e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

ANALYSIS OF THE EFFECT OF HEAVE AND PITCH MOTION RESPONSES ON A CARGO VESSEL

Apresai, Ernest P.[*1], **Kilakime, Tari A.**[*2]

[*1]Lecturer, Department Of Marine Engineering, Niger Delta University, Bayelsa State, Nigeria.

[*2]Technologist, Department Of Mechanical Engineering, Niger Delta University, Bayelsa State, Nigeria.

ABSTRACT

It is possible to anticipate motion of a vessel theoretically or experimentally, experiments are costly, time-consuming, and impractical in the early stages of design. Therefore, at least in the initial stages of ship design, the designer mostly relies on theoretical methods. Cargo vessel transport cargoes from one country/port to another and passes through sea. The wave disturbance on the sea is sometimes of great magnitude which is devastating on the vessel and cargoes. The analysis of the effect of wave on cargo vessel motion were determined in heave and pitch force and moment acting on the vessel with varying wave direction from 0° to 120°. The analysis was estimated using MATLAB. While from 30° to 120° wave directions, the Sw_5 fluctuates between 0 m^2s/rad to 0.2777 m^2s/rad (30°), 0.8746 m^2s/rad (60°), 1.1944 m^2s/rad (90°) and 0.9172 m^2s/rad (120°), which later dropped to 0.1632 m^2s/rad (30°), 0.5618 m^2s/rad (60°), 0.7992 m^2s/rad (90°) and 0.6388 m^2s/rad (120°) respectively. From the analysis, the wave response effect on the vessel is more significant at 90° wave direction than at any other wave direction.

Keywords: Motion, Heave, Pitch, Wave, Response, Cargo, Vessel.

I. INTRODUCTION

The buoyancy of a ship changes as it moves through wave crests and troughs due to wave action. The ship goes downward when there is a wave trough because the buoyancy along the ship decreases there. Ship buoyancy increases and travels upward where a wave crest is present. A wave is a disruption that moves through water, usually brought on by wind or other weather-related factors. These waves can significantly affect a vessel's motion and stability at sea and they vary in size, frequency, and energy. Along with interacting with other bodies of water like tides and currents, waves can also be influenced by the depth and form of the ocean floor (1-3).

Often referred to as freighters, cargo vessels are ships built especially to move materials and products across the ocean. These ships range in size from tiny coastal craft to massive, deep-sea freight carriers that have the capacity to transport thousands of containers. Raw materials, manufacturing commodities, consumer goods, and a variety of other items can be transported by these vessels. Among the most frequently carried commodities are vehicles, coal, oil, and grain. A particular kind of cargo vessel that has grown in popularity recently is the container ship, which can move big loads of freight fast and effectively. They are crucial for establishing connections between producers, suppliers, and customers and are necessary for the expansion and advancement of worldwide economy (4, 5).

A vessel's vertical movement in reaction to waves is known as heave motion, as the waves flow beneath the ship, it will move up and down. Passengers and staff may find this uncomfortable, especially on larger ships like cruise ships or offshore installations. It may need to be considered during the vessel's construction and operation because it can also impact the vessel's performance and stability. When choosing a voyage route, it's critical to take the ship's motion into account. Sea state forecasts are crucial for mitigating the motion, and locations with large waves should be avoided as they can enhance heave motion (6, 3).

Ships are built expressly to move materials and goods across oceans and, are referred to as freighters or cargo vessels. These ships range in size from modest coastal craft to enormous, deep-sea cargo ships capable of transporting thousands of containers. A broad variety of goods, including consumer goods, manufacturing goods, and raw materials, can be transported by these vessels. Among the most often moved commodities are cars, coal, grain, and oil. Because they can move big loads of cargo swiftly and effectively, container ships are one kind of cargo vessel that has grown in popularity in recent years. They facilitate communication between producers, suppliers, and customers and are necessary for the expansion of the world economy (4, 5).

The rotating movement of the vessel around the transverse axis, which extends from port to starboard, is referred to as pitch motion. The bow and stern of the ship move up and down as a result of this movement, which may have an impact on the ship's performance and stability. Pitch motion is brought on by the way the ship interacts with waves and currents, as well as by the steering and propulsion systems. The weight and distribution of the ship's passengers and cargo may also have an impact. Passengers and crew may also experience pain due to pitch motion, especially on bigger ships like cruise ships or offshore installations vessels. Additionally, it can impact on the vessel's performance and stability, and it might need to be considered when designing and operating the vessel (7, 6, 3, 1).

However, the interaction between the forces and moments caused by waves and the forces and moments associated with ship manoeuvring determines the motion that a ship experiences at sea. Additionally, simulating the forces and moments caused by waves and manoeuvring in many degrees of freedom is necessary for consideration of, for example, strategies for counteracting roll motion in waves using rudder movement. Therefore, it is preferable to create a single model that captures ship motion in several degrees of freedom while accounting for waves and manoeuvring effects (8). Ship motion caused by wave manoeuvring has been described by a number of unified models developed in recent decades. Fossen (8) presents a nonlinear unified state-space model for ship manoeuvring and control in seaway. The unified model is created by superimposing a model for seakeeping and manoeuvring.

Ship Motion

It may be necessary for a ship designer to evaluate a vessel's performance in various environments, including adverse weather conditions. A designer must be able to accurately forecast the motion response of a vessel because it directly affects the vessel's performance. It is possible to anticipate motion theoretically or experimentally. Experiments are costly, time-consuming, and impractical in the early stages of design. Therefore, at least in the initial stages of ship design, the designer mostly relies on theoretical methods. For the past 40 years, a number of scholars have been working on 2-D based theoretical and computational approaches of ship motion computations, such as rational strip theory. In erratic, short-crested waves, a ship moving at a constant speed will oscillate in six different directions. The ship will heave (vertical motion), pitch (tilting motion), and surge (bow-aft motion) around its mean forward progressing position in the simplified scenario of steady speed while encountering or following regular waves. Its motion will follow the motion of the sea surface in extremely long waves; but, in shorter waves, the motion will be greatly amplified and out of phase with the motion of the sea surface around the vertical heave and pitch resonances of respective motion as shown in Figure 1 (9-11).

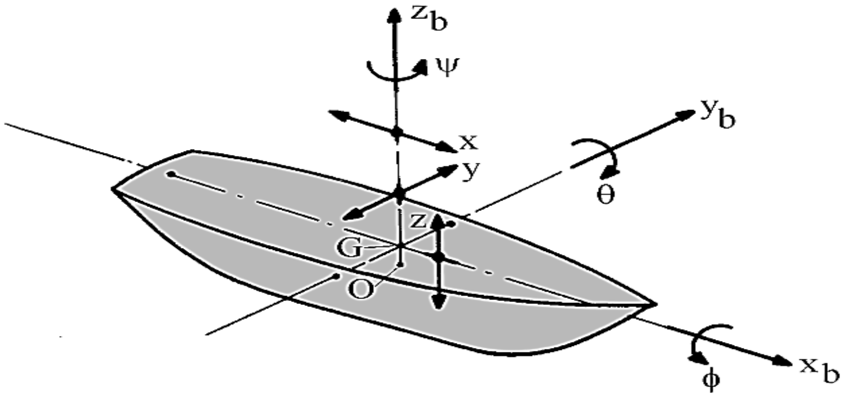

Figure 1: Ships motion in water (12)

Heading Wave Effect on Ship Motion

While the motion characteristics of the ship are evaluated in calm waters, the evaluation of the ship in waves is more accurate because seagoing ships navigate through waves. Wave action modifies the kinematics of the water particles surrounding the ship and the hydrodynamic forces operating on it, changing the ship's motion. Therefore, when assessing the motion of the ship during an ocean-going towing operation, it is crucial to take wave impacts into account for the safety of the towed ship. Particularly, waves with varying heads causes the vessels to respond with motion, which could restrict the towing process operational capacity. By analysing turbulent free surfaces with viscosity taken into account, computational fluid dynamics can be used to illustrate that pressure variations surrounding a ship and the impact on its motion characteristics (13-16).

Linear Wave Theory

Regular waves are those that have the same height (amplitude), frequency, and length as seen in Figure 2. They produce periodic loads on ships and other offshore structures that are floating or free in the deep sea or on the water's surface. From horizon to horizon, the seas appear to be a never-ending moving sequence of hollows and irregular humps, with minor abnormalities, if the waves are modest, if the waves are high. However, the outcome will be enormous stormy seas (12).

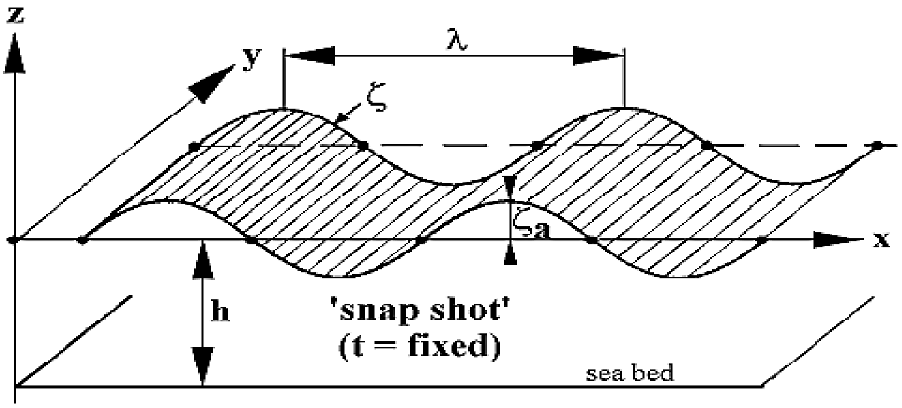

Figure 2: Water wave structure (12)

The sea wave state and the wind wave state are the two district states that essentially distinguish waves at the ocean's surface. As a general rule, 10 seconds is considered to separate the sea waves from the swell waves, however significant overlap must be allowed. Sea waves are often shorter than swell-induced wind waves. In contrast to swell waves, which are created by wind and eroded as a result of the wind raising the sea surface, these waves are rougher and more angular (12).

Irregular Waves

Irregular waves are the result of regular waves superposed with short crests and varying wave heights and lengths. Time series elevation can be created from wave spectra composed of different frequencies from a regular wave, which is a combination of first and second order correction term solution, in a stochastic sea state, which provides a good depiction of the irregular wave model. The term "wave envelope" refers to the combining of two or more successful wave crests to a curve that provides information on the waves grouping (12).

Response Amplitude Operation

The wave's frequencies determine the potential damping, the force that is already there, and the added mass. The phase shift and heave motion can be expressed as a ratio of the wave amplitude; this ratio is referred to as the response amplitude operator (RAO). It explains the response of a vessel in first order motion to a wave and is created using the wave potential theory with a specified amplitude and period. By establishing a link between the vessel's motion amplitude and the wave's ($Za/\zeta a$), the phase shift that occurs between the moment the crest passes the RAO origin and the positive excursion reaches its maximum ($\epsilon z,\zeta a$) is explained. The load RAOs ($Fa/\zeta a$) reflect the phases and amplitude of the roll, pitch, and yaw (moment) or the surge, swag, and heave (force). A vessel's dynamic reaction to an incoming harmonic wave is analysed in order to determine the RAOs displacement in each of the six degrees of freedom. The motion spectrum of the vessel can be analysed by first computing the RAOs, and then determining the hydrodynamic constants Aij and Bij, that affect the shallow water effect (12, 17).

Moments and Forces

The exciting force on the body, the Fraud-Krylor (FK) force, and the diffraction force from the integration of pressure at the point of the submerged vessel (S_H) are the sources of the fluctuating fluid pressure waves that prevent the body from moving. The incident wave potential (ϕ_I) of the incoming wave that is undisturbed, the diffraction potential (ϕ_D) of the incoming wave that is undisturbed, and the radiation potential (ϕ_R) are superposed to form the velocity potential in linear wave theory (12, 17).

Wave Effect on Cargo Ship

When cargo ships traverse the ocean, wave action causes them to experience six different types of ship motions. The ship's motions, which have varying effects on the ship, its containers, and the cargo, apply to both the shipping containers it is carrying and the cargo it holds as shown in Figure 3. The motion in which the ship's hull hits wave crests and then suddenly submerges in the ocean is called slamming. As the ship passes over a wave's crest, its bow rises out of the water before falling to strike the water below. Heaving, swaying, and surging are examples of lateral motions that generally have a greater impact on a ship than rotational motions like yawing, pitching, and rolling. Several important aspects determine how the ship is impacted by the lateral and rotational forces (accelerations) produced by these ship motions are as follows:

- Shape, size and weight of the ship
- Position of the center of gravity within the ship
- Position of the center buoyancy within the ship
- Maximum width at the waterline (beam) of the ship (18).

Figure 3: Container ship (6)

Heaving Motion on a Cargo Ship

Heaving is the application of force both upward and downward (acceleration) along the vertical axis of the ship. There is always wave activity when there is this motion, heaving only occurs in perfectly still water with no waves. As a ship moves across the sea between wave crests and troughs, wave action causes buoyancy to change along the ship. The buoyancy along the ship decreases and the ship goes downward where there is a wave trough. The buoyancy of the ship increases and moves upward where there is a wave crest. The heave movement will cause the ship to bend when it has a segment of hull on one side of a wave crest and the next section on the other side, the ship may experience significant twisting force as a result. The shipping containers and their cargo may be significantly impacted by the ship's continuous rising, lowering, and bending (oscillation) (18).

Pitching Motions on a Cargo Ship

When a ship pitches, its bow is raised and its stern is lowered, and vice versa. The greatest pitching angles that can occur in a given wave movement depend on the length of the ship. Short ships can normally have a pitch angle of five to eight degrees, very long ships will typically have a pitch angle of fewer than five degrees. These sizes of pitching angles have little effect on shipping containers or the goods they contain, but if containers are not packed correctly, high rolling tilting may cause contents to slide within the vessel hull or those on top of the vessel deck (18).

Ship Stability

A floating structure's ability to right itself in the event of an imbalance or disruption caused by a force, moment, or other external force is referred to as its static stability. The structure will translate and/or spin around its centre of gravity as a result of these (additional) loads. Formally, this depends on both the static and dynamic features of the structure, in still water, a structure will be subject to the hydrostatic forces and moments generated by the surrounding water. (12).

II. METHODOLOGY

The analysis on the wave effect in heave and pitch motion on the cargo vessel in heading sea waves was achieved with model equations as shown in Eqns (1) to (32) for both the heave response and pitch responses on the cargo vessel. MATLAB software was used in the simulation of the data gotten from the analysis. Tables 1 and 2 shows the cargo vessel parameters and wave parameters used for the analysis of the effects of the wave on a cargo vessel, the state of the sea is a calm sea with heading wave direction of 82.29°.

Table 1: Cargo vessel parameters (19)

S/N	Parameter	Value
1	Length between perpendicular	218m
2	Breadth	32.1m
3	Depth (d)	13.67m
4	Design draft (T)	10m
5	Vessel speed	18knots
6	Block coefficient (CB)	0.588
7	Water plane coefficient (CW)	0.757
8	Midship section coefficient (CM)	0.95
9	Longitudinal centre of gravity (LCG)	-3.85m
10	Meta centric height (GM)	0.64m

Table 2: Wave parameter (20)

S/N	Parameter	Value
1	Significant wave height	1.909m
2	Crossing wave period	6.577s
3	Peak wave period	10.526s
4	Wave heading direction	82.29°
5	Water density/ Depth	1.025kg/m^3/3000m

- Wave frequency calculation (ω)

$$\omega = \frac{2\pi}{T_p} \quad (1)$$

- Wave number calculation (k)

$$k = \frac{\omega^2}{g} \quad (2)$$

- Wave amplitude calculation (a)

$$a = \frac{H_S}{T_p} \quad (3)$$

- Wave length calculation (L)

$$L = 1.56{T_p}^2 \quad (4)$$

- Wave speed calculation (C)

$$C = \frac{\omega}{k} \quad (5)$$

Where

g = Acceleration due to gravity (9.81m/s^2)

Tp = Peak period

Hs = Significant wave height

g = Acceleration due to gravity.

Wave exciting force

$$\zeta^* = \zeta_a e^{-kD} \cos(\theta) \qquad (6)$$

Where

ζ^* = Wave elevation

ζ_a (a) = Wave amplitude

K = Wave number

D = Water depth (3000m)

Heave added mass (A_{33})

$$A_{33} = C_a \left[\rho \frac{\pi}{2}\left(\frac{B}{2}\right)^2\right] L \qquad (7)$$

Where

Ca= Constant (1)

B = Vessel breadth (32.1m)

L = Length of the vessel (218m)

Heave potential damping coefficient (B_{33})

$$B_{33} = 2\sqrt{C_{33}(M + A_{33})} \qquad (8)$$

Heave restoring coefficient (C_{33})

$$C_{33} = \rho g B L \qquad (9)$$

Mass of the vessel

$$M = \rho A_\omega L C_B \qquad (10)$$

Where

A_ω = Vessel water plane area

D = Vessel draft (10m)

C_B = Block coefficient (0.588)

Exciting force (F_{33}) in heave

$$F_{33} = A_{33}\ddot{\zeta}^* + B_{33}\dot{\zeta}^* + C_{33}\zeta^* \qquad (11)$$

Exciting force amplitude (F_{a3}) in heave

$$F_{a3} = \frac{F_{33}}{Cos\,\theta} \qquad (12)$$

Heave amplitude for consideration of a simple harmonic motion

$$Z_a = \frac{F_{a3}}{\sqrt{[C_{33} - M\omega^2]^2 + (B_{33})^2}} \qquad (13)$$

Where

Z_a = Heave amplitude

Heave velocity ($\dot{Z}$)

$$\dot{Z} = -Z_a \omega sin\theta \qquad (14)$$

Heave acceleration

$$\ddot{Z} = -Z_a \omega^2 cos\theta \qquad (15)$$

Motion in heave

$$F_{\omega 3} = (M + A_{33})\ddot{Z} + B_{33}\dot{Z} + C_{33}Z \qquad (16)$$

Heave RAO

$$RAO_3 = \frac{Z_a}{\zeta_a} \qquad (17)$$

Where

Z_a = Heave amplitude

ζ_a = Wave amplitude

JONSWAP spectral

$$S_{(\omega)} = A\omega^{-p} e^{(-B\omega-q)} \qquad (18)$$

Where

$\mathcal{S}_{(\omega)}$ = Wave spectral

$$A = \frac{124H_s^2}{T_z^4}$$

$$B = \frac{496}{T_z^4}$$

$$P = 5$$

q = 4

H_s = Significant wave height

T_z = Wave zero up-crossing period

ω = Wave frequency

Heave spectrum $\mathcal{S}_{(\omega 3)}$

$$\mathcal{S}_{(\omega 3)} = \left|\frac{z_a}{\zeta_a}(\omega)\right|^2 . \mathcal{S}_{(\omega)} \tag{19}$$

(11, 21-23).

Pitch motion on the vessel

$$\mathrm{A}_{55} = \mathrm{a}_{33}\frac{1}{12}\mathrm{L}^3 \tag{20}$$

$$\mathrm{C}_{55} = \rho g \mathrm{B}\frac{1}{12}\mathrm{L}^3 \tag{21}$$

$$\mathrm{B}_{55} = \mathrm{b}_{33}\frac{1}{12}\mathrm{L}^3 \tag{22}$$

$$\mathrm{I}_5 = \frac{\mathrm{C}_{55}}{\omega^2} - \mathrm{A}_{55} \tag{23}$$

Exciting force (F_{55}) in pitch

$$\mathrm{F}_{55} = \mathrm{A}_{55}\ddot{\zeta}^{*} + \mathrm{B}_{55}\dot{\zeta}^{*} + \mathrm{C}_{55}\zeta^{*} \tag{24}$$

Exciting force amplitude in pitch ($F_{\theta 5}$)

$$\mathrm{F}_{\theta 5} = \frac{\mathrm{F}_{55}}{\mathrm{Cos}(\theta)} \tag{25}$$

Pitch amplitude θ_a

$$\theta_a = \frac{\mathrm{F}_{\theta 5}}{\sqrt{[\mathrm{C}_{55} - \mathrm{I}_5\omega^2]^2 + (\mathrm{B}_{55}\omega)^2}} \tag{26}$$

Where

θ_a = Pitch amplitude

Pitch displacement (θ)

$$\theta = \theta_a \cos(\theta) \tag{27}$$

Pitch velocity ($\dot{\theta}$)

$$\dot{\theta} = -\omega\theta_a \sin\theta \tag{28}$$

Pitch acceleration ($\ddot{\theta}$)

$$\ddot{\theta} = -\omega^2\theta_a \cos\theta \tag{29}$$

Pitch wave motion

$$\mathrm{F}_{\omega 5} = (\mathrm{I}_5 + \mathrm{A}_{55})\ddot{\theta} + \mathrm{B}_{55}\dot{\theta} + \mathrm{C}_{55}\theta \tag{30}$$

Where

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

Pitch RAO response

$$\mathrm{RAO}_5 = \frac{\theta_a}{\zeta_a k} \tag{31}$$

Pitch spectrum $\mathcal{S}_{(\omega 5)}$

$$\mathcal{S}_{(\omega 5)} \;=\; \left|\frac{\theta_a}{\zeta_a k}(\omega)\right|^2 . \mathcal{S}_{(\omega)} \tag{32}$$

(12, 21-22)

III. RESULTS AND DISCUSSION

The analysis of the effect of wave on cargo vessel motion were determined in heave and pitch force and moment acting on the vessel with varying wave direction from 0^o to 120^o. The motion response analysis on the vessel in heave and pitch responses due to the effect of wave motions, the wave exciting motion (F_{33}, F_{55}), the wave motion amplitude (F_{a3}, F_{a5}), the wave motion (F_{w3}, F_{w5}), the RAO_3, RAO_5 and the response spectrum (S_{w3}, S_{w5}) are shown in Figures 4 to 13 at varying wave frequency.

Figure 4 shows the graph of the heave response amplitude operator (RAO_3) against the frequency of the heading wave as the wave direction varies from 0^0 to 120^0. As the wave frequency increases from 0.05 rad/s to 0.5rad/s, the RAO_3 at 0^0 to 60^0 decreases from 0^0 to -1.6752, -13927, and -0.7370 respectively. While at a wave direction from 90^0 to 120^0, the RAO_3 increases from 0 to 0.1162 (90^0) and 0.9382 (120^0) respectively. From the analysis, it can be seen that the effect of varying the wave direction were significant at a wave direction of 90^0 and 120^0, while from 0^0 to 60^0, the effect was minimal.

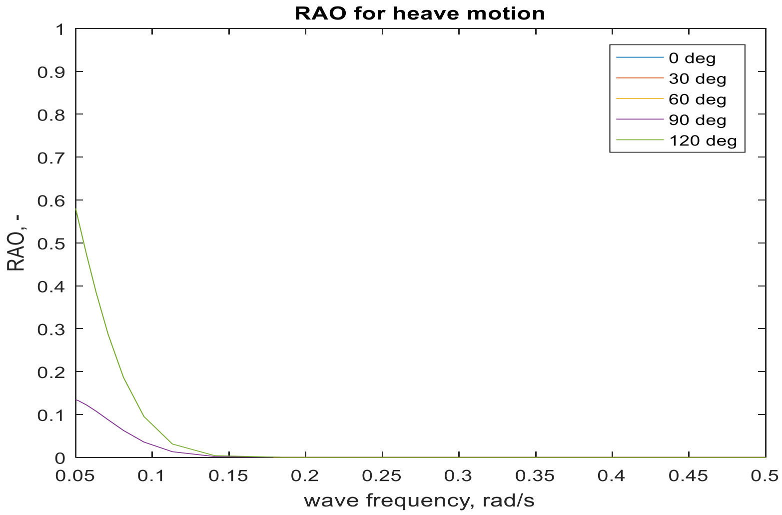

Figure 4: RAO_3 against wave frequency

Figure 5 shows the graph of the heave wave force response motion (F_{W3}) against the wave frequency at varying wave direction. As the wave direction increases from 0.05rad/s to 0.5rad/s the F_{W3} increases from 0N to 2.1713 x 10^8N (0^0), 1.8051 x 10^8N (30^0), 0.9552 x 10^8N (60^0) respectively as the wave direction increases. But at 90^0 to 120^0, the F_{W3} decreases from 0N to -0.1506 x 10^8N (60^0) respectively as the wave direction increases. But at 90^0 to 120^0, the F_{W3} decreases from 0N to -0.1506 x 10^8N (90^o) and 1.216 x 10^8N (120^0) respectively as the wave frequency increases from 0.05rad/s to 0.5rad/s. From the analysis, the $F_{W3}$was significant at 0^0 (2.1713 x 10^8N) wave direction and less significant at 120^0 (-1.2161 x 10^8N) wave direction.

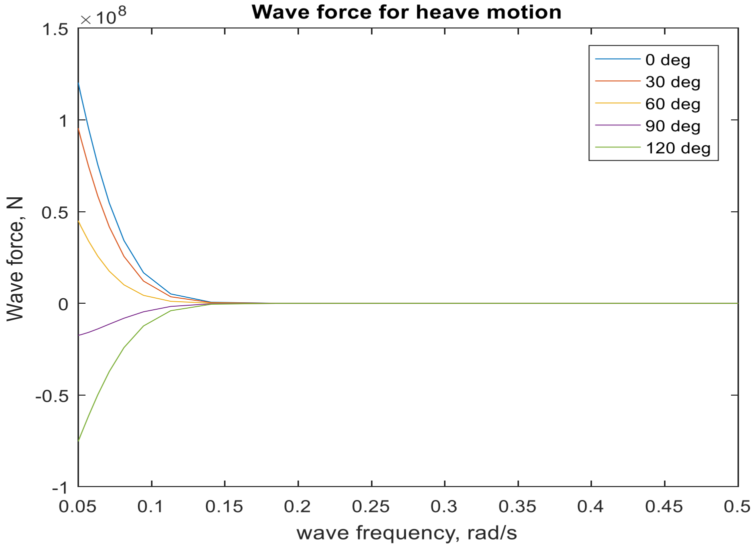

Figure 5: Fw_3 against wave frequency

Figure 6 shows the graph of the heave force amplitude (Fa_3) against the wave frequency at 0^0 to 120^0 wave directions. As the wave frequency increases from 0.05 rad/s to 0.5 rad/s, the Fa_3 at 0^0 to 60^0 wave direction decreases from 0N to -1.1273 x 10^8N, -0.9372 x 10^8N and –0.4959 x 10^8N respectively while the Fa_3 at 90 to 120 wave directions increases from 0N to -1.1273 x 10^8N and 0.6314 x 10^8N respectively. From the analysis, the Fa_3 was more significant at 120^0 (-0.6314 x 10^8N and less significant at 0^0 (-1.1273 x 10^8N) wave directions.

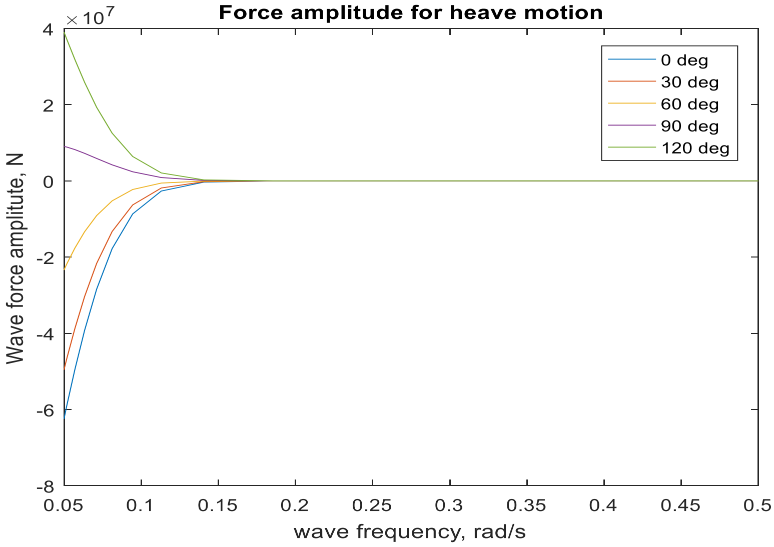

Figure 6: Fa_3 against wave frequency

Figure 7 shows the graph of the heave wave exciting form motion (F_{33}) against the wave frequency at varying wave directors from 0^0 to 120^0. As the wave frequency increases from 0.05 rad/s to 0.5 rad/s, the F_{33} at 0^0 to 60^0 increases from 0N to 5.6365 x 10^7N (0^0), -4.6859 x 10^7N and 2.4797 x 10^7N (60^0) respectively. While at 90^0 and 120^0 wave directors, the F_{33} decreases from 0N to -0.3910 x 10^7N (90^0) and -3.1568 x 10^7N (120^0) respectively. From the analysis, it can be seen that the effect of varying wave direction was more significant at 0^0 (5.6365 x 10^7N) wave direction and less significant at 120^0 (-3.1568 x 10^7N) wave direction.

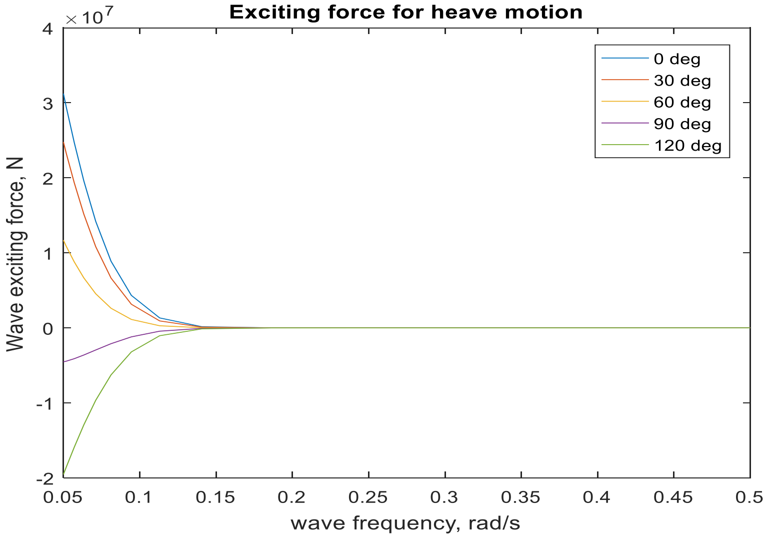

Figure 7: F_{33} against wave frequency

Figure 8 shows the graph of the heave energy spectrums of the motion of the vessel (Sw_3) against the wave frequency at varying wave directions from 0° to 120°. as the wave frequency increases from 0.05rad/s to 0.5rad/s, the Sw_3 increases from 0 m²s/rad to 0.7988 m²s/rad (0°), 0.5531 m²s/rad (30°), 0.1546 m²s/rad (60°) and 0.2506 m²s/rad (120°) respectively. But, the Sw_3 increases from 0 m²s/rad to 0.057 m²s/rad, before it fell to about 0.0038 m²s/rad at a wave direction of 90°. The analysis shows that the Sw_3 was significant at a wave direction of 0° (0.7988 m²s/rad) and less significant at a wave frequency of 90° (0.0057 m²s/rad).

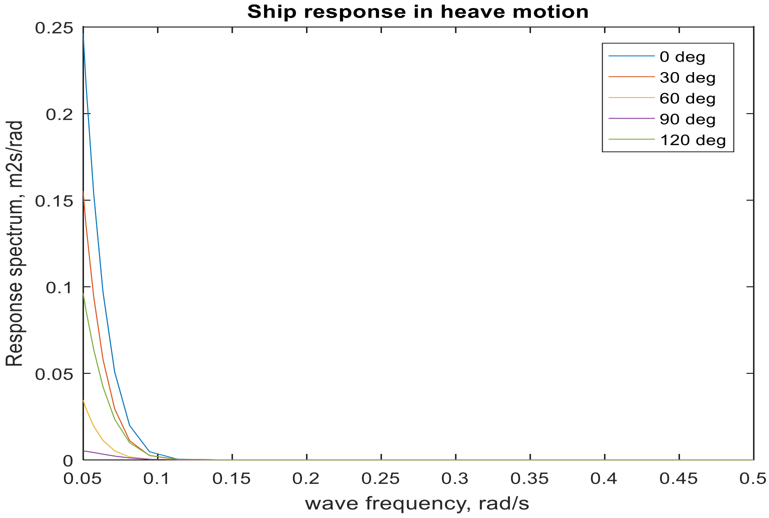

Figure 8: Sw_3 against wave frequency

Figure 9 shows the graph of the pitch from 0° to 120°. As the wave frequency increases from 0.05rad/s to 0.5rad/s, the RAO_5 at 0° wave direction decreases from 0 to -0.0932. While at a wave direction of 30° to 120°, the RAO_5 increases from 0 to 0.7573 (30°), 1.4049 (60°), 1.6760 (90°) and 1.4981 (120°). The RAO_5 increases from 0 to 0.9877 (30°), 1.7529 (60°), 2.0484 (90°) and 1.7951 (120°) before they began to decrease as the wave frequency increases from 0.05rad/s to 0.5rad/s respectively. From the analysis, it can be seen that the RAO_5 was more significant at 60° wave direction.

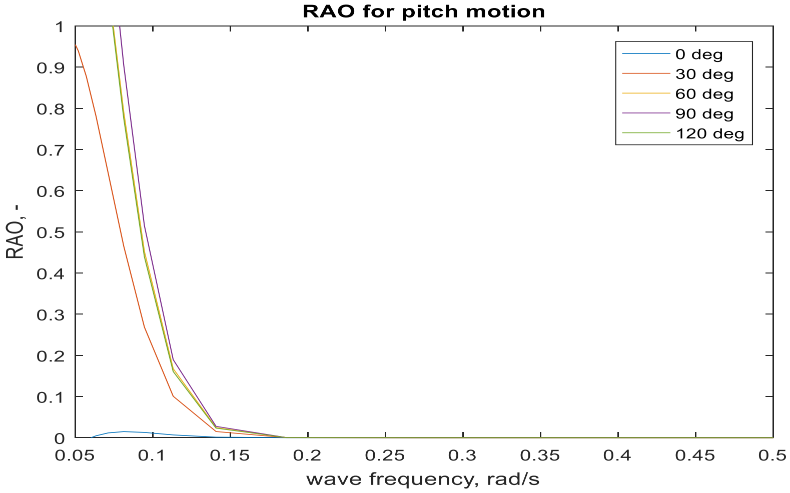

Figure 9: RAO_5 against wave frequency

Figure 10 shows the graph of the pitch wave force response motion (Fw_5) against the wave frequency at varying wave direction from 0° to 120°. As the wave frequency increases from 0.05rad/s to 0.5rad/s, the Fw_5 at 0° wave direction increases from -0.0001 x 10^{12}N to 0.3348 x 10^{12}N, while those at 30° to 120° wave direction decreases from 0 to -2.7205 x 10^{12}N (30°), -5.0456 x 10^{12}N (60°), -6.0209 x 10^{12}N (90°) and -5.3816 x 10^{12}N (120°) respectively. From Figure 10, the Fw_5 values were fluctuating between 0, -0.0535 x 10^{12}N and 0.3348 x 10^{12}N at 0° wave direction which also fluctuated from 30° to 120° wave direction. At 120° wave direction, the Fw5 fluctuated between 0, -0.0000 x 10^{12}N, -6.4488 x10^{12}N to -5.3816 x10^{12}N. From the analysis, it can be seen that the Fw_5 was more significant at 0° (0.3548 x 10^{12}N) wave direction and less significant at 90° (-7.3588 x 10^{12}N) wave direction.

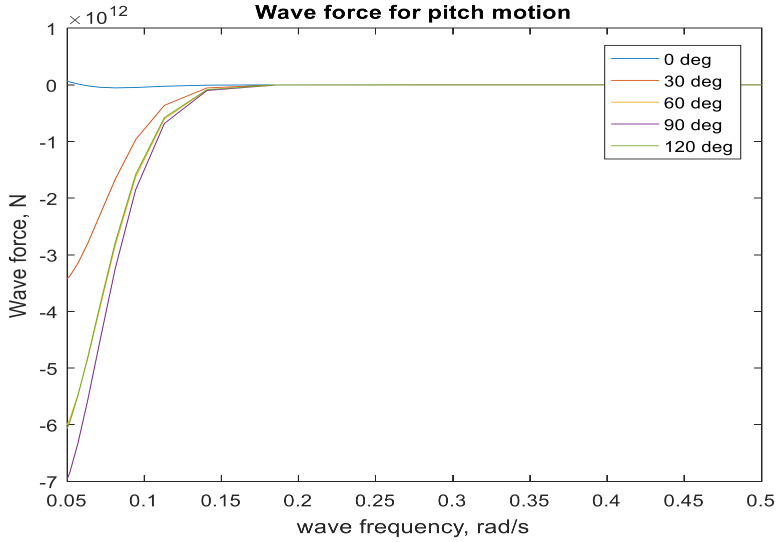

Figure 10: Fw_5 against wave frequency

Figure 11 shows the graph of the pitch force amplitude (Fa_5) against the wave frequency at varying wave directions from 0° to 120°. As the wave frequency increases from 0.05rad/s to 0.5rad/s, the Fa_5 at 0° decreases from 0N to -0.3753 x 10^{12}N, while at 30° to120° wave directions, the Fa_5 increases from 0 to 3.050 x 10^{12}N (30°), 5.6587 x 10^{12}N (60°), 6.7508 x 10^{12}N (90°) and 6.0341 x 10^{12}N (120°) respectively. The Fa_5 at 30° fluctuates between 0N and 3.9785 x 10^{12}N to 3.0504 x 10^{12}N and at 60° wave direction, it fluctuates between 0 and 7.0605 x 10^{12}N before it fell to about 5.6587 x 10^{12}N. The Fa_5 also fluctuates at 90° and 120° wave directions. From the analysis, the Fa_5 was more significant at 90° (8.2510 x 10^{12}N) wave direction and less significant at 0° (-0.3753 x 10^{12}N) wave direction.

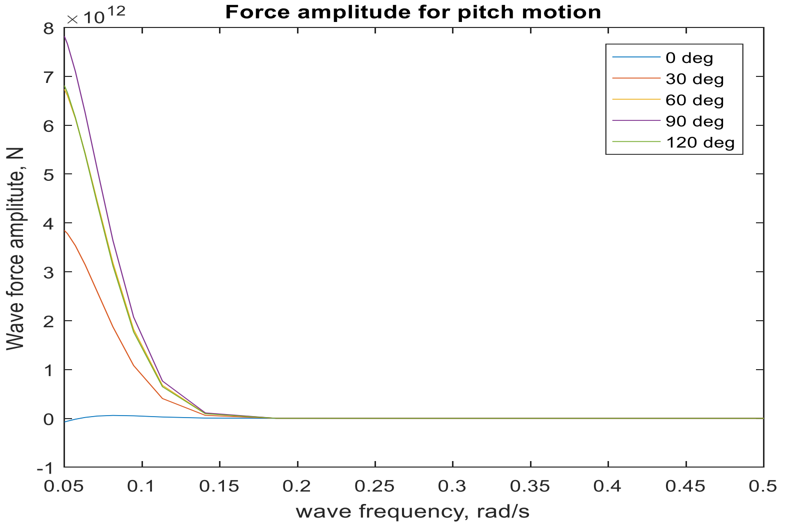

Figure 11: Fa_5 against wave frequency

Figure 12 shows the graph of the pitch wave exciting force motion F_{55} against the wave frequency at varying wave directions from 0° to 120°. As the wave frequency increases from 0.05rad/s to 0.5rad/s, the Fwm_5 fluctuates between 0N and -0.0300 x 10^{12}N before it started raising from -0.0300 x 10^{12}N to about 0.1877 x 10^{12}N at 0° wave direction. At 30° wave direction, the F_{55} started decreasing from 0 to -1.9892 x 10^{12}N before it started rising at -1.9892 x 10^{12}N to about -1.5252 x 10^{12}N. And at 120° wave direction, the Fwm_5 also decreases from 0N to -3.6153 x 10^{12}N before it started rising from -3.6153 x 10^{12}N to -3.0170 x 10^{12}N. From the analysis, the Fwm_5 was more significant at 0° (0.1877 x 10^{12}N) wave direction then the others, but less significant at 90° (-4.1255 x 10^{12}N) wave direction.

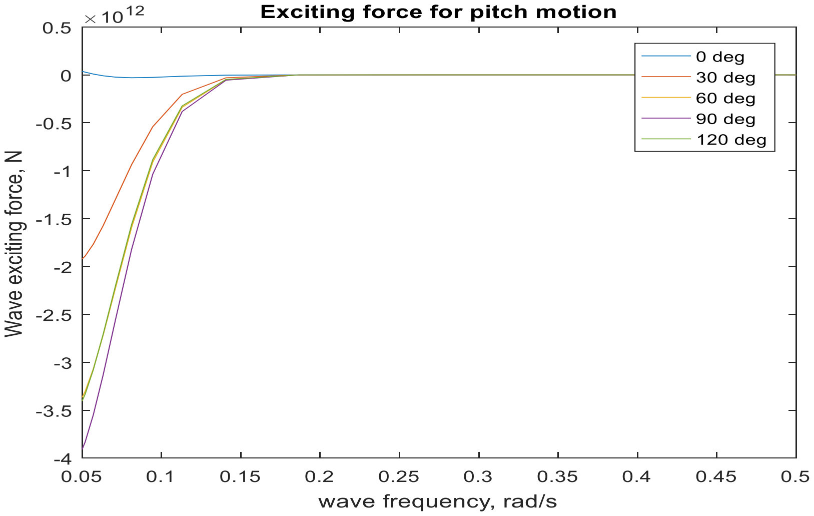

Figure 12: F_{55} against wave frequency

Figure 13 shows the graph of the pitch energy spectrum motion of the vessel (Sw_5) against the wave frequency at varying wave directions from 0° to 120°. As the wave frequency increases from 0.05rad/s to 0.5rad/s, the Sw5 increases from 0m^2s/rad to 0.0025 m^2s/rad. While from 30° to 120° wave directions, the Sw_5 fluctuates between 0 m^2s/rad to 0.2777 m^2s/rad (30°), 0.8746 m^2s/rad (60°), 1.1944 m^2s/rad (90°) and 0.9172 m^2s/rad (120°), which later dropped to 0.1632 m^2s/rad (30°), 0.5618 m^2s/rad (60°), 0.7992 m^2s/rad (90°) and 0.6388 m^2s/rad (120°) respectively. The analysis shows that the Sw_5 shows more significant effect at 90° (1.1944 m^2s/rad) and less significant effect at 0° (0.0025 m^2s/rad) wave direction.

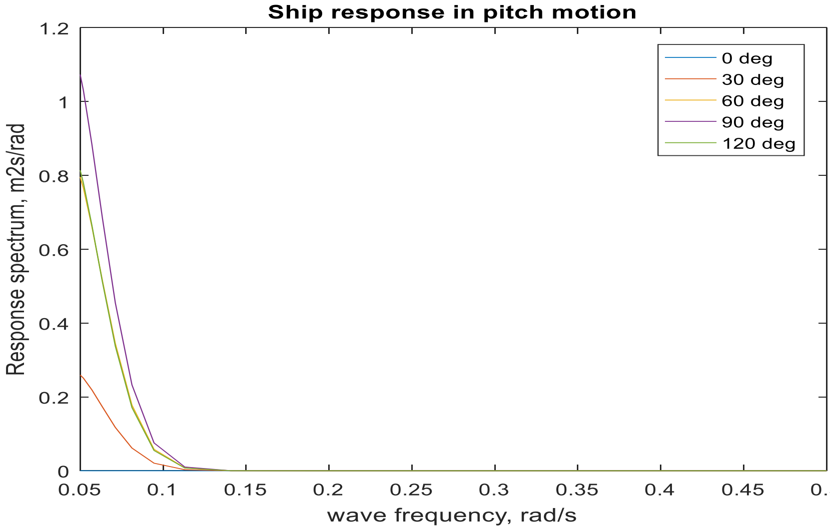

Figure 13: S_{w5} against wave frequency

IV. CONCLUSION

The motion response of a vessel is directly related to the performance of the vessel in which accurate estimate can be done either theorically or experimentally. It is important for a designer to do extensive analysis before the final design stage of a vessel. The response of a cargo vessel at various wave directions differs and affects the vessel differently. The RAO_3 at 0^o was at -1.6752 while that of the RAO_5 at the direction was -0.0932. From the analysis, the responses show that the RAO_5 shows more significant response than the RAO_3 response at 0^o wave direction. Furthermore, at 120^o, the RAO_3 and RAO_5 responses were 0.9382 and -5.3816×10^{12} respectively. From these values, the response was more significant on the RAO_5 motion position than at the RAO_3 motion position. Finally, the RAO_3 was more favourable at 0^o than at 120^o, while at 120^o, the RAO_5 was more favourable than the RAO_3 wave motion position.

V. REFERENCES

[1] Li, G. “Velocity and attenuation of ultrasonic S-wave in berea sandstone,” Acta Geodaetica Geophysica, Vol. 55, Issue 2, pp. 335-345, 2020.

[2] Zhang, Y. “Coastal environmental monitoring using remotely sensed data and GIS techniques in the modern yellow river delta,” China Environmental Monitoring and Assessment, Vol. 179, pp. 15-29, 2011.

[3] Gong, J.; Yan, S.; Ma, Q. and Li, Y. “Added resistance and seakeeping performance of trimaran in oblique waves,” Ocean Engineering, Vol. 216, pp. 1-19, 2020.

[4] Kahuina, Miller and Andrea, Clayton “Measuring the causal effect of Panama Canal expansion on Latin America and the Caribbean’s economic growth: A Bayesian structural time series approach,” Marine Economics and Management, Vol. 6, Issue 2, pp. 37-58, 2023.

[5] UNCTAD “Review of maritime transport,” United Nation Publication, 2015.

[6] Wang, Y. “Development of megawatt wind turbine based on godesys variable pitch PID controller,” IOP conference series: Material and Science Engineering, Vol. 452, pp. 1-7, 2018.

[7] Shen, H. H. “Modelling ocean waves in ice covered seas,” Applied Ocean Research, Vol. 83 Issue 30, pp.1130-1141, 2019.

[8] Fossen, T. I. “A nonlinear unified state-space model for ship maneuvering and control in a seaway,” Department of Engineering Cybernetics Norwegian University of Science and Technology. NO-7491 Trondheim, Norway, 2005.

[9] Baso, Suandar; Asri, Syamsul R.; Bochary, Lukman and Pratama, L. A. H. “New strip theory approach to ship motions prediction,” Inovasi Teknologi Kelautan, pp. D9-D16, 2013.

[10] Jiao, Jialong and Tezdogan, Tahsin “Ship motion and wave loads,” Journal of Marine Science and Engineering, Vol. 11, Issue 491, pp. 1-5, 2023.

[11] Lars, B. “Wave induces loads and ship motions,” Goteborg, Sweden: Chalmers University of Technology, pp. 9-170, 2009.

[12] Journee, J. M. J. and Massie, W. W. “Offshore hydrodynamics (1st ed.),” Mekelweg, Netherlands: DU Technology, pp. 1-76, 2001.

[13] Fitriadhy, A. and Adam, N. A. “Heave and pitch motions performance of a monotricat ship in head-seas,” International Journal of Automotive and Mechanical Engineering, Vol. 14, pp. 4243-4258, 2017.

[14] Tezdogan, T.; Incecik, A. and Turan, O. “A Numerical investigation of the squat and resistance of ships advancing through a canal using CFD,” Journal of Marine Science and Technology, Vol. 21, Issue 1, pp. 86-101, 2016.

[15] Cercos-Pita, J. L.; Bulian, G.; Pérez-Rojas, L. and Francescutto, A. “Coupled simulation of nonlinear ship motions and a free surface tank,” Ocean Engineering, Vol. 120, pp. 281-288, 2016.

[16] Fitriadhy, A.; Azmi, S.; Mansor, N. A. and Aldin, N. A. “ Computational fluid dynamics investigation on total resistance coefficient of a high-speed" deep-V" catamaran in shallow water,” International Journal of Automotive and Mechanical Engineering, Vol. 14, pp. 4369-4382, 2017.

[17] Faltinsen, O. M. “Sea loads on ships and offshore structures,” Cambridge University Press, England, pp. 13-35, 1990.

[18] Freight Forwarder “Ship motions at sea and their effects on cargo ships,” [Online] www.freightforwarderquoteonline.com/news/six-types-of-cargo-ship-motions-at-sea-and-their-effects/ 2015 (Accessed October 15, 2024).

[19] Zakaria, N. M. G. “Effect of ship size, forward speed and wave direction on relative wave height of container ships in rough seas,” Journal – The Institution of Engineering, Malaysia, Vol. 72, Issue 3, pp. 21-34, 2007.

[20] Gold Coast “Wave data – 2023,” [Online] www.data.qld.gov.au/dataset/coast-data-system-waves-gold-coast/resources/618d4d1e-fa39-4e04-929a-94ca6e107973?inner_span=True. 2023 (Accessed October 8, 2024).

[21] Det Norske Veritas “Rules for classification of ships part 3 chapter 3 section 9,” DNV: Hovik, Norway, pp. 121-128, 2011.

[22] Naaijen, P. “Offshore hydrodynamics part 2 introduction and ship motion,” Mekelweg, Netherlands: Delft University of Technology, pp. 50-156, 2013.

[23] Yuming, L. “Design of ocean systems lecture 7 sea keeping III,” [Online] www.ocw.mit.edu|course|mechanical-engineering/2-019-design-of-ocean-system-spring-2011/# 2011(Accessed October 17, 2024).