NUMERICAL STUDY ON THE SEAKEEPING PERFORMANCES OF KCS HULL USING STRIP THEORY

A thesis submitted in partial fulfilment of the requirements for the Degree of

"MASTER OF TECHNOLOGY"

In

MARINE ENGINEERING & MANAGEMENT

By

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INDIAN MARITIME UNIVERSITY KOLKATA CAMPUS

Department of Marine Engineering & Management

CERTIFICATE

This is to certify that the thesis entitled **"Numerical study on the seakeeping performances of KCS hull using strip theory"** submitted by Mohammed Bhatia to Indian Maritime University Kolkata Campus for the award of the Degree in **Master of Technology in Marine Engineering and Management**, is a bonafide record of the project work carried out by him under our supervision. The contents of this thesis, in full or in parts have not been submitted to any other institute or University or the award of any degree or diploma.

The Project has been carried out at Indian Maritime University Kolkata Campus.

23/08/2022

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Contents

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List of Tables

Abbreviations

CFD	Computational Fluid Dynamics
DOF	Degree Of Freedom
DYN	Dynamic Ship Analysis
EEOI	Energy Efficiency Operational Indicator
IMO	International Maritime Organization
KN	Knots
KRISO	Korea Research Institute Of Ships And Ocean Engineering
KCS	Kriso Container Ship
KVLCC	Kriso Very Large Crude Carrier
RAO	Response Amplitude Operator
RANS	Reynolds-Averaged Navier–Stokes Equation
3D	Three Dimensional
2D	Two Dimensional

Nomenclature

A	Wave amplitude
Ω	Frequency
B	Heading angle
A_{jn}	Mass
M_{jn}	Mass matrices
B_{jn}	Damping coefficient
C_{jn}	Restoring coefficient
f_3	Sectional froude-krilov wave force
ρ	Density
ξ	Row
M	Mass of vessel
I_5	Moment of inertia for pitch
A_{33}	Added mass coefficient for heave due to heave.
A_{35}	Added mass coefficient for heave due to pitch.
A_{53}	Mass coefficient for pitch due to heave.
A_{55}	Added mass coefficient for pitch due to pitch.
B_{33}	Damping coefficient for heave due to heave.
B_{35}	Damping coefficient for heave due to pitch.
B_{53}	Damping coefficient for pitch due to heave.
B_{55}	Damping coefficient for pitch due to pitch.
C_{33}	Hydrostatic restoring coefficient for heave due to heave.
C_{35}	Hydrostatic restoring coefficient for heave due to pitch.
C_{53}	Hydrostatic restoring coefficient for pitch due to heave.
C_{55}	Hydrostatic restoring coefficient for pitch due to pitch.
F_3	Heave exciting force.
F_5	Pitch exciting moment.
η_3	Instantaneous heave displacement.
$\dot{\eta}_3$	Instantaneous heave velocity.
$\ddot{\eta}_3$	Instantaneous heave acceleration.
η_3	Instantaneous pitch displacement.
$\dot{\eta}_3$	Instantaneous pitch velocity.
$\ddot{\eta}_3$	Instantaneous pitch acceleration.

Abstract

The race of taking more cargo on a ship has increased the size of ships as well as other aspects such as their capacity and structural complexity, which affect the stability of ships. For naval architects and academics, accurately predicting seakeeping performances is difficult. In order to address this, the seakeeping performance of a container ship (KCS) vessel built by KRISO (Korea Research Institute of Ships and Ocean Engineering, Daejeon, South Korea) is described in this research utilizing a numerical method.

MAXSURF software based on strip theory was used to determine the results, where the containership hull was considered and input motions were applied with appropriate boundary conditions. Later the ship heading and speed were changed to see the effect of the seakeeping performance of the container ship. The current study is concentrated on systematic comparative research on the investigation of the ship's pitch, heave, and roll movements in irregular waves.

The strip theory is applied in this research for the irregular wave heights of 7m and 9m, a heading angle range of 30 to 180 degree with a step of 30 degree for three forward speeds, 15knots, 18knots, and 22 knots using the full-scale KCS hull numerical model. The effect of several heading angles and the sea circumstances on the seakeeping performance of the ship based on Response Amplitude Operators (RAO), Significant Amplitude, and Time series data of the ship's heave, Roll and Pitch movements in irregular waves are analyzed.

The calculation findings shows that seakeeping performance is directly related to ship direction and speed. Furthermore, threatening heading angles during sailing are classified, which could also help in enhancing ship stability.

CHAPTER 1

1. Introduction

The thesis' background is briefly discussed in this chapter, along with its objectives and area of study.

1.1 Background

Around 80% of worldwide trade is carried out via shipping, which is sometimes regarded as the primary mode of transportation for the whole world economy. Due to a growing emphasis on environmentally friendly shipping, Vessel hull designers are under pressure to further ensure the ship's safety, ship operations, and more importantly to comply with International Maritime Organization (IMO) regulatory incentives regarding the energy efficiency operational indicator (EEOI) and emissions minimization. An extensive understanding of the hydrodynamics process and the forecasting of ship behaviour in high waves have received a lot of attention. In addition to safety, the wave loads may cause effectiveness, operability, and structural collapse. As it affects both the design and management of the ship, accurately predicting seakeeping performances is a challenging job for naval designer and of tremendous practical importance to shipbuilders, owners, and operators [1]. The maritime sector has embraced technology more and more in recent years. With the use of physical-numerical modelling, simulation, and the digital twin idea, better vessel prediction, behavior control, and response may be achieved.

Seakeeping is one of the most difficult challenges in ship hydrodynamics due to a number of factors like boundary conditions at free-surface formulation, interference between external waves and the vessel hull, fluid viscosity and hydrodynamic pressure-induced nonlinearities, the distinctive geometry of the hull shape, and all of these factors necessitate sophisticated iterative time-domain procedures for the analysis of the ship's oscillations response, necessitating a notable computational investment [2].

Before the Froude and Michel experiments, researchers have been trying to solve the problem of how waves interact with a moving body. Since then, numerous methods for assessing the seakeeping abilities have been created, including potential flow, experimental fluid dynamics, and most recently the CFD. The hydrodynamic performances of a full-scale ship are frequently determined by extrapolating the results of model-scale towing tank studies. Numerical methods are another strategy often used in ship hydrodynamics to resolve the equations' system of ship movements. Due to the intricacy of the problem and the fact that the outcomes largely depend on the details of the hull form and the incidence wave state, numerical prediction of non-linear phenomena peculiar to ship motions in waves is difficult. With the introduction of numerical modelling tools and an increase in computing power, direct prediction of full-scale ship performance became a practical option. The majority of methods for forecasting ship movements are based on potential flow theory presumptions. Although the natural tendency in ship hydrodynamics is to move to time domain from frequency-domain, from linear 2D strip theory type to fully 3D nonlinear techniques, and also from potential to viscous computing, velocity flow methods are still widely utilized in ship design. This is because they offer trustworthy and precise findings in view to moderate sea states [3].

As time dependency may be eliminated by considering that the result is harmonic in time, the frequency-domain method is typically used to solve linear or weakly nonlinear wave theories. This leads to the resolution of only stable solutions. Under the premise that the vessel hull is thin, strip theory simplifies the 3D flow problem into a 2D formulation by modelling the hull as a collection of various 2D ship stations [4]. Lewis form or the boundary element techniques can be used to analytically answer the independent boundary value issue for single station. Different strip theories have been developed since the 1950's to address the seakeeping issue in the 2D hydrodynamic formulation [5]. The fundamental elements of the strip theory for computing ship movements depends on the thin body theory that was established by Korvin-seminal Kroukovsky's work [6]. This was the first viable hypothesis for accurate numerical ship motion computations for marine engineering purposes. For head wave situations, it was demonstrated that an improvised strip theory technique developed by Gerritsma and Benkelman [7] produced a good agreement with actual tests. Ogilvie and Tuck [8] carried out a thorough investigation on the slender body issue based on a short wave-length approximation in order to learn about the additional mass and damping for heave & pitch motions. The majority of strip method used this day are modifications of the strategy put forth by Salvesen et al. [9], which is one of the most thorough versions and solves ship motion equation in five degrees of freedom without taking into account the surge component, which is irrelevant for a thin body oscillation. Thenceforth more thorough strip theories have been developed for ship design, including [10] and [11]. Professors V. Bertram, J.N. Newman, and O.M. Faltinsen [4, 12, 13] have reported on a limited number of thorough examinations of variants on the strip theory. Recently, Lin H Lin, C.W. [14] proposed using a fusion of two-dimensional strip theory and two-dimensional Green function based on potential theory to solve boundary values and motion responses of a semi-displacement hull. Strip theory has the benefit of being quick, affordable, and accurate enough for a variety of hull types and moderate speeds despite its theoretical drawbacks.

The attempt to describe non-linear processes and overcome the drawbacks of strip theory approaches guides to the success of new feasible flow options depend on numerical 3D techniques that intensify the modelling strategy of the relevant physical domain. The Neumann-Kelvin technique [2], which assumes that the boundary condition of the body is applied on actual body surface at mean position and linearized free-surface boundary condition, was developed in the late 1970s because of a latest treatment of the boundary conditions. The perfect technique for solving the Neumann-Kelvin problem is to use the boundary integration method, where the solution is represented as singularities such as sources or dipoles, on shells and free surfaces. Two different classes of procedures are obtained based on the type of singularity used in the integral equation. One depends on the Green's function [13], which describes the linearization conditions of the free surface and radiation, and the other directly depends on the simple distribution rankine source that exists on both the hull surface and the free surface. Some shortcomings of strip theory and the Green's function method can be solved by using a 3D time-domain panel method based on rankine sources, which includes the complete 3D effect of flow and forward velocity.

Most RANS seakeeping simulations were performed on a model scale. In CFD modelling of 3-dimensional motion of a ship in waves. Application to an advancing ship in normal heading waves, the first effort to solve ship movements in waves was made by [14]. Due to the poor grid quality, the findings indicate potential issues with free-surface accuracy. Later, Simonsen et al. [15] used the CFDSHIP-IOWA algorithm to analyse the movements of the KRISO container ship (KCS) hull in pitch and heave motions in normal head waves. Using the NUMECA/FineMarine code, Lungu and Bekhit [16, 17] recently evaluated the seakeeping capabilities of the KCS and KVLCC (KRISO Very Large Crude Carrier) ship models under typical head wave circumstances. For the model scale, their findings are in good accord with the experiment. However, the scale impact appears to be considerable, as demonstrated by Hochkirch and Mallol [18], who showed noteworthy scale effects as a result of the differences between model-scale flows and full-size flows. Using the Star-CCM+ software, Tezdogan et al [19] studied the nautical and performance of the KCS model at a moderate forward speed (Siemens PLM Software, Plano, TX, USA).

1.2 Aim of Thesis

The current efforts focus on systematic comparative studies to analyse ship pitch, heave, and roll movements in irregular waves in scale ship model. The strip theory was applied to the study of irregular wave heights of 7m and 9m, a course angle range of 30-180 degrees in 30-degree increments, with three forward velocities, 15 knots, 18 knots, and 22 knots. The calculations were performed using the KCS full-scale hull model and several set of results obtained.

1.3 Scope of work

Specific constraints that define the scope of work:

- This treatise focuses on the stability of ships in bad weather conditions.
- There are multiple parameters to understand the movement of the ship at sea and multiple tools were used at each steps. However, the focus is on sea state analysis of ships using strip theory.
- The process of ship seakeeping analysis based on maxsurf is described in this thesis. It begins with exporting the container ship hull .igs extension in maxsurf modeller and then transferring all data in maxsurf motion.
- The results will be converted into graphs to understand ship motion better.
- A mathematical model will be obtained by time series data of the KCS hull.

CHAPTER 2

2. Computational Methodology

The author's of this thesis objective is to integrate all the methods that have been previously presented into a single study in order to develop a methodology that supports quick decisions in the case of further research choosing the most accurate method for estimating wave motions, taking into account its cost and computational time, depending on the specific needs of the study. The key benefit of the suggested methodology was improved administration of the input data, working circumstances, calculation assumptions, and analysed instances. The proposed methodology entailed addressing the described approaches, worldwide, using in-house Maxsurf advanced software. It is important to note that while the majority of the literature references reported assessments on the model-scaled ship, the current paper considers full-scaled ship simulations.

2.1 Strip Theory Method

A strip theory method has been employed for the seakeeping analysis as most methods for predicting ship movements for design purposes rely on potential flow theory assumptions. The ship movements in head waves were solved in this study using the Maxsurf advanced Software.

A ship is travelling forward at a constant speed (U), it may be assumed that its coordinate system is also moving in the incident wave, as illustrated in Figure 1, where A, ω and β represent the amplitude, frequency, and heading angle of the incident wave.

The hull is divided into multiple segments along the longitudinal axis as seen in Figure 2. In order to implement the strip theory's main concept. The hydrodynamic coefficients, such as additional mass, additional damping, Froude-Krylov wave force, and diffraction wave force, were calculated on each slice by applying a unit amplitude regular wave to the hull under given loading conditions and speed conditions, for any combination of wave frequency and wave direction. The force of the entire hull is then calculated by longitudinally integrating the force of each slice [20].

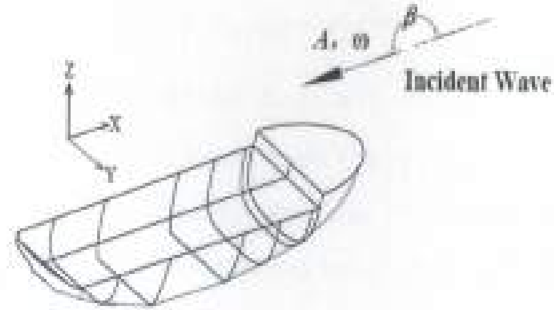

Figure 1 Coordinate system of ship motion.

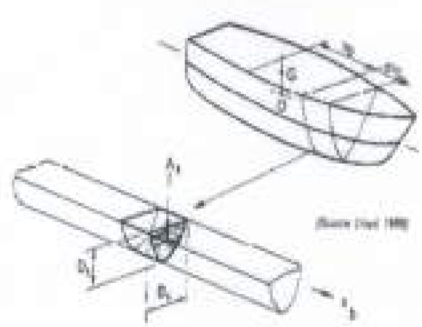

Figure 2 Strip theory representation by cross sections (Journee & Massie, 2001)

In a regular wave, a ship's movement may be broken down into two separate issues to solve (Xiao-ping, 2010) [21]:

1. Radiation issues: Only the ship's free swing motion is taken into account because there is no impact wave. This condition's hydrodynamic force is made up of words for increased mass force, damping force, and restoring force.

2. Diffraction Problem: Only the impacts of regularly occurring incident waves on the hull are considered, assuming the ship is stationary. Wave forces make up the hydrodynamic force at this moment. Incident wave force and diffraction wave force make up wave force. The latter is the wave force produced by the wave when it contacts the hull, whereas the former just takes into account the impact of the incident wave on the hull and ignores the impact of the hull's presence on the flow field. When the ship motion responses are linear and harmonic, the coupled equation of motion in the frequency domain is as follows:

$$\sum_{n=1}^{6}\left[(M_{jn} + A_{jn})\eta''_n + B_{jn}\eta'_n + C_{jn}\eta_n\right] = F_j e^{i\omega_e t}, \text{ for } j=1, 6 \text{ .... i}$$

Where A_{jn} & M_{jn} are the generalized mass and add-mass matrices, B_{jn} & C_{jn} are the damping and restoring coefficient, both the A_{jn}, B_{jn}, C_{jn} are collectively called the hydrodynamic coefficient representing the j^{th} degree of freedom caused by mentioning the k-th DOF. F_j is the exciting force and moment. $\eta''_n, \eta'_n, \eta_n$ represent displacement, velocity and acceleration of the n-th DOF. The frequency domain transfer function of the hull motion is then calculated by substituting the hydrodynamic and wave forces into the equation for the six-degree-of-freedom motion of the hull. The relative motion connection makes it clear that the motion response may be acquired at any point along the hull, and that time differentiation can be used to get the appropriate speed and acceleration.

2.2 Head Sea Approximation

Suppose that the ship is sailing in seas of waves coming from directly ahead, this approach is made simpler. It is possible to derive the sectional Froude-Krilov and diffraction forces using this approach, which makes it appropriate for load calculations.

The Sectional Froude-Krilov wave force is given in the equation below:

$$f_3 = \rho\xi g e^{-ikx\cos\mu} \int_{C_s} \hat{Z} e^{iky\sin\mu} e^{-kz} dl \text{ .... ii}$$

In below equation, which incorporates the water density, row, and wave amplitude, gives the head seas approximation to the sectional Froude-Krilov wave force.

$$f_3 = \rho\xi g b e^{ikx} e^{-kds} \text{ ....iii}$$

Where b is the total section beam and d is the section draft.

2.3 Heave, Pitch and Roll motions of the ship.

These heave, pitch, and roll movements vibrate due to the restoring force created by the changes in buoyancy associated with them. When the ship moves in response to waves, it can be considered a forced damping spring mass system.

The relevant equations of motion are for heave:

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$$(M + A_{33})\ddot{\eta}_3 + B_{33}\dot{\eta}_3 + C_{33}\eta_3 + A_{35}\ddot{\eta}_5 + B_{35}\dot{\eta}_5 + C_{35}\eta_5 = F_3 e^{i\omega_e t} \quad \text{iv}$$

For Pitch:

$$(I_5 + A_{55})\ddot{\eta}_5 + B_{55}\dot{\eta}_5 + C_{55}\eta_5 + A_{53}\ddot{\eta}_3 + B_{53}\dot{\eta}_3 + C_{53}\eta_3 = F_5 e^{i\omega_e t} \quad \text{v}$$

The foundation of our calculations is the strip theory, which is called the strip theory method for calculating ship seakeeping. The method used is the frequency domain. In other words, the issue is defined as a function of frequency. The primary benefit of this is a significant increase in processing speed. The technique eventually becomes constrained to calculating the linear vascular response, though the ship is divided into many transverse pieces. The hydrodynamic properties of each of these sections are then calculated as two-dimensional sections. Then, by integrating the coefficients of the sections along the length of the hull, the global coefficients of the equation of motion for the entire ship are calculated. The linked equations of motion are finally solved. As is generally known, strip theory continues to be a reliable foundation for seakeeping calculations and competes well with more modern and exacting techniques, even at high speeds. The ship is viewed as a rigid body floating in a fluid that meets all the criteria for an ideal fluid: it is homogenous, incompressible, surface tension-free, irrotational, and devoid of viscosity. The movements of this floating body in waves are thought to be a linear or linearizable issue.

2.4 Harmonic Response of Damped Spring Mass system

For most purposes, it is sufficient to model the ship as a set of spring mass damper coupling systems that undergo a simple harmonic motion. Maxsurf movements and most other voyage prediction methods assume this. This method works well for analysis of ship motions if the ship motions are linear and the superposition principle is applied. These assumptions apply when the ship is not exposed to extremely harsh conditions.

2.5 Response Amplitude Operator

The response amplitude operator (RAO), also known as the transfer function (similar to the response curve of an electronic filter), describes how the response of the vessel changes with frequency. These are usually dimensionless due to the height of the waves and the slope of the waves. Below is a typical elevation and pitch RAO.

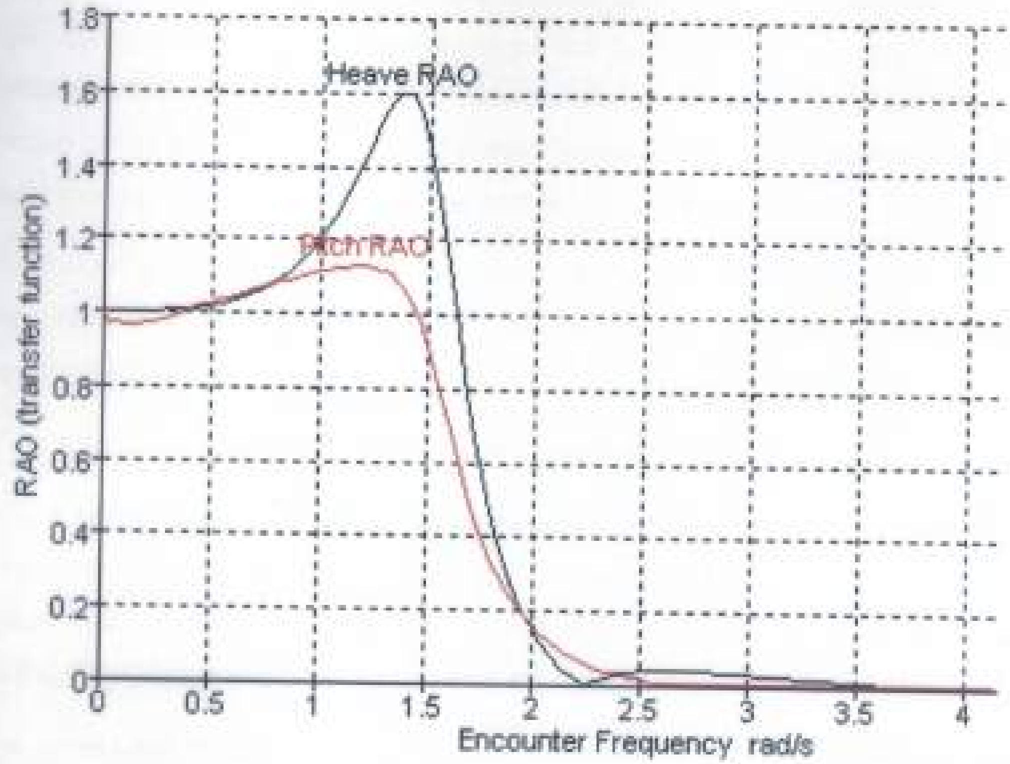

Figure 3 Heave and Pitch RAO example graph.

It can be seen that RAOs tend towards unity at low frequencies; this is where the ship simply moves up and down in waves and acts as a stopper. At high frequencies, the response tends to zero due to the effects of many destructive micro waves along the length of the ship. Usually, ships will also have larger peaks than unity; this occurs near the natural period of the circuit. The peak is due to resonance. An RAO value greater than unity indicates that the ship's response is greater than the amplitude (or slope) of the wave.

2.6 Motion Response Theory in Irregular Waves

When a ship moves across the water, an endless number of waves with tiny amplitudes, irregular frequencies, random direction angles, varied amplitudes, and variable phases are overlaid on the actual waves. The techniques of probability theory and random theory may be used to explain the properties of the three- and four-dimensional irregular wave system.

We typically believe that the response of a ship's linear system may be superimposed homogeneously when predicting a ship's seakeeping performance in irregular waves. Additionally, the output is treated as a stationary random process when the input is a stationary random process. Under such assumptions, hydrodynamic calculation also known as the transfer function, may be used to determine the relevant connection between the response variable and the wave frequency (or period, wavelength) for each wave direction, each wave speed, and each loading condition (or Response Amplitude Operators).

The following formula (Parunov, Senjanovi, & Pavlevi, 2004) may be used to get the response spectral density function from the transfer function and wave spectral density function.

$$S_R(\omega, \beta, H_s, T_z, U, C) = H^2(\omega, \beta, U, C) \cdot S(\omega, H_s, T_z) \quad \text{......vi}$$

Where $H(\omega, \beta, U, C)$ is the response amplitude operator transfer function, S_R is the response spectral density function, β, U, C represents the heading angle, ship speed and ship loading condition respectively. $\omega, H_S T_z$ are the wave frequency (rad/s), Significant wave height (m) and average zero-crossing period (s).

The encounter frequency will alter with the heading angles as the ship moves across the waves. The link between the encounter frequency and the wave frequency is as follows because the wave spectral density function at the encounter frequency and the wave spectral density function at the wave frequency have the same amount of energy.

$$\omega_e = \omega - \frac{\omega^2}{g} \cdot U \cdot \cos(\beta) \quad \text{......vii}$$

The Motion variance is given by the area under the motion energy spectrum:

$$m_{o_e} = \int_0^\infty S_r(\omega_e) \cdot d\omega_e \quad \text{......viii}$$

Hence the $\sqrt{m_{o_e}}$ represents the RMS motion, and the significant motion amplitude is twice the RMS motion. Besides, the RMS velocity and acceleration are given by $\sqrt{m_{2_e}}$ and $\sqrt{m_{4_e}}$.

CHAPTER 3

3. Hull Geometry and setup

The focus of the present study is to learn the seaworthiness abilities of KCS when sailing at three speeds 15, 18 and 22 Knots in an irregular wave.

The KCS hull is a widely used reference test case for understanding ship hydrodynamics in the field of marine hydrodynamic science. The hull is modelled like a present commercial container ship, with a flared fore and bulbous bow under the waterline. The calculations for seakeeping have been performed on a bare hull without a rudder. KCS hull geometry is Figure 4 and the main dimensions of hull are presented in Table 1.

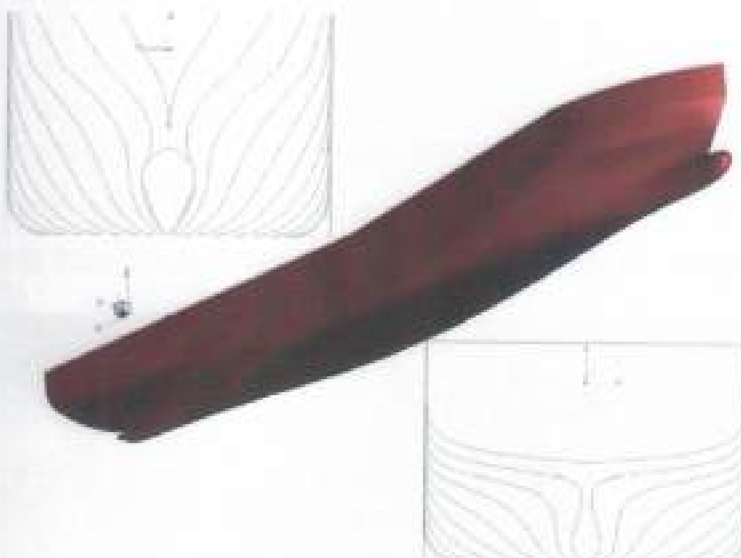

Figure 4 KRISO container ship (KCS) hull geometry.

Table 1 Main dimensions of KCS hull.

Dimensions	Value	Units
Length between perpendiculars (l_{PP})	230	m
Length of waterline (L_{WL})	232.5	m
Beam at the waterline (B_{WL})	32.2	m
Depth (D)	19.0	m
Design Draft (T)	10.8	m
Displacement (Δ)	52,030	m^3
Block coefficient (C_B)	0.6505	-
Roll gyradius	37.892	m
Pitch gyradius	104.875	m
Yaw gyradius	104.875	m
Vertical centre of gravity	10.8	m
Speed (v)	15,18 & 22	Kn

3.1 Numerical Setup

The computer program used is Maxsurf Modeler and Motion. Maxsurf is a very potent design tool. You may specify the strip quantities and then measure the hull after importing the constructed ship model into the Maxsurf programme. Since there are no multiple contours and the waterline beam is not very narrow for the depth, sections are by default mapped using Lewis sections (Lewis, 1988), as seen Figure 5.

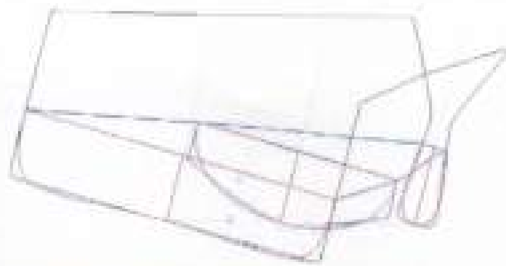

Figure 5 Three-parameter Lewis mappings.

After the model is built in modeler and all parameters are set in Motion, the resulting ship from different views and striped ship is shown in Figure 6~8.

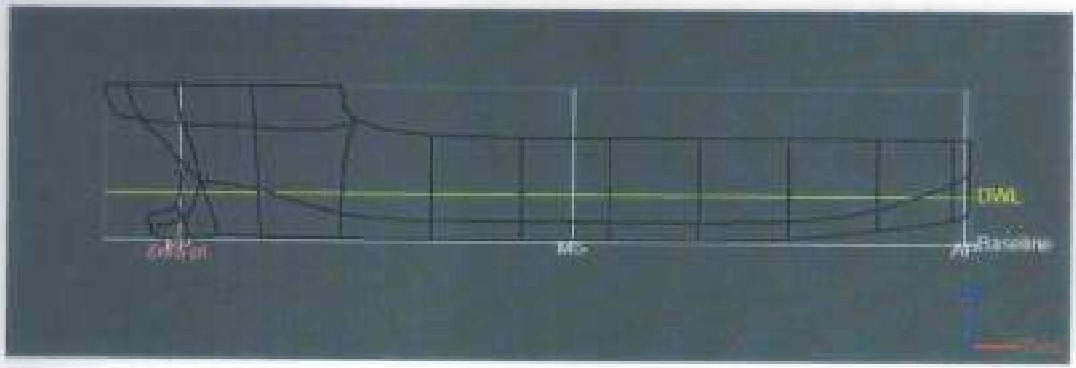

Figure 6 Profile View of KCS hull in Maxsurf Modeler.

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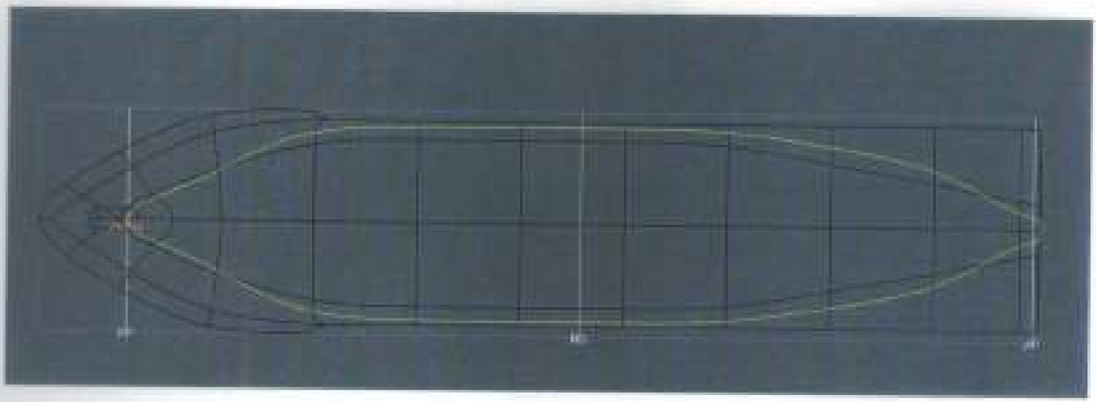

Figure 7 Plan view of KCS hull in Maxsurf Modeler.

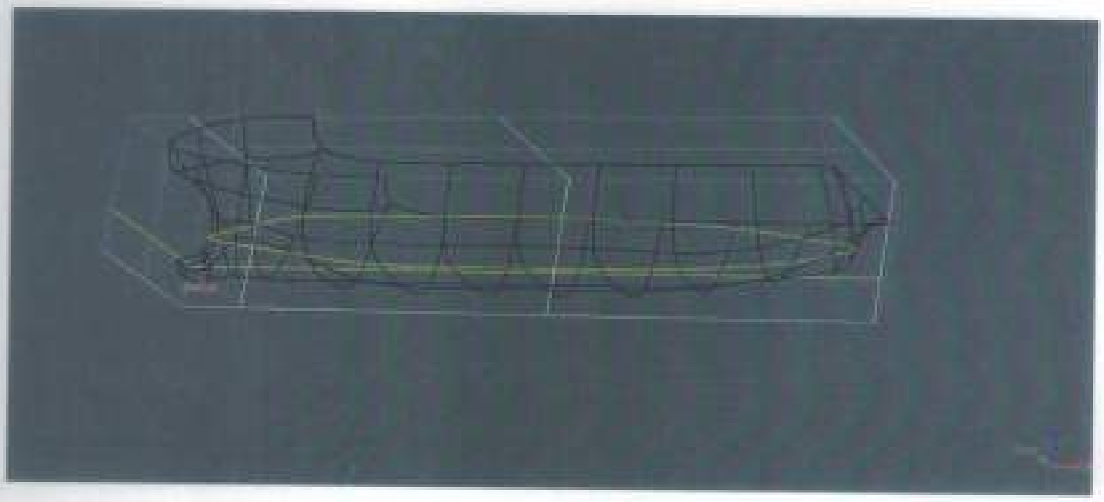

Figure 8 Perspective view of KCS hull in Maxsurf Modeler.

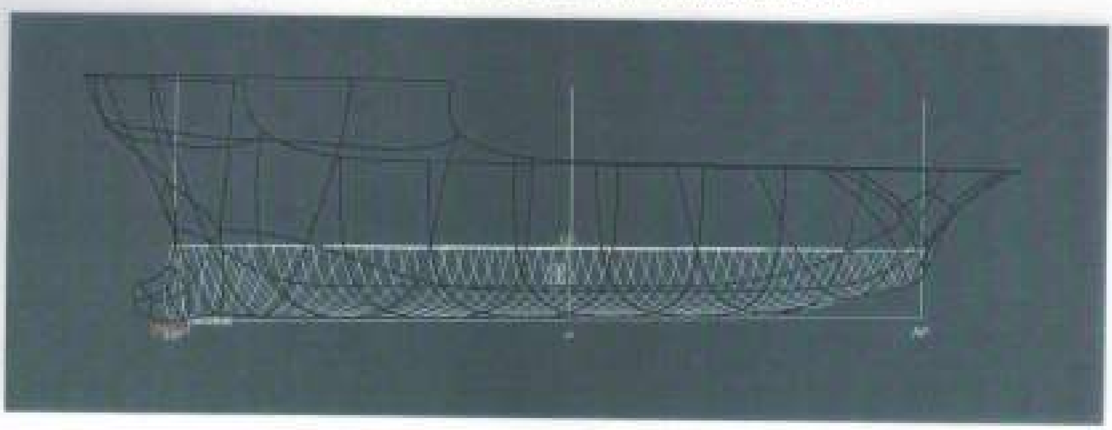

Figure 9 The mapped sections view.

3.2 Sea Conditions

The test cases for the study of seakeeping are in Table 2. Tship'ship movements are calculated using the assumption that it is travelling on an irregular wave at 15, 18 & 22 Knots with a wave height of 7 and 9 meters, and a heading angle between 30 and 180 degrees with a 30-degree step.

Table 2 Test Cases.

Wave height (m)	Vessel Speed (knot)	Method	Heading angle (deg)	Wave spectrum
7 m	15,18,22 knots	Strip Theory	30,60,90,120,150,180	Jonswap
9 m	15,18,22 knots	Strip Theory	30,60,90,120,150,180	Jonswap

CHAPTER 4

4. Validation and Results Discussion.

4.1 Validation

For the purpose of Validation, The current study has been contrasted with the simulation work done by Florin Pacuraru in 2020. The aforementioned researcher has simulated ship motions on the hulls of the KRISO Container ship at 12 knots. In the present simulation, similar conditions were taken into consideration for the KCS hull. The numerical results in form of graphs represent a matching tendency seen in the study of researcher. This investigation has been taken further on the KCS hull by adding more speeds, wave heights and heading angles to understand ship motion in detail.

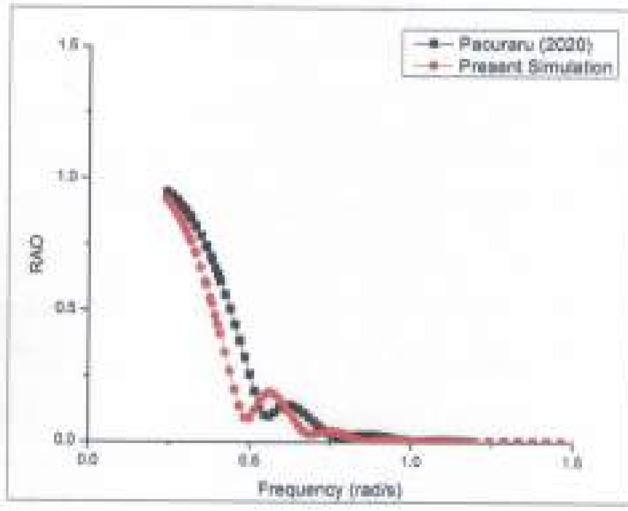

Figure 10 RAO assessment graph with present simulation and Pacuraru (2020).

4.2 Results discussion

To assess the impact of nautical performance on a vessel's operational capacity, operational requirement must be converted to nautical performance requirement. However, there is no clear universal standard for travel performance. Criteria can vary widely from ship to ship depending on the working of the ship. The Nordic Cooperation Research Program (Journee & Massie, 2001) investigated seakeeping performance and proposed basic seakeeping criteria for forecasting ship operating characteristics.

4.2.1 Response Amplitude Operator (RAO) curves for different headings

The analyzed results in the present study concern the heave (the translation along X-axis), the pitch (the rotation around the Y-axis), and the roll (rotation around) motions. The motions are calculated considering the ship advancing at a constant forward speed. The response amplitude operator RAO is defined as the ratio between the first motion harmonic and the regular wave amplitude. Because the wave frequency will change with different angles of the ship motions, the ship will produce different degrees of frequency domain motion response. Under the considered speed of 15kn, 18kn, and 22kn, Figure 10~12 below show the heave, pitch, and roll motion response amplitude operators (RAO) curve of the target ship at 30°,60°, 90°, 120°,150° and 180° heading angles.

Primarily, the ship motion has a minimal effect on the response amplitude operators (RAO) for all considered heave, pitch, and roll motions; whereas, the directions of ship movement have a major effect on RAO. It has been clearly observed that, when the wavelength tends to be infinite, that is, the wave frequency tends to zero, except the heave, the roll and pitch motion tends to 0, which confirms that when the wave frequency tends to be infinite, the KCS hull basically does not produce a motion response. The results confirm to the general calculation rules also. When the heading angle is 90°, the response amplitude for the heave motion reaches its maximum. For the pitch motion, when the wave frequency is within the range of 0.25 to 0.5, the motion response is large. This is because the wavelength is close to the ship length and resonance occurs. From the this analysis, it can be observed that the calculation results of the motion response of the ship are in line with objective laws, so the calculation results performed in this paper have credibility. When the wave frequency is between 0.2 and 0.4 rad/s, the hull rolling motion response is noticeable. At around this point, the natural frequency of the ship rolling is nearer to the wave frequency, and the ship is in the wave's resonance zone.

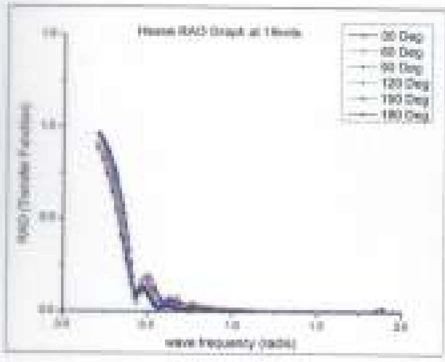

Figure 11 (a)

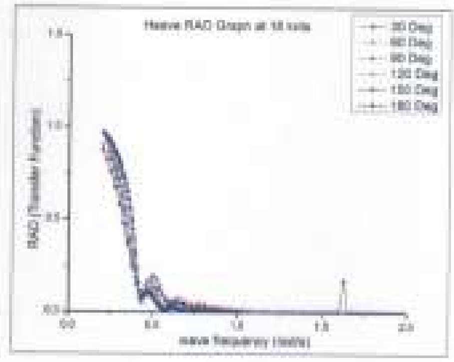

Figure 11 (b)

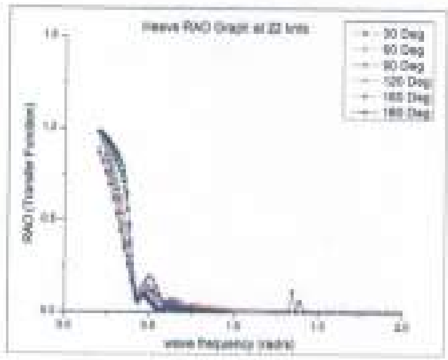

Figure 11 (c)

Figure 11 Heave motion response amplitude operators curves for different wave directions.

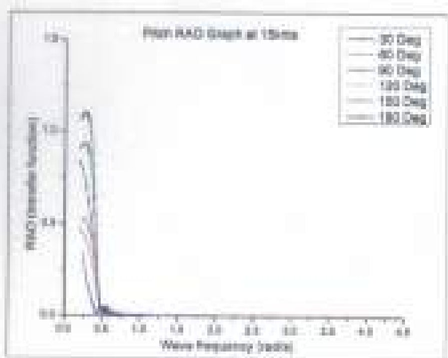

Figure 12 (a)

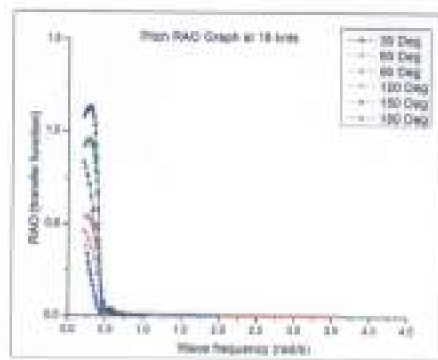

Figure 12 (b)

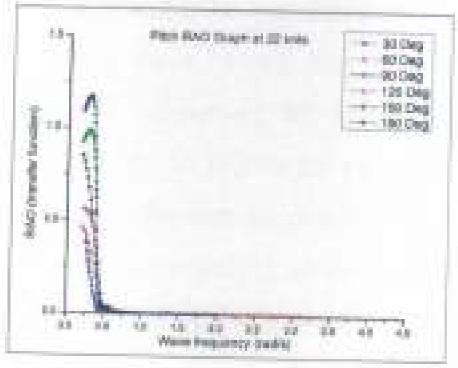

Figure 12 (c)

Figure 12 (a), (b), & (c) Pitch motion response amplitude operators curves for different wave directions.

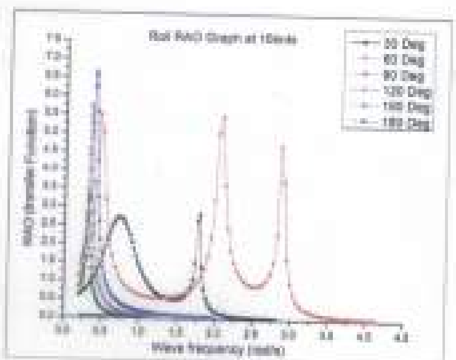

Figure 13 (a)

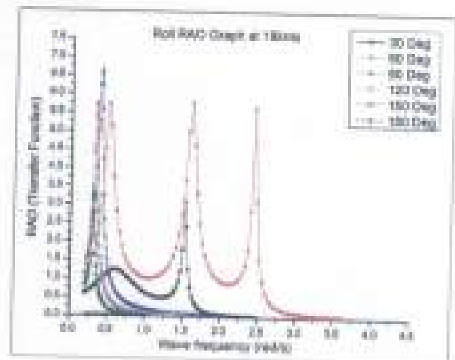

Figure 13 (b)

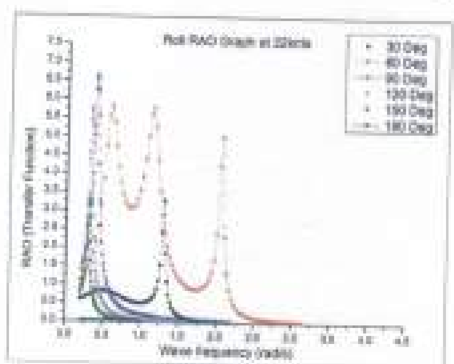

Figure 13 (c)

Figure 13 (a), (b), & (c) Roll motion response amplitude operators curves for different wave directions.

4.2.2 Significant Amplitude for different headings

From the relationship between the response spectrum and the wave spectrum, one can obtain the heave, pitch, and roll significance amplitude values for various types of sea conditions, evolving with the heading angle at the rated speed and draught, for comparison with normative standards. For this present analysis, along with 7m and 9m wave height, two other wave height (8m and 10m) is also included. As obvious, a higher response is observed for higher wave height. Significant amplitude for heave motion was found higher for ship heading angles between 30 to 90 degrees and as the speed of the ship increases, the corresponding significant amplitude also increases for higher heading angels. On the other hand, for pitch motion, higher values of significant amplitude are observed for 30 degree of a ship heading angle and a minimum is observed for the 90-degree case. This is observed for all ship speed cases. In the range of the heading angle from 30° to 180°, the roll significant amplitude value under various sea conditions exhibits a trend of first increase and then decrease. When the wave direction is 60°, the roll motion is the strongest. Furthermore, the roll motion gradually lessens as the navigation generally involves following or heading waves.

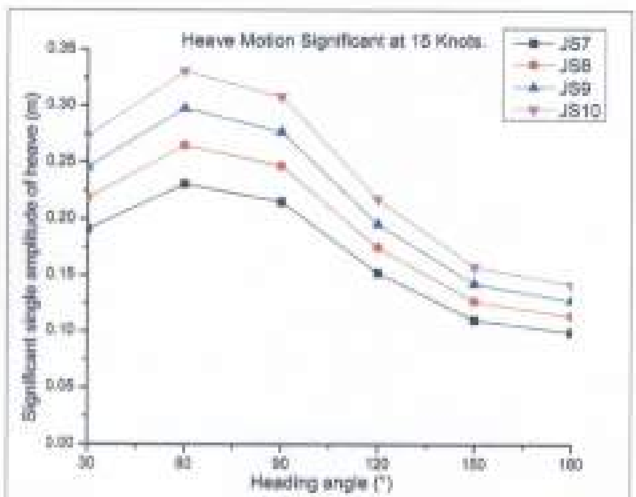

Figure 14 (a)

Department of Marine Engineering and Management
Indian Maritime University (A central University, Govt. of India)

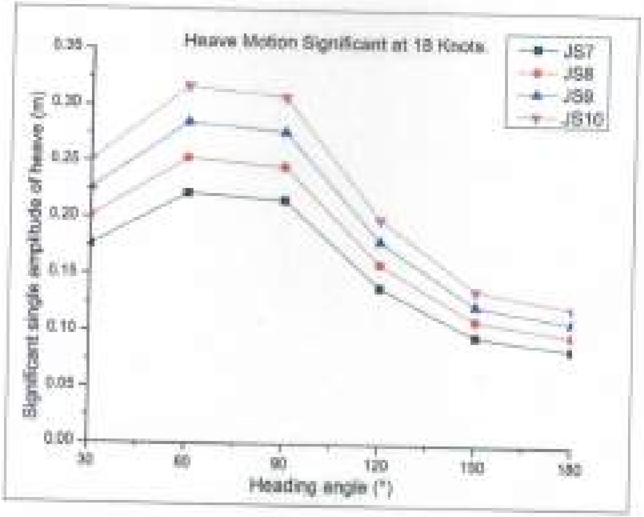

Figure 14 (b)

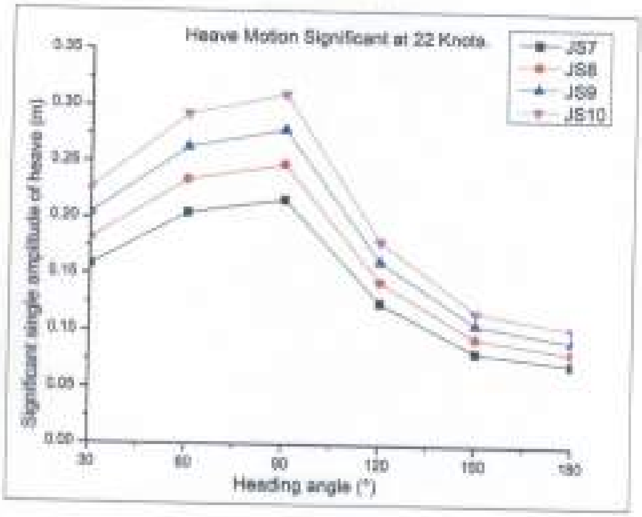

Figure 14 (c)

Figure 14 (a), (b), & (c) Heave motion significant single amplitude curves for different wave heights.

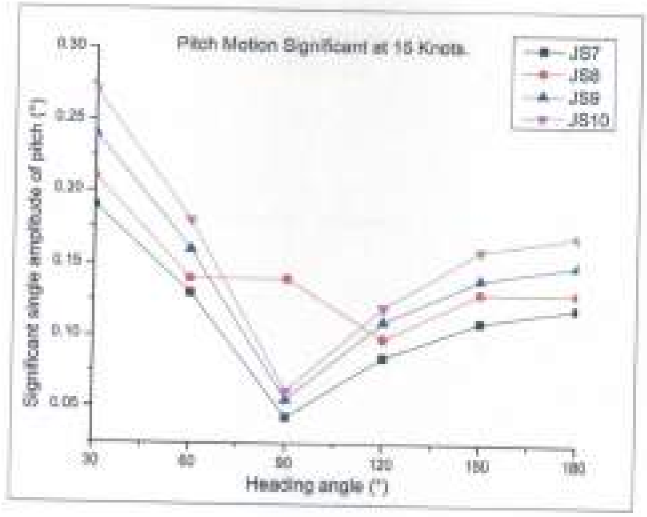

Figure 15 (a)

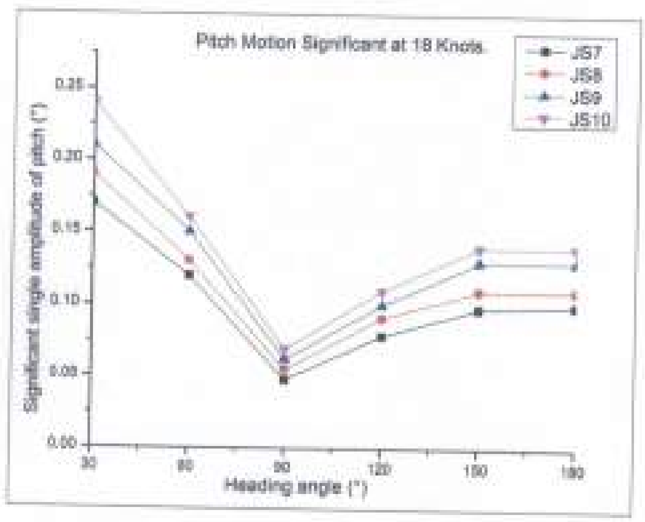

Figure 15 (b)

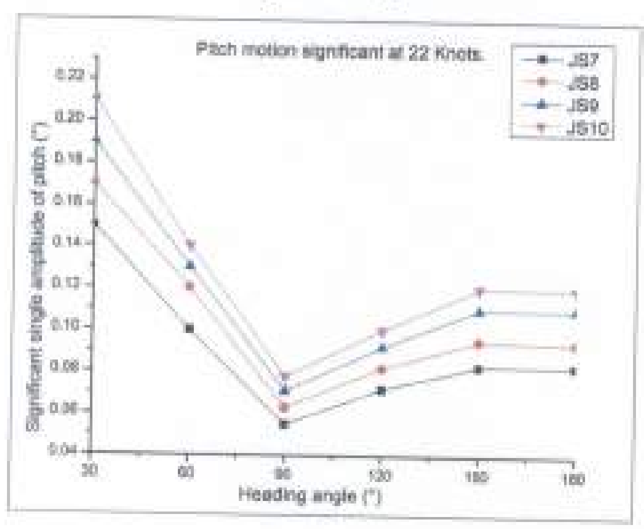

Figure 15 (c)

Figure 15 (a), (b), & (c) Pitch motion significant single amplitude curves for different wave heights.

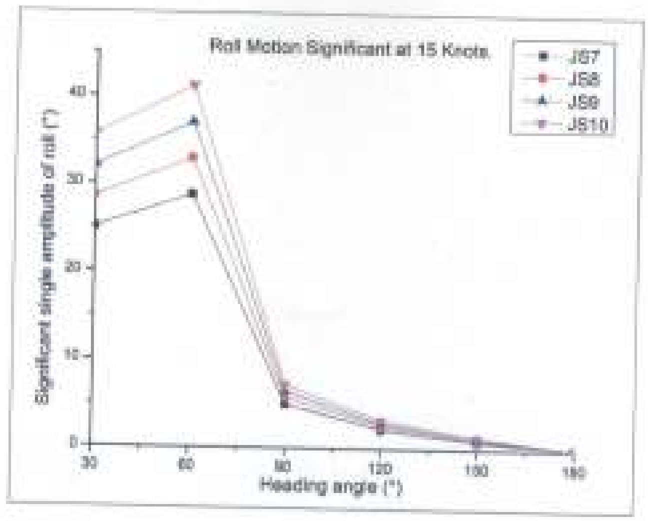

Figure 16 (a)

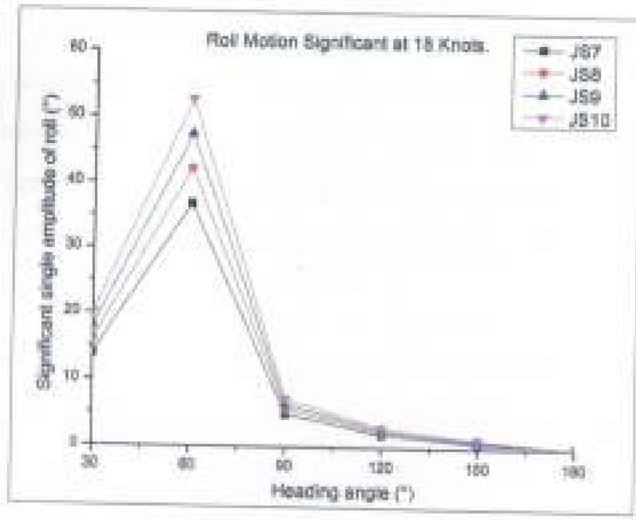

Figure 16 (b)

Department of Marine Engineering and Management
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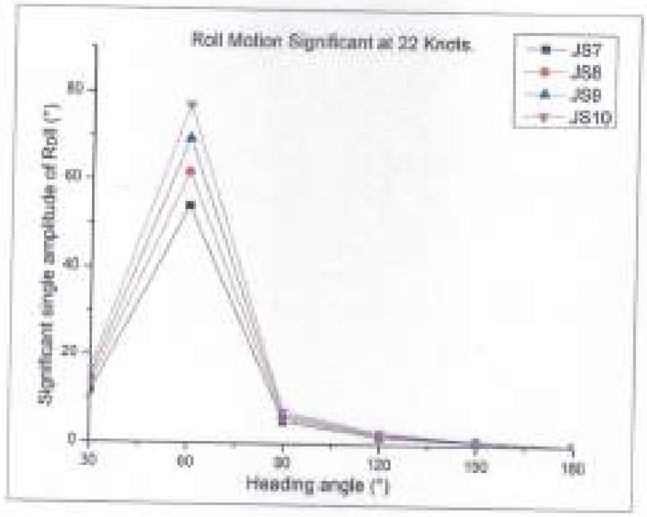


Figure 16 (c)

Figure 16 (a), (b), & (c) Roll motion significant single amplitude curves for different wave heights.

4.2.3 Time series response of Heave, Pitch and Roll motion

The time series response of Heave, Pitch, and Roll movements for various sea states and ship motions taken into consideration in the current study is shown in Fig. 16~18. For ship heading angles between 30 and 60 degrees, the reaction is at its peak, while an angle of 180 degrees has the least impact. Only heave motion is seen at 30 degrees of a ship heading angle for higher ship speed and wave height (22 Knot, 9m). The increased ship speed, notably in the 22 Knot example, is found to significantly lessen the heave motion at degrees of ship heading angles and wave heights.

Additionally, it is shown from the time series analysis that the rolling at 22 knots was greater than at other speeds. This demonstrates how a ship's rolling motion may worsen as vessel speed increases. Furthermore, it is shown in Figure 19 that increasing speed in large waves increases the probability of a ship capsizing. The result of 22 knots, 7m & 9m wave height demonstrates the vessel capsizing in deep ocean.

As an overall analysis, we can say that the rolling motion was greatest around the 60-degree heading angle, which might have a significant effect on ship stability.

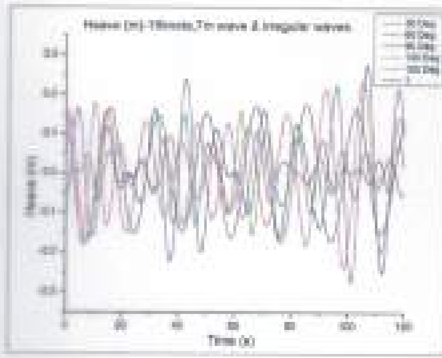
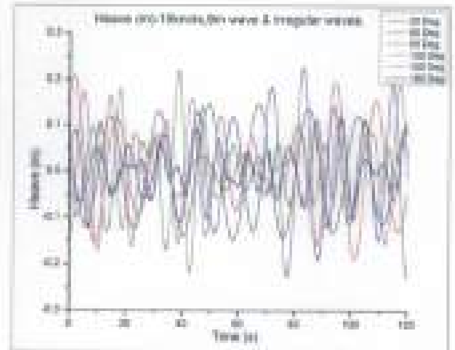


Figure 17 (a)



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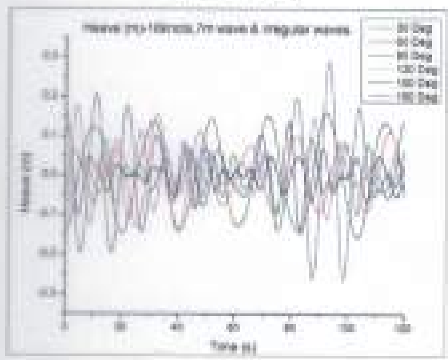

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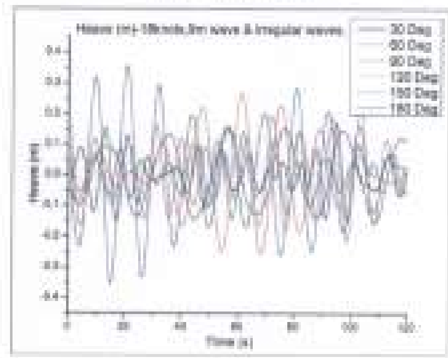


Figure 17 (d)

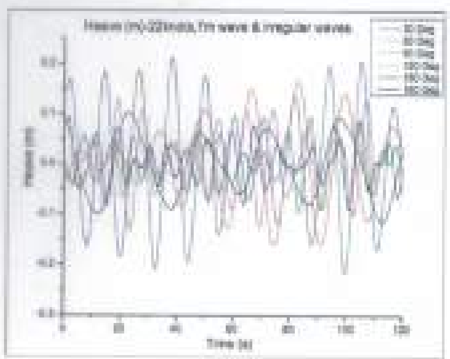


Figure 17 (e)

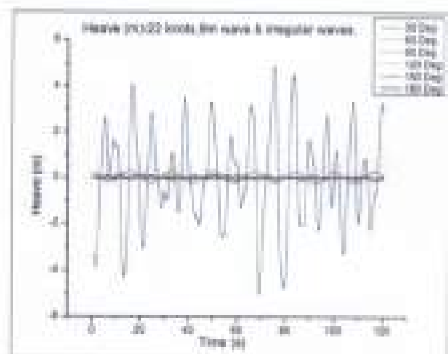


Figure 17 (f)

Figure 17 (a), (b), (c), (d), (e) & (f) Time series response of Heave motion.

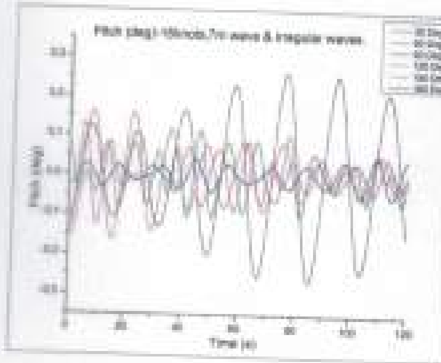


Figure 18 (a)

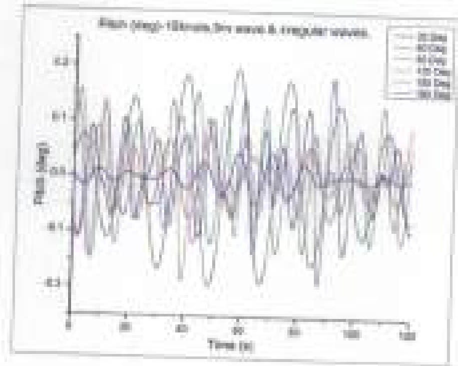


Figure 18 (b)

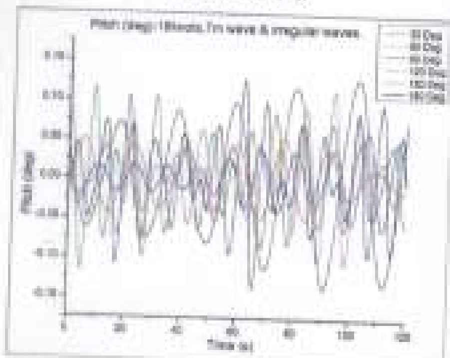


Figure 18 (c)

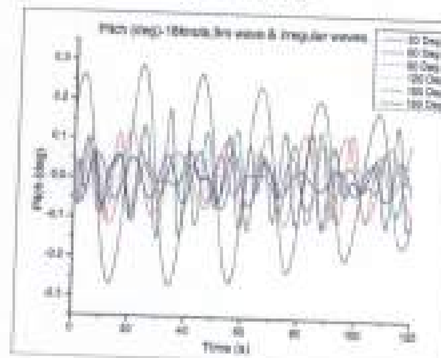


Figure 18 (d)

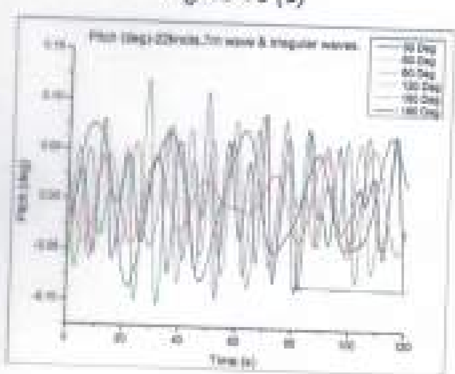


Figure 18 (e)

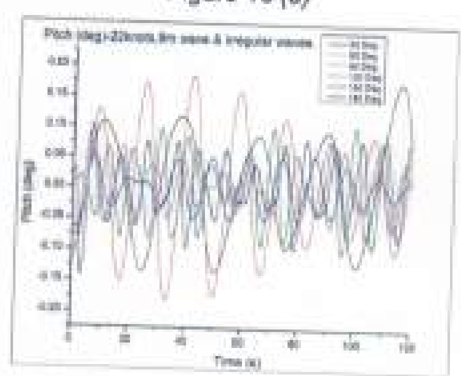


Figure 18 (f)

Figure 18 (a), (b), (c), (d), (e) & (f) Time series response of Pitch motion.

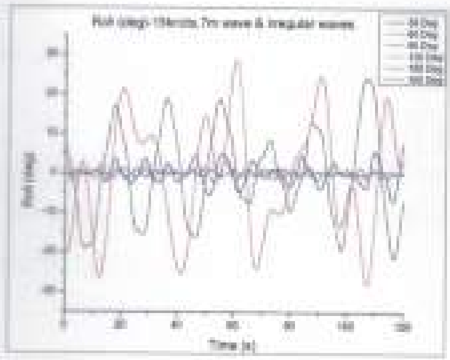


Figure 19 (a)

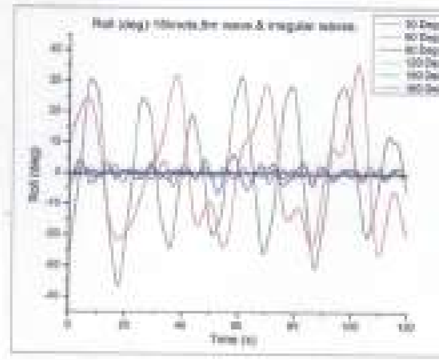


Figure 19 (b)

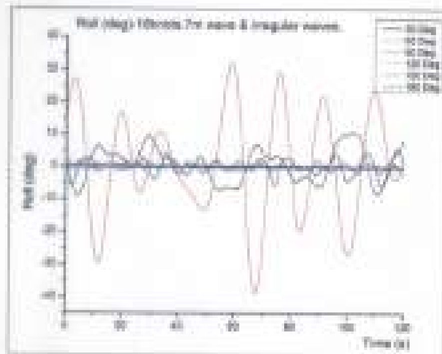


Figure 19 (c)

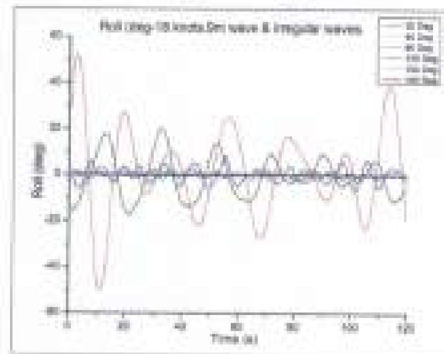
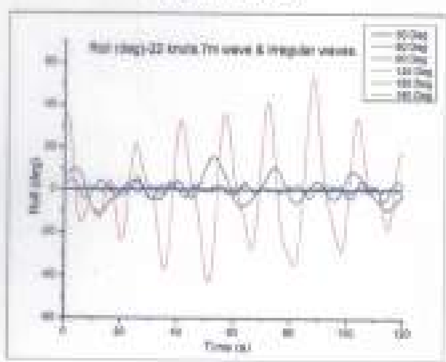


Figure 19 (d)



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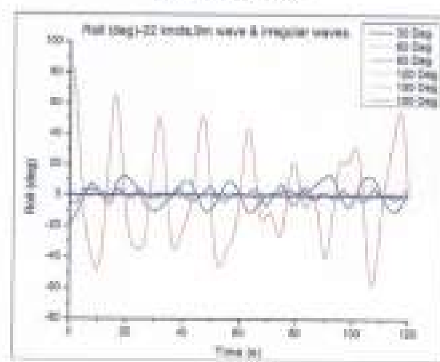

Figure 19 (f)

Figure 19 (a), (b), (c), (d), (e) & (f) Time series response of Roll motion.

4.2.4 Proposed Mathematical model of KCS hull in irregular waves.

The visual depiction of the general function is known as a sine wave. The sine wave oscillates uniformly and periodically above and below zero. The Time series information received after the simulation of the KCS hull was utilized in Origin software to find the mathematical model of obtained waveforms. Different waveform functions were tried and compared with the available amplitude. In comparison, the least error was observed in the Sine function. The mathematical function mentioned below has been derived from all the time series graphs shown in the above topic.

$$y = y_0 + A\sin(\pi\frac{x-x_c}{w}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ix}$$

A is an area under the wave, y_0 is the offset, x_c is the center of the curve, and w is the width of the wave.

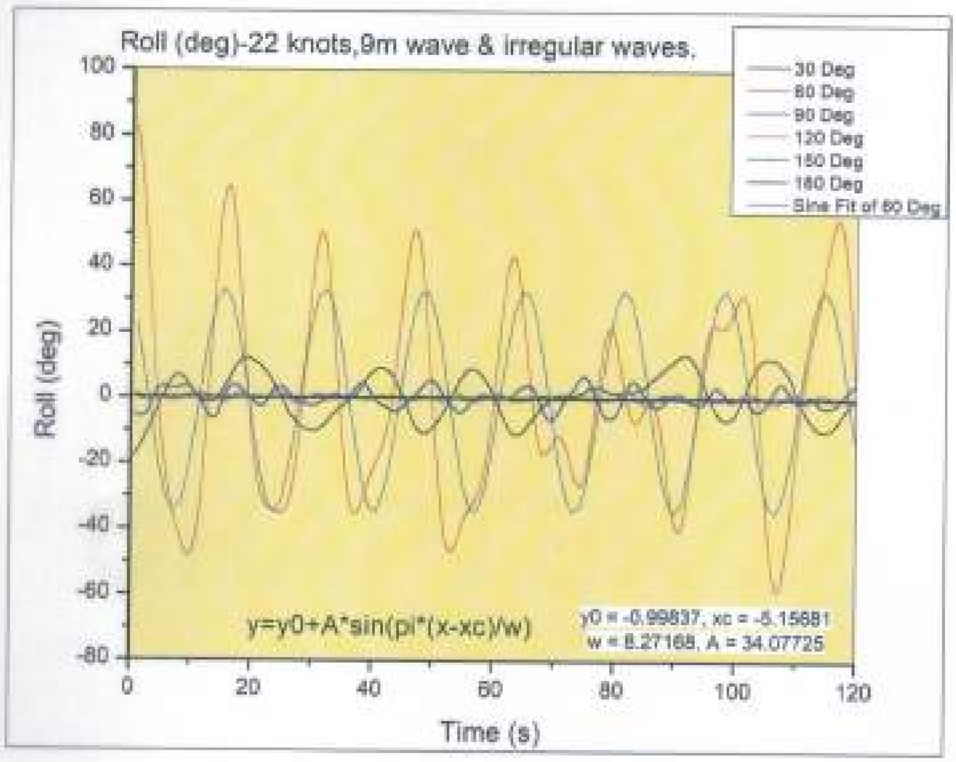

Figure 20 Waveform Sine function with 22knots at 60 degree.

A graph of 22knots, 9m wave height at 60 degree has been shown for the comparison with the sine function wave representing a ship in irregular waves mathematically. Using the above function an error of between 3-8 % has been observed in the results.

CHAPTER 5

5 Conclusion

The full-scale KCS hull numerical model was used in this study to apply the strip model for the irregular wave heights of 7 and 9 metres, a heading angle range of 30 to 180 degrees with 30 degrees step, and three forward speeds of 15 knots, 18 knots, and 22 knots.

1) For all heave, pitch, and roll movement taken into consideration, the ship motion has a negligible impact on the response amplitude operators (RAO), however, the directions of ship movement have a significant impact on RAO.
2) The rolling motion of the hull may be effectively controlled and the movement generally tends to be safe when the speed of the vessel is reduced and ship course is changed.
3) The rolling motion was found maximum near the 60 degree of heading angle at 22knots, which could high impact on ship stability.
4) The significant amplitude analysis shows that the roll motion is highest when the wave direction is 60 degrees. Additionally, because most navigation involves following or heading waves, the roll motion progressively becomes less pronounced.
5) The pitch motion response for each heading angle is near when the wave frequency is larger than 0.5 rad/s. The heading angle now has a negligible impact on the pitch motion.
6) The heave motion response for each heading angle is near when the wave frequency exceeds 1 rad/s. The heave motion is currently not significantly impacted by the heading angle.
7) A mathematical model was obtained using the times series data and the error of 3 to 8% was observed.

CHAPTER 6

6 Further Scope of work

Further studies will extend this analysis to more numerical results of Motion sickness incidence (MSI) & RMS of vertical acceleration at specific locations on ship based on strip and Panel method considering the shiploads and at different drafts. The draft of the hull may have a greater impact on wave resistance. This thesis only selects the state of motion at the designed draft for analysis. When the draft changes, additional research is required to ensure navigation safety. Furthermore, the obtained mathematical model can be used to compare with other ship models and a general mathematical model can be derived.

Publication from present work:

Mohammed Bhatia., M, Das., N., Chakraborty, S., Chakraborty, S. and Dutta P., Numerical study on the seakeeping performances of KCS hull, International Conference on Recent Advances in Fluid Mechanics (ICRAFM-2022), Manipal Institute of Technology, MAHE, Manipal, 04-06, 2022, (Accepted).

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