23]. They stated that prediction of the seakeeping performance of a ship in the earlier ship's design step is necessary to ensure the safety of navigation during sailing. To accommodate such a demand, their research proposed to analyze the seakeeping performance of a rounded hull catamaran. The vertical motion of the catamaran including the heave and pitch motions were quantified by her RAO. The Computational Fluid Dynamic software was used to develop the model, where several effects of various Froude numbers, hull lateral separation ratios and wavelengths on the heave, and pitch motions of the rounded hull catamaran have been considered. The results revealed that the higher Froude number associated with less hull lateral separation ratio was proportional to the subsequent increase of her heave and pitch motions. In the case of $\lambda/L \leq 1.0$, the seakeeping quality of the rounded hull catamaran has been improved and presented in the form of a reduction of the heave and pitch motions. It was shown that the estimated seakeeping performance of the rounded hull catamaran greatly depends on the Froude numbers and magnitude of wavelength.

Omar et al. (2015) carried out stability, seakeeping, and safety assessments of small fishing boats operating on the Southern Coast of Peninsular Malaysia[24]. They stated that fishing boats in Malaysia were built traditionally, usually with no guidance and approval from naval architects. Thus, hydrodynamics performance, viewed in terms of stability and seakeeping as well as safety performance, has become a major concern in traditional fishing boat designs. Their study mainly focused on the assessment of hydrodynamics performance and safety of small fishing boats. Two small boats, each from the East and West Coast of Peninsular Malaysia, were selected for measurement of their hulls. Maxsurf Ship Design software was used to assess the seakeeping and stability performance according to the respective requirements or standard criteria. The assessments showed that although both boats fulfill static stability requirements, one of the boats should only be allowed to operate in a restricted operational area with maximum sea state 2, while the other can be allowed to operate in an operational area up to sea state 3. A survey on safety equipment showed that both boats lacked the necessary equipment stipulated by international guidelines for the safety of small fishing boats.

Tan (2005) investigated seakeeping considerations in ship design and operations[5]. His study dealt with the application of seakeeping research in designing ships that can operate more effectively, safely, and economically in rough seas. He asserted that seakeeping research may be carried out using theoretical methods, model experiments, full-scale trials, or a combination of these tools. Important ship parameters and wave characteristics, which play a significant role in the ship's performance at sea, were discussed. With increasing acquired information on quantitative criteria various ship designs may be well evaluated and compared. As a result, the ship design with the best seagoing qualities may be assessed. Furthermore, the seakeeping studies may be used by the ship master to avoid dangerous situations or to select a ship's route with respect to a minimum traveling time or fuel consumption. In his study, some examples were given to illustrate the advantages of considering the seakeeping considerations in ship design and operations.

Conceptual Framework.

Seakeeping Performance

According to Tan (2005), seakeeping assessment generally covers four major categories of seakeeping characteristics, which are habitability, operability, and survivability[5]. In considering the performance of the ship at sea, the designer is primarily concerned with three qualities: habitability, operability, and survivability. Habitability deals with human comfort and performance on board ships. The requirements depend on the ship type and its mission. For example, a much higher degree of habitability is required for a passenger ship than for ordinary merchant vessels. Operability is concerned with the ability of the ship, with all mechanical equipment and instrumentation systems on board, and its crew to carry out the assigned tasks at sea. Survivability is concerned with the safety of the ship, its crew, and cargo when sea conditions become so rough that the ship, its crew, and cargo, are in danger of damage or destruction. Even though these three qualities are quite different in their nature, they may be affected by the following quantities or aspects:

i. Ship motions like heave, pitch, and roll.
ii. Accelerations, in vertical and transverse directions.
iii. Course keeping including tendency to broach.
iv. Increase in required power to attain the speed.
v. Global hull girder loads.
vi. Local sea loads.
vii. Deck wetness and water ingress.
viii. Slamming (bow flare, bottom).
ix. Propeller emergence and racing.

The importance of these quantities or aspects depends mainly on the type and mission of the ship. The general conclusions of the operators in order of priority for ship performance in a seaway were roll control, reduction of deck wetness, and slamming[25].

Design for Seakeeping

A simplified flow diagram is given in Figure 2, showing the necessary steps to be taken for designing a ship that should satisfy a certain prescribed seakeeping performance.

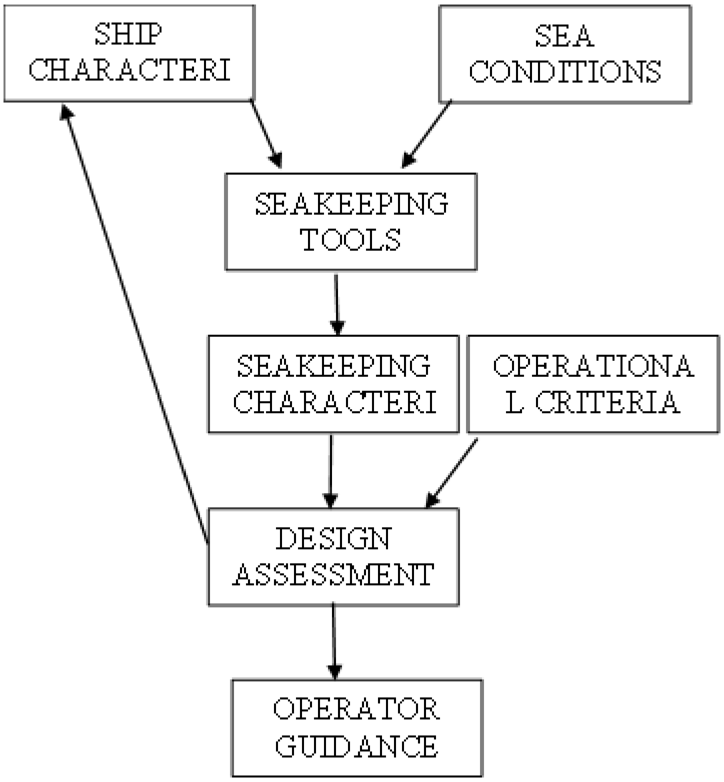

Figure 1: Seakeeping Performance[5]

III. MATERIAL AND METHODS

A. Materials

The materials used in this research work are the relevant data needed for the ship design and its seakeeping analysis which include ship dimensions (like length, beam, and draft) and their proportions, displacement and weight distribution, the longitudinal position of the centre of buoyancy (LOB) and of floatation (LOF), the shape of sections (U or V) below water, freeboard and flare, ship speed, bulbous bow, anti-rolling device, and anti-pitching devices. The design and analysis conducted in the research were done using a finite element analysis computer tool called ORCAFLEX, which also constituted part of the materials used in this study. After the design of the PSV had been achieved with SACS CAD software, it was subjected to the environmental condition in which it was to operate. The JONSWAP wave spectrum was used to model the local wind sea wave for the modelling. This analysis showed the dynamic movement of the PSV in the various degrees of freedom (heave, surge, sway, yaw, roll, and pitch).

B Methods and Analytical Model

In this study, wave spectrum methods were used to predict the impact of the marine environment on the design and operation of the PSV. The shallow waters of the Gulf of Guinea cannot be over-emphasized because most projects on the Gulf of Guinea are sited there which makes this study vital research in improving the design and operation of vessels operated there. Local wind sea wave using the JONSWAP spectrum was used as the environmental loading for this study because, from research, it was found to be an important wave spectrum used in analyzing the wave experienced at the Gulf of Guinea. The three directions with the most environmental loading on offshore floating structures at the Gulf of Guinea were found to be from the south, southwest, and west (180°, 225°, and 270°). Designing the PSV to withstand the offset motions in the various degrees of freedom due to the extreme conditions (100 years) of these directions would ultimately mean its ability to withstand any other direction of environmental loading during its life cycle.

The impact on the PSV would be obtained by getting the positive or negative offset for each degree of freedom and then subtracting the initial position from the highest offset to get its maximum offset. Determining the maximum offset of the PSV is crucial because it helps to determine the effectiveness of the structure in use. A good system in use would ensure the PSV does not exceed an offset of 10% of the water depth. This chapter elucidates the methodology used to analyze the impact of the characteristics of the marine environment such as winds, currents, and waves on the design and operations of a PSV in different simulated offshore environments of a region in the Gulf of Guinea shallow waters. According to ABS rules for building vessels, the following would be considered in the design and analysis of the PSV in this study:

i. Structural analysis
ii. Stability analysis

Also, the following design loads should be considered.

i. Dead Loads and Buoyancy
ii. Environmental Loads
iii. Fatigue Loads

The PSV to be analyzed was simulated in local wind sea wave for 1 year and 100 years (normal and extreme conditions) return period using the JONSWAP wave spectrum according to an environmental condition in the Gulf of Guinea of 100m water depth and the above rules guiding the construction of PSV earlier stated. The formula to calculate PSV offset is:

Offset = Maximum displacement – initial position (1)

C. JONSWAP Spectrum

The JONSWAP (Joint North Sea Wave Project) spectra are an empirical relationship that defines the distribution of energy with frequency within the ocean. It is an extensive wave spectrum used to measure waves. The JONSWAP spectrum is effectively a fetch-limited version of the Pierson-Moskowitz spectrum, except that the wave spectrum is never fully developed and may continue to develop due to non-linear wave-wave interactions for a very long time. Therefore, in the JONSWAP spectrum, waves continue to grow with distance (or time) as specified by the α (alpha) term, and the peak in the spectrum is more pronounced, as specified by the γ (gamma) term.

From the analysis of the measured wave spectra, a JONSWAP wave spectral formulation was derived which is a representative of wind-generated seas with a fetch limitation. It is given as a function of frequency f in Hz expressed by:

$$S(f) = \alpha \frac{g^2}{(2\pi)^4} \frac{1}{f^5} \exp\left\{-1.25\left(\frac{f_m}{f}\right)^4\right\} x\, \gamma^{\exp\left\{\frac{-(f-f_m)^2}{2(\sigma f_m)^2}\right\}} \quad (2)$$

Where,

γ = peak shape parameter, 3.30 as an average

α = $0.076\left(\bar{x}\right)^{-0.22}$ (3)

σ = 0.07 for $f \leq f_m$, and 0.09 for $f \succ f_m$

f_m = $3.5\left(\frac{g}{\bar{U}}\right)\left(\bar{x}\right)^{-0.33}$ (4)

$\bar{x}$ = dimensionless fetch = $\frac{gx}{\bar{U}^2}$ (5)

x = fetch length (Km)

$\bar{U}$ = mean wind speed (m/sec)

It is noted that the peak-shape parameter γ obtained from analysis of the original data varies approximately from 1 to 6 even for a constant wind speed. It is a random variable that is normally distributed with a mean of 3.30 and a variance of 0.62. Hence, it is possible to generate a family of spectra for various γ values with their weighing factors based on the probability distribution of γ.

It is also noted that equation (2) is given as a function of wind speed. It is very convenient in practice if the spectrum is presented in terms of significant wave height. For this, a series of computations was carried out on equation (2) for various combinations of fetch and wind speed, and the following relationship was derived:

$$\bar{U} = kx^{-0.615} . H_S^{1.08} \quad (6)$$

Where;

k =83.7 for $\gamma = 3.30$

H_s = significant wave height (meters)

$$H_s = 4.\sigma = 4.\sqrt{m_o} \quad (7)$$

With equations (2) and (6), the JONSWAP spectrum can be obtained for a specified sea severity and fetch length.

D Methods of Data Analysis

The data was analyzed using the Numerical Simulation method. This method uses computer software to model complex systems or phenomena. The data obtained are analyzed to understand the system (PSV) behavior, validate theoretical models, and optimize design.

The PSV Data used for the Design.

The following PSV properties were imputed after the geometry data:

i. Drag force.
ii. Drag moment.
iii. Added mass coefficient.

These properties help to achieve a more realistic condition the ship experiences when submerged in seawater. The data used in the ship design are presented in Table 1.

Table 1: PSV Design Particulars[5]

Design Parameter	Unit	Dimension
Length o. a.	M	26.7
Length w/ l.	M	24.85
Beam mid.	M	5.80
Depth mid. (1/2L)	M	3.35
Draught amidships	M	1.6
Draught aft approx.	M	1.95

Displacement	Tons	970
Deadweight	Tons	170
GM	M	1.62
Total Engine power	Kw	2000

i. Static Analysis of the PSV

After the design of the marine structure has been achieved, the PSV needs to be subjected to the environmental condition in which it is to operate. The JONSWAP wave spectrum was used to model the local wind sea wave. The local wind-sea wave data was as follows:

The static analysis was a necessary procedure to follow before the PSV could undergo a dynamic analysis. It helped to know the initial position of the PSV. The design of the ship model was achieved in 3-D by SACS Computer Software with the body plan, half breadth and profile line drawings, the PSV model was subjected to static analysis to determine its initial position using Orcaflex software. In this case, an Orcaflex model was set up without the influence of local sea load.

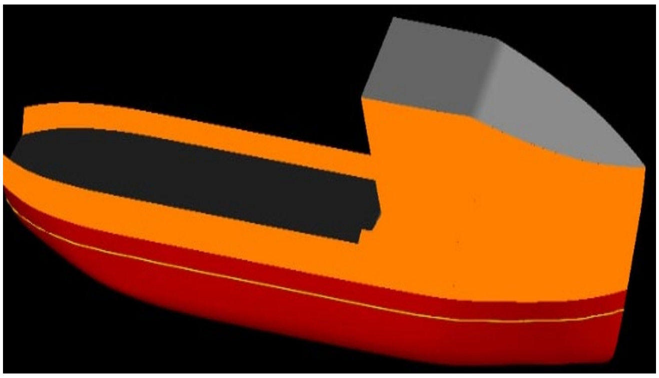

Figure 2: Computer Aided Design of the PSV (Side View)

Other isometric views of the PSV is presented in Figures 3 and 4

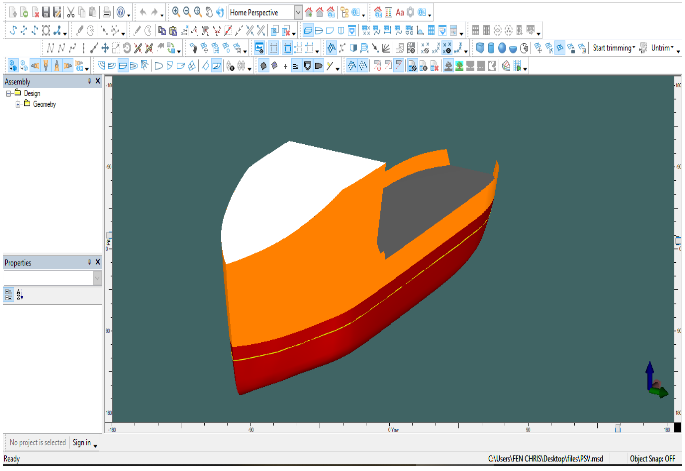

Figure 3: Computer Aided Design of the PSV (Front View)

Next was to set up an Orcaflex model containing just the vessel and with no waves or current at a sea depth of 100m.

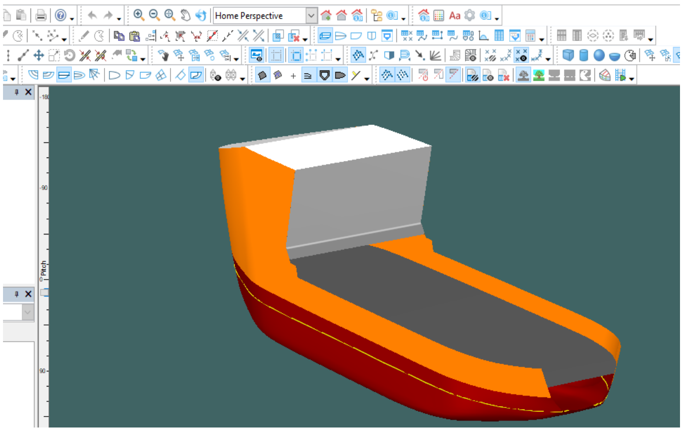

Figure 4: Computer-Aided Design of the PSV (Rear View)

ii. Dynamic Analysis of the PSV

The JONSWAP wave spectrum was used to model the local wind sea wave in different directions. This analysis showed the dynamic movement of the PSV in the various degrees of freedom (heave, surge, sway, yaw, roll, and pitch).

iii. Design of Ship Model

The design of the ship model was achieved in 3-D by SACS Computer Software with the body plan, half breadth, and profile line drawings represented.

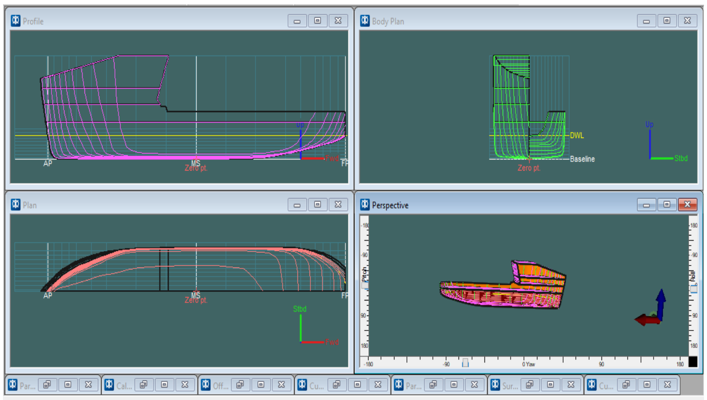

Figure 5. Ship Line Drawings

The design started by modeling the free-floating behavior of the PSV without any loads or lines attached. This allows us to get the basic behavior of the PSV correctly before complications such as moorings are introduced.

Normal Condition (1 Year)

For the operational condition, the PSV was subjected to various directions such as 180° (S), 225° (SW), and 270° (W) for local sea wind waves using the JONSWAP spectrum. The various directions produced different offset values for the PSV in the 3 primary degrees of freedom which will help us to know how the PSV behaves in these various environmental loading.

South Direction (180°)

After the static analysis was completed, the initial position of the buoy was obtained at X of -6.8782, Y of 5.5806, and Z of -0.887.

After the dynamic analysis was completed, the various PSV offsets in the 3 primary degrees of freedom for this direction are presented in Figure 6

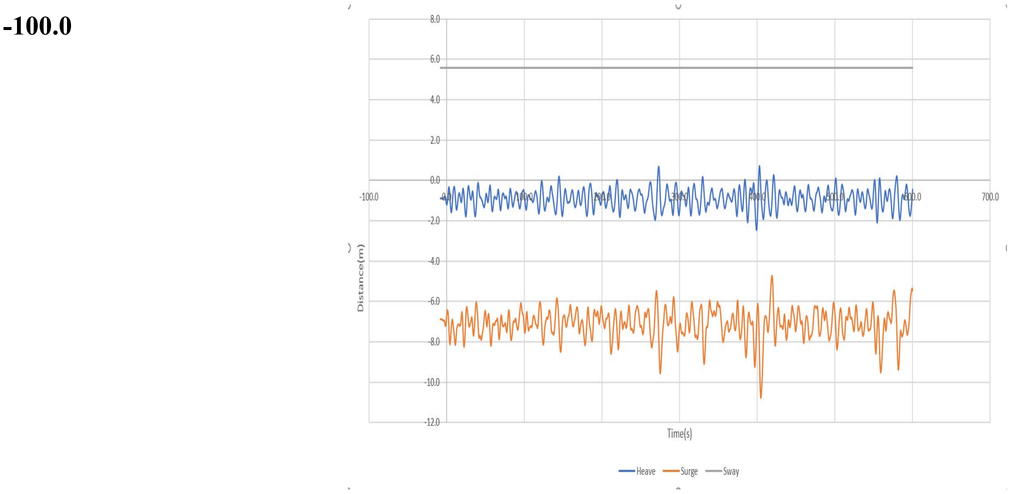

Figure 6: PSV Offset of Heave, Surge, and Sway due to Wind Wave South

i.
Heave
The PSV experiences a maximum displacement of 0.7162m at 402.8s and a minimum displacement of -2.4547m at 399.05s. The offset of the PSV in the heave direction was 1.6032m.

ii. Surge
The PSV experiences a maximum displacement of -4.7275m at 418.95s and a minimum displacement of -10.7670m at 404.65s. The offset of the PSV in the surge direction was 2.1507m.

iii. Sway
The PSV experiences relatively no offset.

Southwest Direction (225°)
After the static analysis was completed, the initial position of the vessel was obtained at X of -6.8748, Y of 5.5725, and Z of -0.8879. After the dynamic analysis was completed, the various PSV offsets in the 6 different degrees of freedom for this direction are presented in Figure 6.

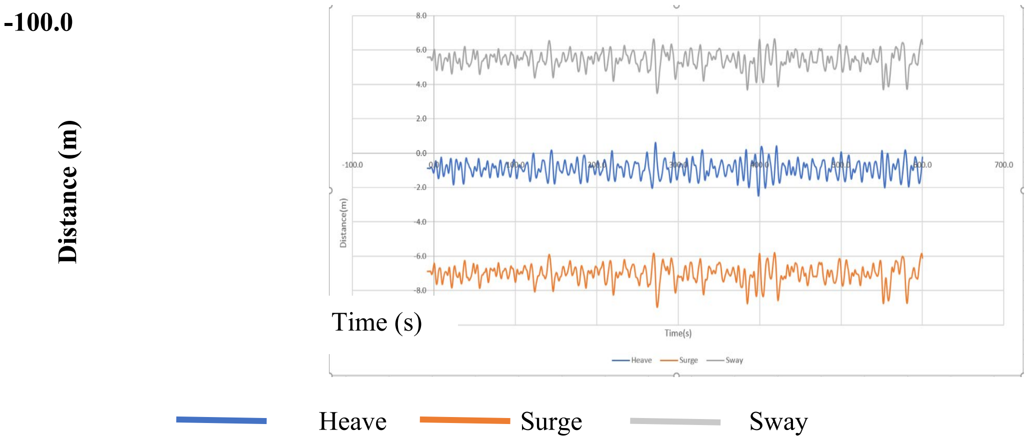

Figure 7: PSV Offset of Heave, Surge, and Sway due to Wind Wave Southwest Direction.

i.
Heave
The PSV experiences a maximum displacement of 0.6154m at 272.15s and a minimum displacement of -2.4956m at 398.55s. The offset of the PSV in the heave direction was 1.5033m.

ii. Surge
The PSV experiences a maximum displacement of -5.7995m at 418.35s and a minimum displacement of -8.9649m at 274.2s. The offset of the PSV in the surge direction was 1.0753m.

iii. Sway

The PSV experiences a maximum displacement of 6.6437m at 418.35s and a minimum displacement of 3.4812m at 274.2s. The offset of the PSV in the sway direction was 1.0712m.

West Direction (270°)

After the static analysis was completed, the initial position of the vessel was obtained at X of -6.8667, Y of 5.5465, and Z of -0.8879. After the dynamic analysis was completed, the various PSV offsets in the 6 different degrees of freedom for this direction were presented

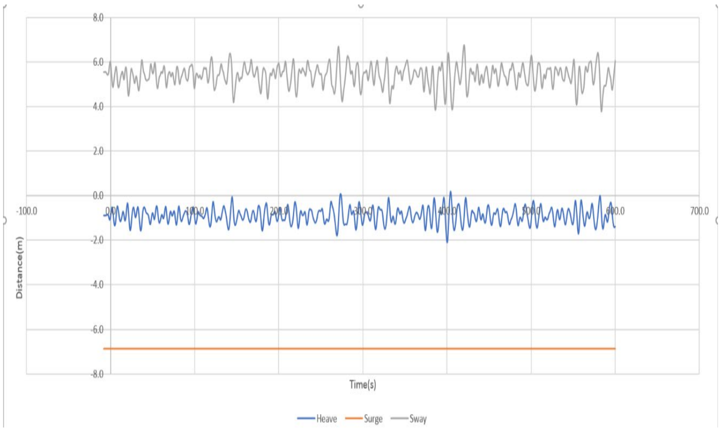

Figure8: PSV Offset of Heave, Surge, and Sway due to Wind Wave West Direction.

i. Heave

The PSV experiences a maximum displacement of 0.1801m at 404.3s and a minimum displacement of -2.0986m at 400.2s. The offset of the PSV in the heave direction was 1.068m.

ii. Surge

The PSV experiences relatively no offset.

iii. Sway

The PSV experiences a maximum displacement of 6.7579m at 420.35s and a minimum displacement of 3.7792m at 583.65s. The offset of the PSV in the sway direction was 1.2114m.

Extreme Condition (100 years): For the extreme conditions, the PSV was subjected to various directions suchas 180° (S), 225° (SW), and 270° (W) for local sea wind waves using the JONSWAP spectrum

The various directions produced different offset values for the PSV 3 primary degrees of freedom which will help us to know which direction exerts the highest environmental loading on the PSV. The same initial position of the PSV obtained during the normal condition was obtained in the extreme condition too.

Heave

The PSV was subjected to different directions and the following offsets were gotten.

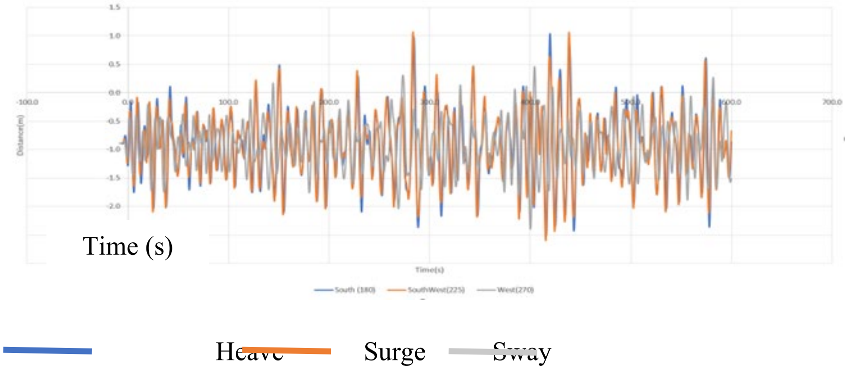

Figure 9: Heave Offset of the PSV at 180,225 & 270 Directions.

i.

South (180°) direction
The PSV experiences a maximum displacement of 1.0387m at 419.7s and a minimum displacement of -2.5126m at 415.95s. The offset of the PSV in the heave direction was 1.9257m.

ii Southwest (225°) direction
The PSV experiences a maximum displacement of 1.0692m at 283.5s and a minimum displacement of -2.6025m at 415.45s. The offset of the PSV in the heave direction was 1.9571m.

iii. West (270°) direction
The PSV experiences a maximum displacement of 0.4587m at 404.35s and a minimum displacement of -2.4002m at 400.25s. The offset of the PSV in the heave direction was 1.3466m.

Surge
The PSV was subjected to different directions and the following offsets were gotten

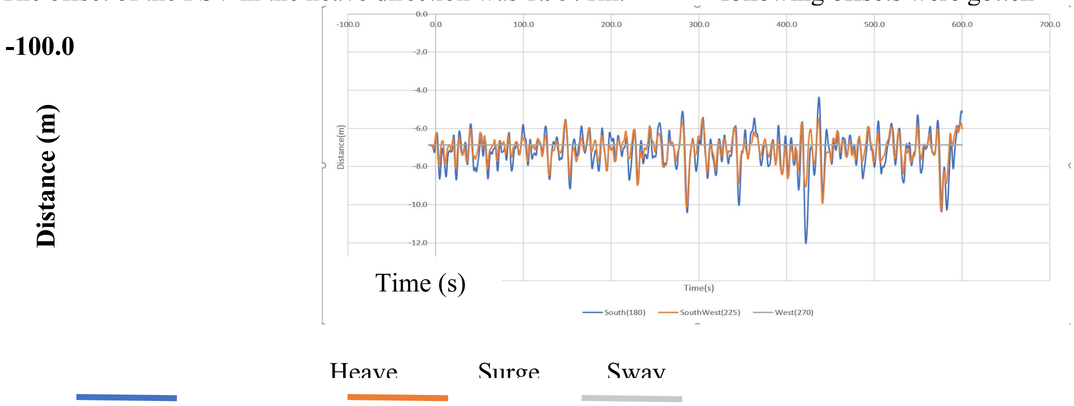

Figure 10: Surge offset of the PSV at 180, 225 & 270 direction

i. South (180°) direction
The PSV experiences a maximum displacement of -4.3713m at 436.7s and a minimum displacement of -12.0393m at 436.7s. The offset of the PSV in the surge direction was 2.5069m.

ii Southwest (225°) direction
The PSV experiences a maximum displacement of -5.4641m at 436.2s and a minimum displacement of -10.316m at 575.8s. The offset of the PSV in the surge direction was 1.4107m.

iii. West (270°) direction
The PSV experiences relatively no offset.

Sway
The PSV was subjected to different directions and the following offsets were gotten.

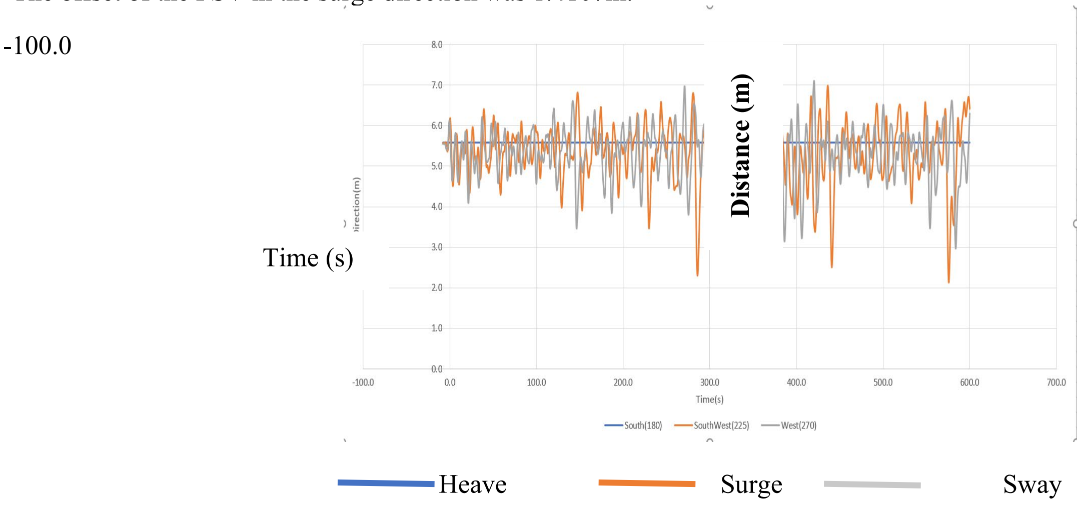

Figure 11: Sway Offset of the PSV at 180, 225 & 270 Direction

i. South (180°) direction
The PSV experiences relatively no offset.

ii. Southwest (225°) direction
The PSV experiences a maximum displacement of 6.9854m at 436.2s and a minimum displacement of 2.1301m at 575.8s. The offset of the PSV in the sway direction was 1.4129m.

iii. West (270°) direction
The PSV experiences a maximum displacement of 7.1007m at 420.3s and a minimum displacement of 2.968m at 583.8s. The offset of the PSV in the sway direction was 1.5542m.

Response of Amplitude Operator (RAO).

The RAO quantifies the amplitude of a ship's motion (e.g., heave, pitch, roll) in response to different wave frequencies and wave directions [26]. It is a crucial concept in ship design and operation because it helps engineers and naval architects predict how a ship will perform in various sea conditions. By analyzing the RAO, informed decisions about the ship's stability, seakeeping ability, and structural integrity.

In more technical terms, the RAO is a complex function that relates the amplitude of the ship's motion to the amplitude and frequency of the incoming waves. It provides valuable information for designing ships that can withstand challenging environmental conditions while ensuring passenger comfort and cargo safety. The RAO was obtained with the aid of ORCAFLEX.

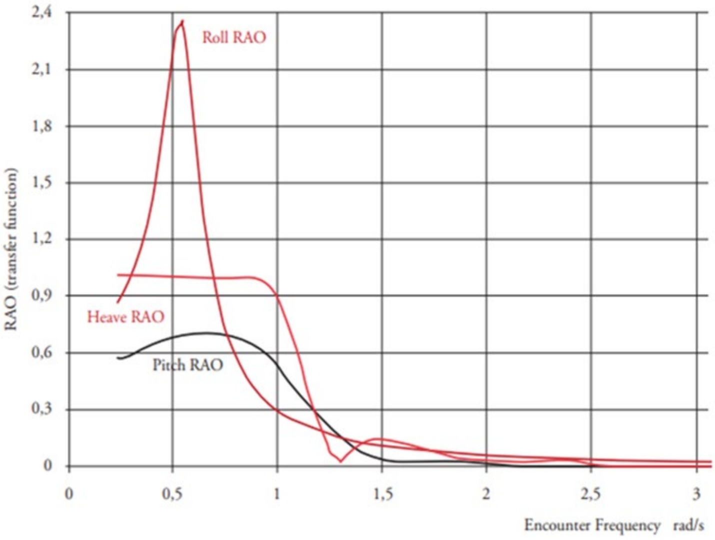

Figure 12: RAO Transfer Function and Wave Frequency[26]

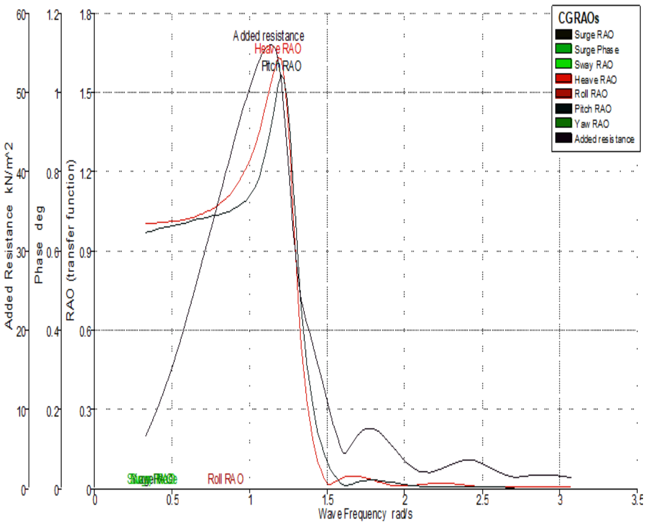

Figure 13: RAO Transfer Function and Wave Frequency of the Designed PSV

Stability Performance Assessment

Usually, building a vessel requires a line plan and calculation of stability and strength before the vessel is built. Traditional supply boats are, however, built only based on experience and have no standard design. Thus, their stability is questionable. In this study, the stability performance assessment for the PSV was carried out using the stability analysis module, Hydromax, which can obtain hydrostatic characteristics of the boat from the integration of its hull forms and the ability to obtain the stability values resulting from a given loading conditions. The Large Angle Stability Analysis method was used in this assessment, enabling the stability curve or righting lever (GZ) curve for the range of specific angles to be calculated and the stability of the vessel evaluated against the IMO stability criteria.

Like the resistance and powering estimation of the vessel, the stability consideration is also an important part of the design spiral, not just for vessels, but for all floating structures. The ability of the vessel to remain in its upright position, before, during, and after operations is very important for the operational life cycle of the vessel and the crew.

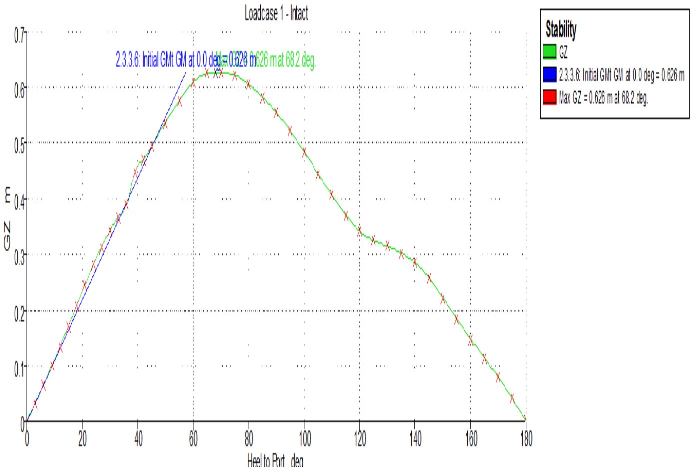

Figure 14: Lever Arm Values with the Heeling Angle

Figure 13 shows the maximum lever arm of the righting moment occurs at a heel angle of 68.2 degrees. This indicates the vessel need not heel more than this, or else there would be capsize which risks the optimum operation of this vessel and its crew in the given terrain. Other cross-stability and Hydrostatics values of the PSV are shown in Figure 14

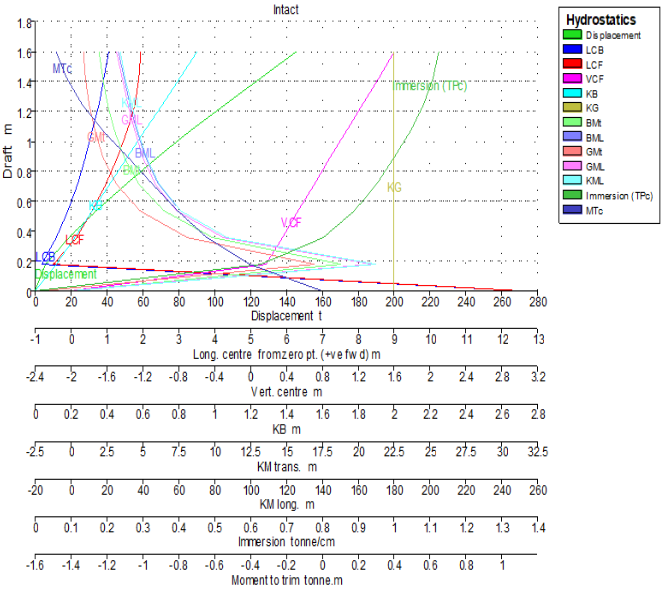

Figure 15: Hydrostatic Curves for the PSV

IV. RESULTS AND DISCUSSION

In seakeeping performance analysis, the sea state is also described by the wave spectrum which represents the spectral wave elevation. It is necessary to choose a wave spectrum appropriate to the Southern region of Nigeria. Since the vessel is frequently operated in coastal waters, the JONSWAP (Joint North Sea Wave Project) spectrum was used in this study. The speed of the boat was assumed to operate at 12 knots. The seakeeping analysis is usually presented in the form of a Response Amplitude Operator (RAO) which describes how the response of the boat varies with frequency. In this study, the RAO graph developed by the Seakeeping module was summarized in Figure 12. After the design of the PSV was achieved, it was subjected to the environmental condition in which it is to operate. The JONSWAP wave spectrum was used to model the local wind sea wave. This analysis showed the dynamic movement of the PSV in the various degrees of freedom (heave, surge, sway, yaw, roll, and pitch).

Findings and Discussion

The results obtained based on the analysis reveal the impact of the stochastic conditions of the marine environment on the PSV. From Figure 6, it is evident that no offset is experienced in the sway direction due to the wave moving in the direction of 180°. The heave and surge offset experienced (1.6032m and 2.1507m) are less than the maximum offset of floating structures (10% of the water depth =10m). From Figure 7, it is evident that the three primary degrees of freedom experience offset due to the wave moving in the direction of 225°. The heave, surge, and sway offsets (1.5033m, 1.0753m, and 1.0712m) are less than the maximum offset of floating structures (10% of the water depth =10m). From Figure 8, it is evident that no offset is experienced in the surge degree of freedom due to the wave moving in the direction of 270°. The heave and sway offsets experienced (1.068m and 1.2114m) are below the maximum offset of floating structures (10% of the water depth =10m). From Figure 9, it is evident that at the 225° wave direction, the environmental loading exerted on the PSV at the heave degree of freedom is 1.9571m.

From Figure 10, it is evident that the 180° wave direction exerts environmental loading to the PSV at the surge degree of freedom (2.5069m). From Figure 11, it is evident that the 225° wave direction exerts the environmental loading on the PSV at the surge degree of freedom (1.4107m).

The PSV stability parameters were also obtained and found to be within the limit of acceptability and the righting lever, GZ was above the 30 degrees requirement of UKMCA criteria for PSVs[28]. The GZ obtained was 62.8 degrees, which should not be exceeded to prevent the PSV from capsizing.

IV CONCLUSION AND RECOMMENDATION

Conclusion

The conclusions are presented as follows;

i. To assess the ship design and operation characteristics, SACS CAD and Hydromax software were used to obtain the characteristics of the PSV from the integration of the hull forms and the ability to obtain the stability values. The results and curve obtained are shown in Figures 2, 3, 4, and 5.

ii. To examine the characteristics of the specified sea environment in which the PSV is to perform its mission, the significant wave height value impacting the PSV in the Gulf of Guinea region was obtained to be 4.012. The value obtained was validated by the study carried out by [27] and falls within the limit of acceptability. The Abs vertical acceleration of the PSV as in the JONSWAP was gotten to be 1.875m/s, which is equivalent to 0.19g. This can be validated by the work carried out by [27], where the vertical acceleration RMS value falls within the range of acceptability for crew or personnel adapted to the movement of vessels.

iii. To evaluate the impact of the specified sea environment on the design and operation of the PSV, the impact was quantified in the form of RAO using the JONSWAP Spectrum. The result obtained is validated by comparing the graph of the RAO transfer function versus the frequency of the designed vessel in Figure 13 with that obtained by [28] in Figure 12 and the values fall within the acceptable limit.

iv. To determine the operational criteria that should not be exceeded, ORCAFLEX software was used to model the static and dynamic analysis in different degrees of freedom and direction and the offset value obtained was within the acceptable limit. All the offsets obtained were below the maximum offset of floating structures (10% of the 100m water depth =10m). Exceeding the offset of 10m will make the vessel not fit for operation. Considering also the stability criteria of the designed PSV with the standard international criteria, the PSV is fit for operation in the Gulf of Guinea. This is validated by comparing the righting lever, GZ, of the designed PSV in Figure 16 with that obtained by [27]. Both righting levers and GZs were above the 30^{0} requirements of [28] criteria for PSVs. Also exceeding the GZ of 62.8^{0} as in Figure 16 will make the PSV capsize.

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