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Response Amplitude Operator Study on an Offshore Supply Vessel (OSV) Operating in the Gulf of Guinea

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ABSTRACT

The aim of this project is to carry out seakeeping analysis of an OSV using wave characteristics of Niger Delta Region. The objectives are to design a novel OSV for Niger Delta region and obtain the necessary principal dimensions, to determine the hydrodynamic analysis of the OSV, and from these calculations, plot engine power and propeller curve. The ability of a RoRo to float crew members and carry vehicles overboard, along with its seaworthiness of the operational life cycle, is of paramount importance not just to the crew members but also in its ability to save life. This is why the designer takes into consideration the possibilities of reducing the heave and roll amplitude effects of the RoRo, which can considerably increase the discomfort of the crew. Heave motion has been considered relatively easy to control and a lot of work has been put into damping the effects by analysing its effect on RoRo. The seakeeping analysis showed a drop and rise in its heave response.

Keywords: Offshore Supply Vessel, Response Amplitude Operator, Seakeeping, Heave Motion, Roll Response, Niger Delta, Gulf of Guinea.

1. INTRODUCTION

With the ever-expanding offshore Supply Vessel (OSV) and specialized interest in services rendered coupled with the discomfort experienced by crew members during journeys by already existing means of transportation, there is now a need for a suitable design model capable of simulating OSV (those with a length of less than 30 metres) manoeuvres (Shin et al, 2004).

To explore these potential benefits, conceptual designs of an OSV are being pursued. The aspiration to improve the Ship Power and Propulsion System performance without hazarding the ship's safety continues to challenge the designers of the world. Propulsion devices have been the subject of recent investigations. A nonlinear unified state-space model for ship manoeuvring and control in seaway is presented by Fossen (2005). Recent experiments have been performed to study formation and dynamics in thrusters and preliminary results are encouraging. However, conclusive proof of these results would best be obtained from open sea testing.

For practical applications, increased propulsion efficiency should be attained. Outside the U.S., Japan and Russia are very interested in novel designs such as catamarans. In the early 1980s, the Japanese Ship and Ocean Foundation launched a research and development program to acquire the technology necessary for optimal design. Min-Guk and Yonghwan (2011) introduced a unified model for ship manoeuvring in waves where the interaction between the manoeuvring and seakeeping model is done similar to the unified models presented above. The ship, Yamato I, was completed in the fall of 1991 and completed sea trials. This $40M ship has a displacement of 185 tons, length of 110 ft, design speed of 8 knots and is propelled by twin thrusters with low temperature superconducting magnets. Manoeuvrability and propulsive model was discussed by Zachrissson (2011).

Since the oil boom in the Niger Delta area of Nigeria, there has been an increase in water transportation used to convey cargoes, equipment, foods and other supplies. The requirement for a novel design to assess its performance in this region has never been researched, since the accuracy of its prediction so far leaves much to be desired. All four rotational motions such as roll, pitch, surge and yaw are to be considered; it is necessary to determine the behaviour of the OSV using wave characteristic readings of the region. This project uses a mathematical model of Maxsurf software which predicts response amplitude operator (RAO), resistance, and power using various methods such as Holtrop and Mennen, Van Oortmerssen and Slender Body Power method. With sufficient data pertaining to the principal dimensions of the OSV, in particular the hydrodynamic properties, there is no reason why this mathematical model cannot be used, if so desired, to assess the OSV behaviour.

1.1 Aim

To carry out the RAO calculations of the OSV.

1.2 Definition of Problem

During the design of an OSV, hydrodynamic analysis is of great importance. Improper analysis of the power, resistance and RAO of the OSV will cause problems with regards to overloading prime movers, inability to attain required speeds while operating, and excessive fuel consumption. Ship hydrodynamics should not only operate satisfactorily in the design conditions, but also in off-design situations which the ship might encounter while underway. If the hydrodynamics analysis of the OSV is not properly analysed with a suitable hull and propulsor, the optimum propulsive efficiency will not be attained and passengers will experience great discomfort.

1.3 Scope of the Project

The scope of this research work is limited to calculating the various parameters needed to suitably analyse an OSV for Niger Delta region at various operating conditions. This project covers the resistance, power and RAO analysis and how they play a crucial role in designing and analysing the safety of the crew members. The design proposal is approached by learning about the underlying assumptions of RAO; the mathematical relationships of the principal dimensions of the OSV were derived with the aim to increase suitability to the crew members and achieve an economical operation.

2. LITERATURE REVIEW

2.1 Strip Theories and Floating Structures

During the 1970s, the application of strip theories was expanded to multi-hulls, particularly SWATH vessels. Clear examples of that development are Ohkusu and Takaki (1971), Lee et al. (1973) and Hadler et al. (1974). Lee et al. (1973) studied heave and pitch motions of a SWATH in head seas and found that the analytical prediction overestimated the response amplitude at the resonance encounter frequencies.

These discrepancies were associated with an inadequate account for two different effects: viscosity and the 3-D hydrodynamic interaction between the two hulls, i.e. interference effect, especially at higher speeds. Regarding the viscosity problem, while the damping mechanism of ship motions is being controlled by the wave making effect, the viscous damping can be neglected. However, for the case of a heaving SWATH, due to the vorticity generated by the flow separation along the struts, the viscous damping gains significance and has to be considered (Brizzolara et al, 2013). Such conclusions motivated the development of strip theories for twin-hulled vessels, which showed that the effects of viscous damping on the motions of a SWATH hull could be predicted by combining strip theory with a cross-flow approach. This idea was later adopted by several authors, including Chan (1993). Triunfante et al. (2004) extended the method to conventional catamaran hull forms. Despite this, viscous effects are generally considered unimportant to the heaving and pitching of floating structures, an idea which is supported by numerical results (Guo et al., 2016).

2.2 Embedding Dynamic Analysis into Design Procedures

Up until the late 1980s, despite a good volume of research on embedding systematic dynamic analysis into the design procedures, the conclusions did not bear substantial developments (Kukner and Sarioz, 1995). The bulk of the work would actually focus on resistance as the hydrodynamic parameter to optimize dynamic analysis.

The reality is that the resistance problem is, without question, a vital aspect of any ship design. In light of this, a great amount of investigation has been continuously presented throughout the years, all of which aimed for the development of optimization procedures that addressed this problem in early stages of the design (Maisonneuve et al., 2003).

The development of FOP and its use on offshore facilities should raise awareness for the importance of including early dynamic analysis in the design and optimization procedures in order to increase wellness and comfort onboard.

In the early 1990s, Hearn et al. (1991) developed a procedure aimed to assess the sensitivity of certain seakeeping characteristics upon the change of the main particulars, for which a numerical tool based on strip-theory was used to perform the dynamic analysis. A destroyer was used as case study. This work, based on systematic variations, resulted in a series of design charts that were intended to aid the designers in modifying hull forms.

Still, as pointed out a few years later by Sarioz (1993), 'it is not possible to produce generalized design guidelines which are applicable to all floating structures, ranging from small high-speed vessels to giant low speed bulk carriers,' being now clear that the dynamic behaviour characteristics are influenced quite differently by changes in the hull form parameters depending on the type of vessel. In light of this, by applying non-linear optimization techniques to the problem of seakeeping design, Hearn et al. (1992) expanded the range of designs covered by the previous model.

The new results were applied to design a trawler and a general cargo vessel. Around the same time, as part of a Greek research project, Papanikolaou (1990) focused on the preliminary design and computer-aided optimization of a high-speed SWATH car-passenger ferry and developed a model that pushed the boundaries of ship design optimization.

Starting from a pre-existing design, a three stage techno-economical optimizer was developed which included: a parametric economical evaluation that had Net Present Value (NPV) and Required Freight Rate (RFR) as measures of merit; a global hydrodynamic optimizer based on Hilleary's tangent search method to generate the main dimensions, proportions and form parameters of the vessel; and a local hydrodynamic optimizer relying on Lagrange's multiplier method dedicated to the refinement of the wetted hull form.

The minimization of the calm water resistance with respect to least power requirement and the improvement of the seakeeping performance, while avoiding resonances in roll/pitch/heave, were the main focus in terms of hydrodynamics. The authors used calm water resistance as a constraint in the procedure. Purvin (2003) studied the design of a slender, semi-displacement catamaran with variable horizontal clearance ratios and its influence upon both the heave/pitch responses and the calm water resistance. The analysis was carried out in SWAN-2 (Ship Wave Analysis), a time domain Rankine panel method developed at MIT (Massachusetts Institute of Technology, Cambridge, Massachusetts, USA).

Around the same period, Maisonneuve et al. (2003) implemented the procedures developed during FANTASTIC, a 3-year research program focused on the improvement of design methodologies of ship hull shapes, into the optimization of a fast mono-hull. The main goal was to identify the main particulars, which were varied by about ±10%, that minimized the calm water resistance while maximizing the seakeeping capabilities of the vessel, measured in terms of comfort of the passengers via Motion Sickness Incidence (MSI) index. The displacement and the transverse metacentric height were used as constraints. The standard linear strip theory software SOAP (Seakeeping Operability Analysis Program) was used to carry the seakeeping calculations while the resistance predictions were performed using WARP (Wave Resistance Program), a linear potential flow code developed by CETENA.

Similar work has been done by Vernengo et al. (2009). In association with the US Navy, Rollings (2003) presented a seakeeping analysis of small displacement high-speed vessels using SHIPMO, a strip theory based software developed by MARIN (Maritime Research Institute Netherlands, Wageningen, The

Netherlands). Several hulls derived from the Series 64 models were generated as combinations of four different parameters: B/T ratio, $\Delta/(0.01LPP)^3$ which is a payload indicator, and Cb. Grigoropoulos (2004) proposed a methodology for hull form optimization in calm and rough water applied to two case studies: a conventional reefer and a naval destroyer. The method was based on an initial optimization of a parent hull form in terms of seakeeping (minimization of the sum of the peak values of vertical acceleration and relative motion near the ship bow in head seas) and the improvement of the resulting optimum hull form for calm water resistance. Hull variants were obtained by applying the method of Lackenby and manipulating both the main dimensions and form parameters Cwp, LCF, Cb, LCB, Cm and KB. The dynamic calculations were carried out in a classic linear strip theory method while for resistance the panel code SWAN-2 (Ship Wave Analysis) was used. Grigoropoulos and Chalkias (2010) presented a development of the previous work in which the hull forms were optimized via wash waves (calm water) and selected dynamic responses (rough water). This time the methodology was implemented in the optimization of a planning hull form and a fast displacement ferry. The hull variations were generated parametrically using FRIENDSHIP-Modeler and evaluated using evolutionary strategies for a dual-objective optimization.

Kapsenberg (2005) presented a method to find a hull form that satisfies a set of seakeeping requirements associated with the minimization of vertical motions and accelerations. The procedure starts with a parent hull of a frigate characterized by polynomials that define the beam on the waterline, the draft and the sectional area as a function of the length.

An optimization routine resorting to Lewis transforms is then used to vary the hull form until the vertical accelerations and relative bow motion are minimum. The seakeeping analysis is performed by linear strip theory software with forward speed corrections as developed by Delft University of Technology.

Resorting to Simulation-Based Design, Campana et al. (2006) presented the fundamentals for hydrodynamic shape optimization, including strategies to reduce the computational effort, techniques for mesh manipulation and methodologies for verification and validation of results, applied to a US Navy surface combatant.

Ang et al. (2015) integrated a geometry modification technique — Free Form Deformation (FFD) — with advanced optimization and evaluation algorithms — Genetic Algorithm (GA) — in order to improve the efficiency and the hydrodynamic performance of offshore vessels. The goal was to reduce the total resistance while optimizing the seakeeping performance by minimizing the roll peak RAO, for which a CFD code and strip theory were used, respectively.

2.3 Dynamic Simulation Methods

According to Salvesen et al. (1970), the performance of floating structures in a realistic seaway should be the ultimate criteria for the design of any hull. Predicting motions and dynamic loads is, however, a very complex problem. As a consequence, these calculations were mostly neglected from the design procedures up until the 1950s. Instead, laboratory experiments with models were performed.

However, besides being expensive and time consuming, these experiments were not feasible to evaluate individual designs, and reliable tools to relate the behaviour of the model with the vessel dynamics in a chaotic ocean environment was unavailable at that time. Inspired by the field of electromagnetic communications, Pierson and St Denis (1953) showed that spectral analysis could be the solution for this problem. The superposition principle was applied and it was hypothesized that the responses of a floating structure to irregular waves could be the sum of the responses to regular waves of all frequencies.

Their work was a clear landmark in dynamic analysis and brought to light the importance of developing theoretical and numerical methods to predict wave responses. Several seakeeping and dynamic behaviour theories have been developed with relative success throughout the years.

The 2-D harmonic flow solution of Ursell (1949) for the heaving motion of a half-immersed circular cylinder and the generalization to arbitrary shapes using conformal mapping techniques was a major breakthrough towards the development of a consistent theory of ship dynamic analysis. These results were later applied in the form of frequency domain strip theories.

Their strip theory for heave and pitch motions in head waves became the first motion theory suitable for numerical computations with adequate accuracy for engineering purposes. Numerous modifications and extensions came afterwards, but the work of Salvesen et al. (1970) is seen today as one of the most significant contributions to the dynamic behaviour of floating structures field, being considered a standard reference and one of the most cited strip theories (Papanikolaou et al., 1996).

These basically simplify the complex, fully non-linear motions into two sets of coupled linear differential equations: one for heave and pitch and the other for horizontal plane motions, i.e. sway, yaw and roll. The hydrodynamic coefficients are calculated for each cross section of the ship resorting to conformal mapping techniques or 2-D panel methods and integrated to obtain the final global forces.

Comparisons with experimental data throughout the years tend to show a satisfactory agreement for heave and pitch motions and for vertical and horizontal wave-induced loads, while for horizontal motions (sway, yaw, roll) the accuracy of strip theories is far more uncertain (Castiglione et al., 2011). Basic assumptions for such theories are potential flow, slenderness of the hull and linearity of the hydrodynamic forces, which implies that, in principle, the results are only valid for relatively small amplitude motions. Often, for large structures, motions can be adequately described by linear theory.

Still, some effects translate into considerable non-linear forces and thus must be considered. This includes large amplitude motions which can induce impact between the ship and the sea surface, a phenomenon that cannot be described linearly and might result in adverse stresses, and the case of smaller ships or ships with prominent hull flare shapes (Fonseca and Guedes, 1997). In order to account for these non-linear effects, time domain solutions are used rather than formulations in the frequency domain.

If the motions are strictly sinusoidal in time and the non-linear effects are not excessively strong, the equations of motion are solved in the time domain while the hydrodynamic forces are represented by frequency dependent coefficients. Otherwise, the hydrodynamic problem is solved in the time domain together with the equations of motions. Some early work following this approach includes Finkelstein (1957) and Stoker (1957), who used it to study water waves; Cummins (1962), who pioneered its application to the unsteady ship motion problem; and Ogilvie and Tuck (1969), who related the time domain motion equations with the frequency domain equations via Fourier analysis. Later, Fonseca and Guedes (1994) applied a time domain strip theory to solve the formulation proposed by Cummins (1962).

Their description of dynamic behaviour problem was developed to study heave and pitch motions and vertical loads of ships in regular waves considering non-linear hydrostatic forces. The results were found close to the frequency domain solution. With Fonseca and Guedes (1998), the authors further refined the previous work to include non-linear Froude-Krylov forces which, together with the hydrostatic forces, dominate the non-linear effects (Fonseca and Guedes, 2004).

Comparisons between numerical and experimental results for a containership advancing in regular and irregular waves showed that, for relatively slow ships, the method was appropriate for engineering applications, being capable of representing the main non-linearities, thus standing as a clear improvement to the linear solution (Fonseca and Guedes, 2002). With the goal of studying the limits of the method in terms of ship speed, the authors tested it with a fast mono-hull, Fn = 0.4, having compared numerical results with experimental data (Maron et al., 2004). Results showed that the method represents well vertical ship responses for low and moderate speeds but over predicts motions and structural loads as the speed increases.

Davis and Holloway (2003) and Holloway and Davis (2006) stand as other publications that refer to a time domain strip theory used to predict ship motions of fast (Fn = 0.6–0.9), slender vessels in head seas, validating it with model testing for conventional hulls suitable for catamarans, SWATH hull forms and hulls suitable for high-speed mono-hulls.

Generally speaking, strip theories assume that the advance velocity of floating structures is small because they do not properly account for the interaction between the steady wave system of the advancing structures and the oscillatory effects of motions (Schoop-Zipfe, 2017). With the intent of adding speed related effects into the hydrodynamic problem, 2½-D strip theories were developed, an approach which lies between standard 2-D strip theories and 3-D panel methods.

The main difference for a typical strip theory is that, although the formulation is still based on the 2-D Laplace equation, the free surface condition is solved in 3-D. A few examples include Faltinsen et al. (1991), Hermundstad et al. (1999) and Holloway and Davis (2006). Despite this, by using strip theories, several important effects are still being neglected, namely, 3-D phenomena related with the interaction between floating structures sections, a proper account for the effect of the advance speed on the ship motions, the computation of the hydrodynamic coefficients at low frequencies, etc. (Moreno, 1993). At the same time, the account for viscous flows and large amplitude ship motions, which motivated the development of time domain theories, continues to be a problem.

To overcome these limitations, there was an increasing focus on 3-D panel methods, mainly via Rankine sources or Green function, both in time and frequency domain, after the 1980s, driven by the breakthroughs in computer sciences (Beck and Allan, 1991). Nowadays, researchers are interested in even more complex, far more powerful, methods that allow more accurately predicting the seakeeping behaviour and resistance of a wide variety of vessels, including multi-hulls (Bertram and Soding, 1991).

The development of CFD solvers, particularly turbulence models like Reynolds Averaged Navier-Stokes (RANS), stand as the state of the art in seakeeping (Carrica et al., 2006). Instead of being added in post-processing, all the previously mentioned effects are implicitly included in the flow equations that are to be solved; the potential for simulating unsteady flows and ship motions is huge. So far, such methods applied to problems associated with steady resistance and propulsion in calm water has achieved high accuracy (Mousaviraad et al., 2010).

As for seakeeping, results are promising and continuously improving (Castiglione et al., 2011). However, the computational effort required to simulate such problems is still extremely high for a wide number of practical applications, particularly at early stages of the design process. Therefore, it still is useful and meaningful to resort to less demanding tools, namely strip theories, of which the work of Datta et al. (2013) and Rajendran et al. (2015) are recent examples.

2.4 Research Gap

More recently, Castiglione et al. (2011) investigated the seakeeping behaviour of a catamaran resorting to ShipX (VERES) that includes a 2½-D strip theory, and compared the results against CFD and experimental data. Despite the fairly good agreements, it became clear that strip theory overestimates the catamaran motions. Despite the limited application range, whether in terms of speed (for which 2½-D strip theories are an alternative), or due to its inability to properly account for the hull interaction, such theories continue to be subject of investigation. This work was further developed during the following years and broadened to include any fast displacement catamaran design.

Modules for the generation of hull forms and to handle the obtained design, including preparation of common naval architecture drawings, were embedded into the overall optimization procedure. Papanikolaou et al. (1990) presented a research paper that focused solely on the hydrodynamic module. To deal with the seakeeping problem, quasi 2-D (strip or slender body theory approach) and 3-D panel methods were used. Kukner and Sarioz (1995) proposed a forward/inverse methodology applied to high speed hull forms, in particular a speed patrol vessel, and developed realistic seakeeping criteria to investigate the possibility of improving existing designs.

Such criteria included minimizing heave/pitch peak RAOs and accelerations, as well as preventing extreme effects such as slamming and deck wetness. In any case, considering the advantages of strip theories in terms of low computational effort, making them ideal for optimization procedures, particularly during early design stages and within academic contexts, it seems clear that there still is room for improvement regarding its use to predict the dynamic behaviour of the RoRo due to heave and roll motion.

3. METHODOLOGY

3.1 Roll Motion on the RoRo

The roll analysis on the pipe-laying vessel was analyzed with Equations 3.1 to 3.10. The effects of roll motion on the vessel were determined as the depth of the sea increases and also with varying wave position. In the course of this research, a transverse meta-centric height of the vessel was considered.

$$I_4 = 0.16\rho V B^2 \quad (3.1)$$

Where:

I_4 = Roll inertia moment

V = Ship volume

B = Ship breadth

$$A_{44} = 0.15 I_4 \quad (3.2)$$

Where:

A_{44} = Hydrodynamic roll added mass coefficient

$$C_{44} = \rho g V \cdot GM_T \quad (3.3)$$

Where:

C_{44} = Stiffness constant

GM_T = Transverse meta-centric height

$$B_{44} = 2\sqrt{C_{44}(I_{44} + A_{44})} \quad (3.4)$$

Where:

B_{44} = Hydrodynamic roll damping coefficient

Calculation of wave exciting force (F_{44}) in roll

$$F_{44} = A_{44}\ddot{\zeta}^* + B_{44}\dot{\zeta}^* + C_{44}\zeta^* \quad (3.5)$$

Calculations of wave roll force excitation due to wave (Fφ4)

$$F_{\varphi 4} = \frac{F^{44}}{\theta} \quad (3.6)$$

Calculation of roll amplitude

$$\varphi_a = \frac{F_{\varphi 4}}{\sqrt{[C_{44} - I_4\omega^2]^2 + (B_{44}\omega)^2}} \quad (3.7)$$

Where:

φ_a = Roll amplitude

Calculation of roll displacement (φ)

$$\varphi = \varphi_a cos(\theta) \quad (3.8)$$

Calculation of roll velocity ($\dot{\varphi}$)

$$\dot{\varphi} = -\omega\varphi_a sin\theta \quad (3.9)$$

Calculation of roll acceleration ($\ddot{\varphi}$)

$$\ddot{\varphi} = -\omega^2\varphi_a cos\theta \quad (3.10)$$

3.1.1 Wave Motion in Roll

The vessel's roll motion effect due to wave was analysed with Equation 3.11, where the roll acceleration, velocity and displacement was used in determining roll effects as the vessel's position and depth varied as the waves passed by.

$$F_{\omega 4} = (I_4 + A_{44})\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi \quad (3.11)$$

Where:

$F_{\omega 4}$ = Vessel roll excitation force

3.1.2 Roll RAO and Spectral

The roll RAO of the pipe-laying vessel was analyzed with Equations 3.12 and 3.13, to determine how the effect of roll response affects the pipe-laying vessel.

$$RAO_4 = \frac{\varphi_a}{\zeta_a k} \quad (3.12)$$

Calculation of roll spectrum S(ω4)

$$S_{(\omega 4)} = \left|\frac{\varphi_a}{\zeta_a k}(\omega)\right|^2 . S_{(\omega)} \quad (3.13)$$

3.2 Wave Amplitude

The wave exciting force developed from the wave height and period can be analyzed using Equations 3.14 to 3.15.

$$\zeta^* = \zeta_a e^{-kD}(\theta) \quad (3.14)$$

Where:

ζ^* = Wave elevation

ζ_a = Wave amplitude (1 m)

k = Wave number (0.010)

D = Water depth

Calculation of the heave added mass (A_{33})

$$A_{33} = C_a \left[\rho \frac{\pi}{2} \left(\frac{B}{2}\right)^2\right] L \quad (3.15)$$

Where:

C_a = Constant (1)

B = Vessel breadth (41 m)

L = Length of the vessel (249 m)

Calculation of the heave potential damping coefficient (B_{33})

$$B_{33} = 2\sqrt{C_{33}(M + A_{33})} \quad (3.16)$$

Calculation of the heave restoring coefficient (C_{33})

$$C_{33} = \rho g A_{wp} \quad (3.17)$$

Where:

A_{ω} = Vessel water plane area

D = Vessel draft (10 m)

C_B = Block coefficient (0.67)

Calculation of heave amplitude for consideration of a simple harmonic motion

$$Z_a = \frac{\frac{F_0}{c} * cos(wt)}{\sqrt{\left[1 - \frac{w^2}{wn^2}\right]^2 + \left(\frac{2w\varepsilon}{wn}\right)^2}} \quad (3.18)$$

Where:

Z_a = Heave amplitude

3.3 Wave Motion in Heave

The motion effect of wave on the vessel in heave is shown in Equation 3.19. This was used to analyse the wave effect as it affects the pipe-laying vessel at different water depth and wave position.

$$F_{\omega 3} = (M + A_{33})\ddot{Z} + B_{33}\dot{Z} + C_{33}Z \quad (3.19)$$

3.4 Pitching Amplitude

The degree of freedom (D.O.F.) represented the possible translations and rotation of the body. The heave amplitude noted as translation, respectively along X, Y, and Z-axis, defines the behaviour of the ship in seaway. The equation of heave amplitude is solved for head waves.

These equations are demonstrated as follows:

For Pitching Amplitude

$$\emptyset_O = B_o + B_1 C_w + B_2 C_B + B_3 \frac{L}{B} + B_4 \frac{L}{T} + B_5 L_{CB} + B_6 \frac{K}{L} + B_7 \frac{V}{\sqrt{L}} \quad (3.20)$$

Where:

$\emptyset_o$ = Pitching amplitude

3.5 Pitch Motion on the Vessel

The pitch analysis on the vessel will be determined with Equations 3.21 to 3.22, in which the effect of pitch motion on the vessel was analyzed as the vessel's wave position and water depth varies.

$$A_{55} = a_{33} \frac{1}{12} L^3 \quad (3.21)$$

$$C_{55} = \rho g B \frac{1}{12} L^3 \quad (3.22)$$

$$B_{55} = b_{33} \frac{1}{12} L^3 \quad (3.23)$$

$$I_5 = \frac{C_{55}}{\omega^2} - A_{55} \quad (3.24)$$

Calculation of wave exciting force (F_{55}) in pitch

$$F_{55} = A_{55}\ddot{\zeta}^{*} + B_{55}\dot{\zeta}^{*} + C_{55}\zeta^{*} \quad (3.25)$$

Calculation of wave exciting force amplitude in pitch (F_θ5)

$$F_{\theta 5} = \frac{F_{55}}{(\theta)} \quad (3.26)$$

Calculation of pitch amplitude

$$\theta_a = \frac{F_{\theta 5}}{\sqrt{[C_{55} - I_5\omega^2]^2 + (B_{55}\omega)^2}} \quad (3.27)$$

Where:

θ_a = Pitch amplitude

Calculation of pitch displacement (θ)

$$\theta = \theta_a cos(\theta) \quad (3.28)$$

Calculation of pitch velocity (θ̇)

$$\dot{\theta} = -\omega\theta_a sin\theta \quad (3.29)$$

Calculation of pitch acceleration (θ̈)

$$\ddot{\theta} = -\omega^2\theta_a cos\theta \quad (3.30)$$

3.6 Pitch Wave Motion

The analysis of the pitch wave motion affecting the stability of the vessel was given in Equation 3.31, in which the acceleration, velocity and the pitch displacement was used in the analysis to show the behaviour of the vessel in the pitch position.

$$F_{\omega 5} = (I_5 + A_{55})\ddot{\theta} + B_{55}\dot{\theta} + C_{55}\theta \quad (3.31)$$

Where:

$F_{\omega 5}$ = Wave pitch excitation force

4. RESULTS AND DISCUSSION

The overall performance of the offshore supply vessel depends on its ability to stay afloat no matter the ocean condition where its mother vessel is designed to operate. The seakeeping performance procedure is based upon the probability of exceeding specified vessel motions in a sea environment particular to the vessel's mission.

Given the operational area of the vessel, the percentage of time the vessel operates in a particular sea state can be determined from an oceanographic database through application of the heave response. The predicted responses in motions are compared to the motion limiting criteria to obtain the operability indices. However, the operability indices are strongly affected by the chosen limiting criteria. Therefore, it is required to describe three principal concepts in order to understand the seakeeping performance — seakeeping analysis is essentially a three-part problem.

The analysis of the effect of heave motion shown in Appendix B is determined from the heave force acting on the RoRo. The phase shift was analysed to determine heave response. Also, the heave and hydrodynamic force acting on the interpolated vessel is estimated using Maxsurf software. The basic ship plan using the dimensions of the proposed RoRo vessel is shown, and plots of the vessel hull design are shown in Figs. 4.1 to 4.5.

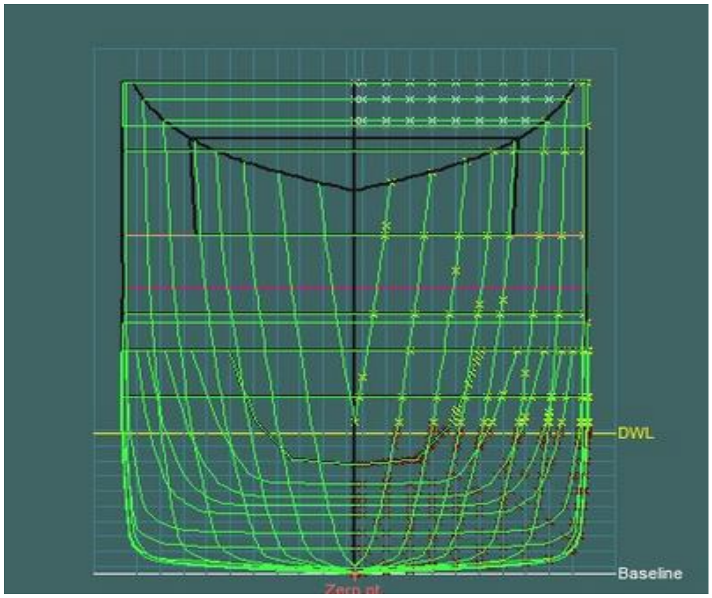

Fig. 4.1: Body Plan of the RoRo Vessel

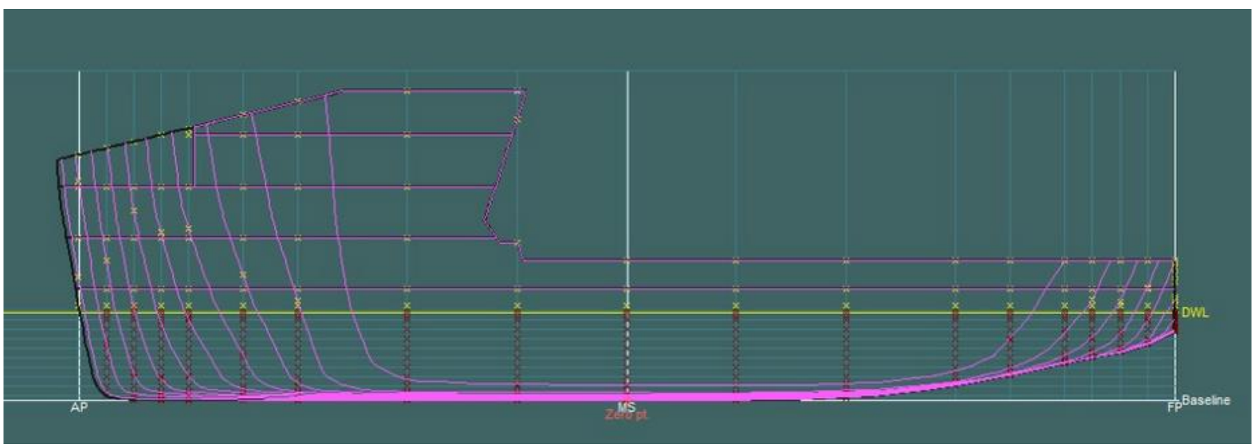

Fig. 4.2: Shear Profile of the RoRo Vessel

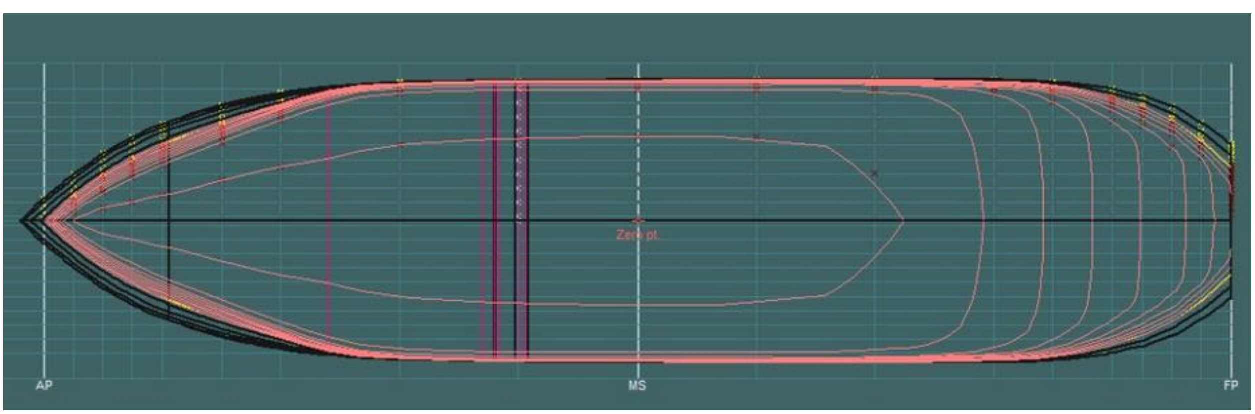

Fig. 4.3: Transverse View of the RoRo Vessel

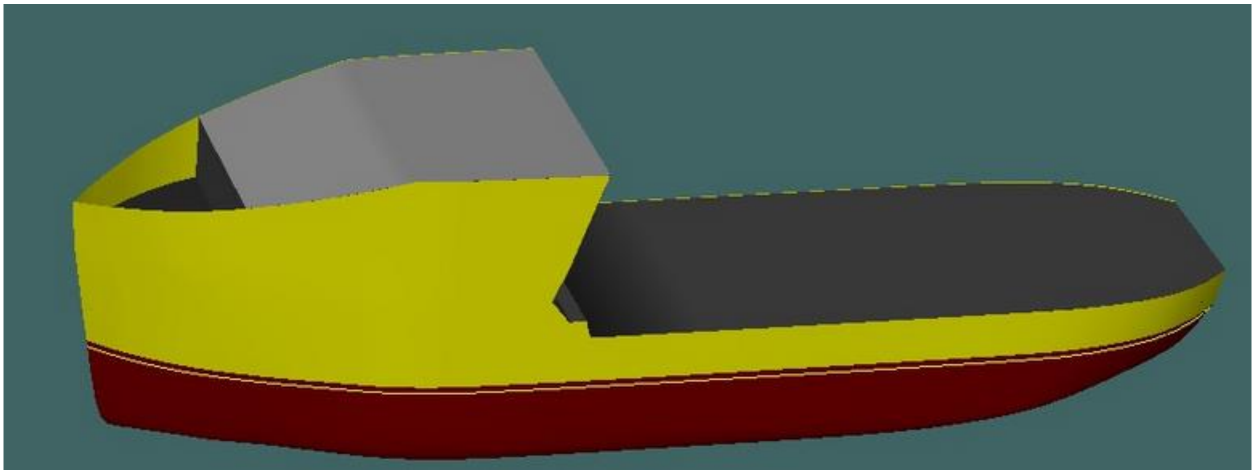

Fig. 4.4: Full Layout of the RoRo Vessel

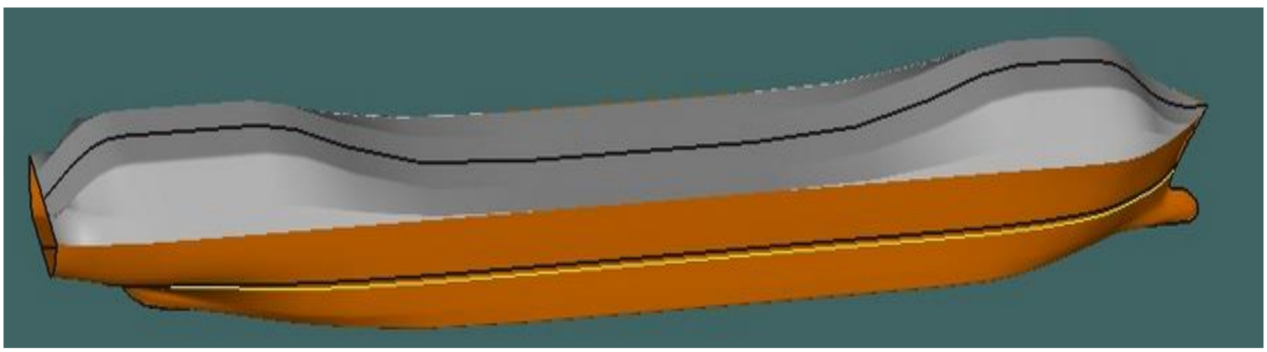

Fig. 4.5: Hull Layout of the RoRo Vessel

4.1 Heave Force

The heave force at various wave times is shown in Figs. 4.6 to 4.8 using a wave length of 6 m tidal wave as a case study. As shown in the figures, as time increases, the heave response displacement reduces until 5 s. There is a rapid fall in heave force from a frequency frame of 0 to 4.5 s. The heave force as observed tends to increase again from 0 to 5 s.

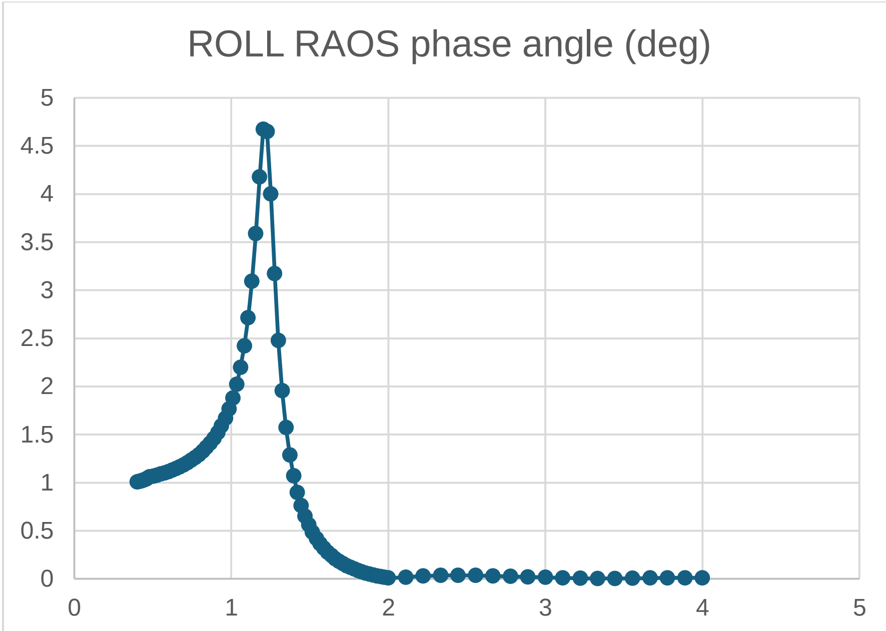

Fig. 4.6: Heave RAO Against Encounter Frequency

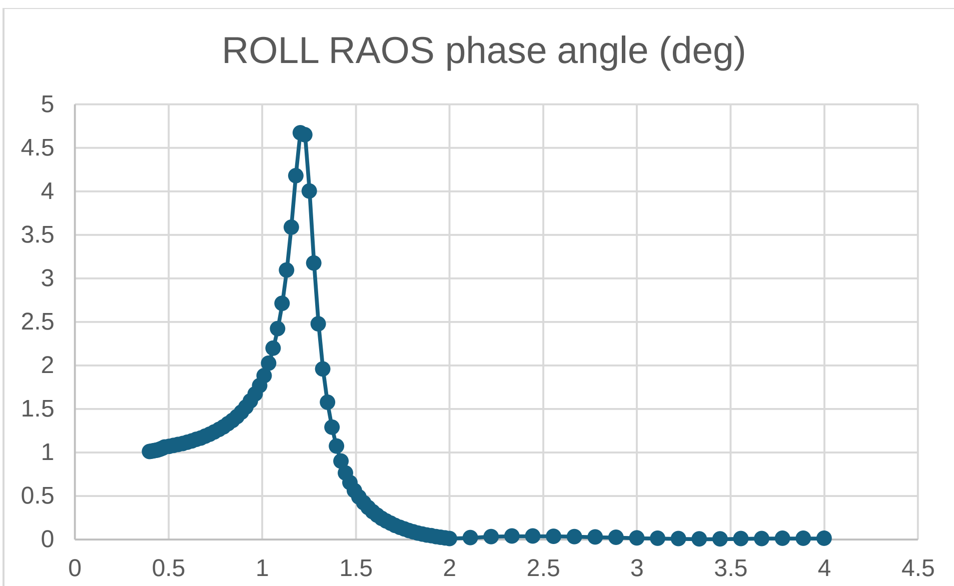

Fig. 4.7: Heave Phase Angle Against Encounter Frequency

As shown in Fig. 4.8, the total heave force of the RoRo is shown as the wave frequency increases from 0 to 5 s and it also decreases from 5 to 10 s. The heave force observed forms a quadratic curve from 0 to 5 s. The displacement directly specifies the motion and the force with which the safety apparatus responds.

4.2 Roll Response

The Roll Amplitude on the ship response was analysed at varying time (0 to 4.5 s) and at a wave frequency of 4 Hz as shown in Fig. 4.3. The heave amplitude of the vessel shown in Fig. 4.8 experiences a spike at 0 to 4.5 rad/s and the heave response shows no significant upward movement.

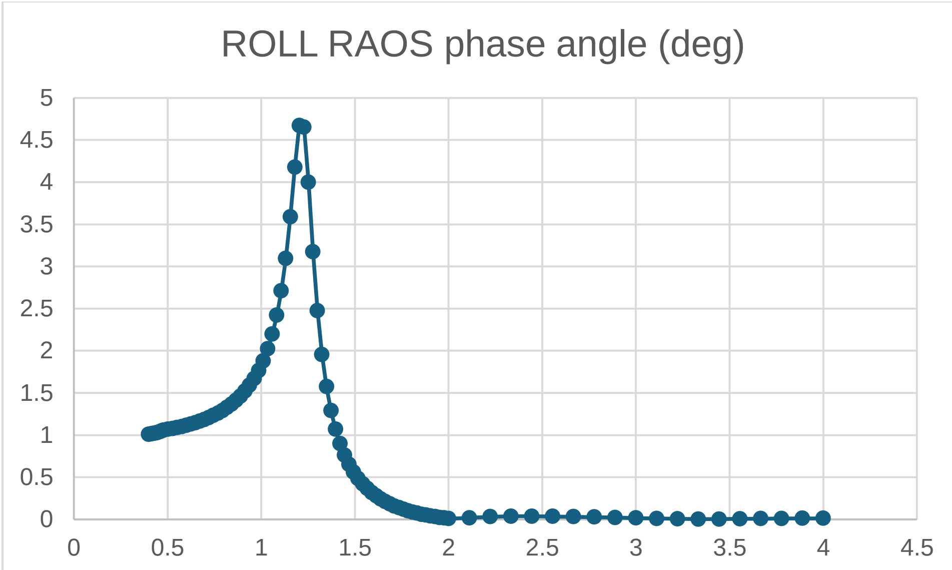

Fig. 4.8: Roll RAO Response

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The ability of a RoRo to float crew members and carry vehicles overboard, along with its seaworthiness of the operational life cycle, is of paramount importance not just to the crew members but also in its ability to save life. This is why the designer takes into consideration the possibilities of reducing the heave and roll amplitude effects of the RoRo, which can considerably increase the discomfort of the crew. Heave motion has been considered relatively easy to control and a lot of work has been put into damping the effects by analysing its effect on RoRo. The seakeeping analysis showed a drop and rise in its heave response.

5.2 Recommendations

This project gives an overview of the different simulations on seakeeping analysis of an OSV. The following recommendations can be made:

1. The effect of other ship motions should be analysed and the results compared to that of heave.
2. Other numerical models of the vessel heave responses can be considered. This can give more room for future studies.
3. Variations with other vessels, especially general cargo, passenger vessels and liquefied natural gas carriers, should be considered at least for further investigations.

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