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Senan, Aswathy; Krishnankutty, P.; Subramanian, Anantha

Experimental and Numerical Study of Motion Chracteristics of An Equi-Hull Trimaran

EXPERIMENTAL AND NUMERICAL STUDY OF MOTION CHRACTERISTICS OF AN EQUI-HULL TRIMARAN

Aswathy Senan[1], P.Krishnankutty[2] and V.Anantha Subramanian[3]

Abstract: *This paper deals with the estimation of wave forces and subsequent motion response of an equi-hull trimaran carrier vessel. Strip theory is used here for the numerical estimation of the forces on and motions of the carrier vessel using its idealized mono hull form. The heave, pitch and roll motions obtained from the model tests, carried out in the wave basin of IIT Madras, for regular waves in head sea, bow-quartering sea and beam sea for zero speed case are compared with the numerical results.*

Keywords: *Trimaran; Strip theory; wave exciting force*

INTRODUCTION

The trimaran consists of a set of three identical river barges, connected together abreast with inter-hull box-girders to form a trimaran hull. It is loaded with identical barges and towed through sea by tugs. The bottom barges are adequately stiffened for sea-going conditions. Figure 1 shows the Equi-hull Trimaran carrier vessel arrangement.

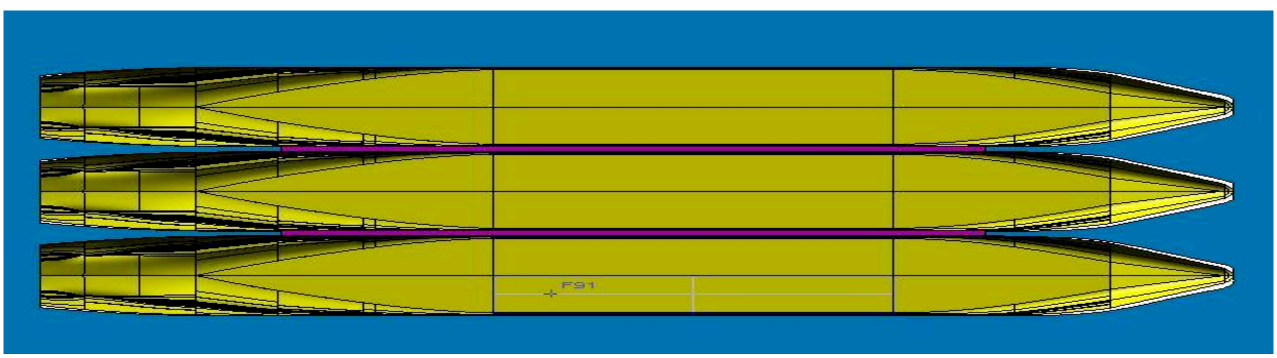


Fig.1. Equi-hull Trimaran carrier vessel

1 Research Student, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, India, Email: aswathysenan@gmail.com
2 Professor, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, India, Email: pkrishnankutty@iitm.ac.in
3 Professor, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, India, Email: subru@iitm.ac.in

The carrier vessel is considered to be a rigid floating body, water is treated as an ideal fluid and flow as an irrotational one for the numerical study of the present wave-vessel interaction problem. Numerical method based on strip theory is used here for the estimation of the forces on and motions of the carrier vessel. Strip theory is based on two-dimensional potential theory, where it considers the vessel to be made up of a finite number of transverse two-dimensional slices which are rigidly connected to each other. Each of these slices will have a form which closely resembles the segment of the vessel. The strip theory is based on the potential flow theory and hence the viscous effects are neglected. This can deliver serious problems when predicting roll motions at resonance frequencies. In practice, viscous roll damping effects are accounted fairly by empirical formulas. Strip theory solves the three-dimensional problem of the hydro-mechanical and exciting wave forces and moments on the vessel by integrating the two-dimensional potential solutions over the vessel's length. The previous works in this field are looked into, for instance Arribas et-al (2006) studied strip theory applications to study the motions of high speed crafts. Fonseca et-al (2004) used non linear time domain strip method to represent nonlinearity and also forward speed effects on a displacement high speed vessel in large amplitude waves. Journée (2001) did comparative motion calculations between the experimental and theoretical data with strip theory for a Flokstra container ship model .Varyani et-al (1998) used strip theory and 3D pulsating source method to predict craft motions and dynamic loads acting on a catamaran hull. Poul Andersen (1979) used strip theory and fluid finite element method to calculate vertical motions and loads for a ship with non zero forward speed in regular waves. Taylor et-al (1979) obtained wave excited dynamic response of a typical offshore structure using conventional strip theory.

NUMERICAL STUDY

Vessel particulars and numerical modeling

The principal particulars of each hull (all three hulls are identical) are shown in Table 1.

Table 1.Carrier Vessel Particulars

Length Overall	135.0m
Moulded Breadth of combination	47.0m
Moulded Breadth of single hull	15.0m
Depth	5.39m
Loaded draft	4.0 m
Inter-hull box size	77m x 1.0m x 4.0m

The carrier vessel configuration has a rectangular box, of 1.0m breadth and 4.0 m depth from deck downward running over 77m throughout the parallel body region, rigidly placed and connected between the hulls. The body plan of one hull of the trimaran is shown in Figure 2. For the strip theory calculations carried out here, the trimaran vessel has been modeled as an equivalent mono-hull one by modifying the fore and aft regions.

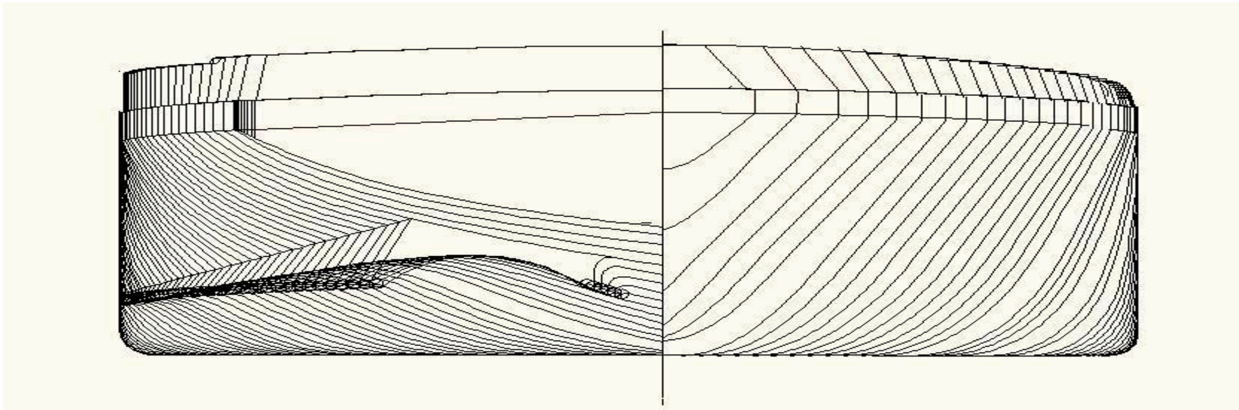


Fig.2. Monohull section form of the carrier vessel

A frequency-domain ship motions computer code based on linear strip theory to calculate the wave-induced loads and motions for six degrees of freedom of displacement ships, yachts and barges, sailing in regular and irregular waves is used here for analysis. When not taking into account interaction effects between the two individual hulls, these calculations can be carried out for twin-hull ships, such as semi-submersibles and catamarans, too. This potential theory program is suitable for deep water as well as for shallow water. Interactions between the cross sections are ignored for the zero-speed case. So each cross section of the ship is considered hydrodynamically as if part of an infinitely long cylinder as shown in Figure 3. This means that all waves which are produced by the oscillating ship (hydromechanical loads) and the diffracted waves (wave loads) are assumed to travel perpendicular to the middle line plane (thus parallel to the y-z plane) of the ship.

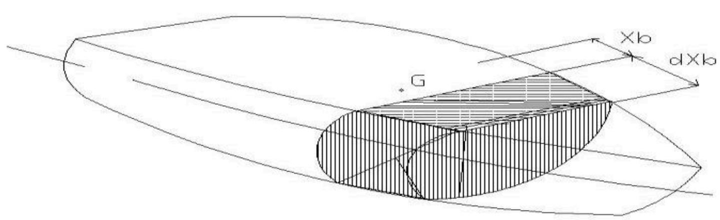


Fig.3. Strip Theory Representations by Cross Sections

EXPERIMENTAL STUDY

Prototype size of the ship is L x B x D = 135m x 15m x 5.39m. During the vessel construction all the three hulls have been interconnected with longitudinal box girders of 1m width and 4.0m depth running over 77m in the prototype. The 9 hulls representing the deadweight cargo exactly similar to the above hulls have been fabricated. The combinations of hulls have been finished smoothed and fitted on board the combination of vessels with Motion sensing transducer namely the MRU.

Model Making

The model was built on scale 1:54. The fabrication was done using the three stage process of construction of timber plug, then a fibre glass negative form and finally the hull in fibre glass. The hulls were connected with timber strips to simulate the box girders between the hulls. Total number of models fabricated: 3 carrier hulls and 9 deadweight cargo hulls. The models were connected together and the nine identical hulls were secured to the main hulls.

Sea-Keeping Wave Basin and Wave Generation Facility

The sea-keeping wave basin facility at IIT-Madras measures 30m x 30m x 3m depth. It is equipped with two adjacent wave maker systems. One consists of a long crested wave maker (LCWM) and the other consists of a Multi-Element Wave Maker system (MEWM). The electro-hydraulic systems can generate computer controlled regular seas as well as fully developed 2D and 3D sea states conforming to any given spectra.

Instrumentation

The equipment for motion sensing is the TSS Dynamic Motion sensor. The sensor package consists of an array of solid state sensing elements that measures the instantaneous linear accelerations and angular rates experienced by the sensors at any time. The motions are derived in the form of roll, pitch and heave. The signal processing is done through high speed circuitry and the data is communicated to a receiving PC .The sensing unit is located by design to coincide with the centre of gravity of the model.

Test setup

Tests were conducted in different heading angles in zero speed stationary conditions covering the range of head sea, bow-quartering sea and beam sea conditions for a range of wave periods and a wave height of 0.12m which is equivalent to 6.48m in open sea. The tests were designed to primarily obtain the largest motion responses in the rigid body six degrees of freedom mode in simulated wave conditions. They were also intended to obtain the dynamic effects like shipping green water. From preliminary trials, the effective range of period of oscillation of the responses of the loaded trimaran barges was established through experiments. The effective range covering all responses was seen to be in the range of periods from 6 to 14 seconds on prototype scale. It was also established that at the higher end of the above periods, typically beyond 10 seconds, the trimaran tended to show quasi-static behaviour. It means that the motions for the higher periods more or less follow the amplitudes of the waves. Hence smaller wave steepness sufficed for the quantification of the behaviour of the loaded trimaran barges. On this basis it was inferred that the waves at lower periods should be sufficiently of large height to obtain realistic transfer function characteristics of heave, pitch and roll as well as dynamic effects such as shipping green water. In other words, the waves should have sufficient steepness in the lower period range. The steepness was not so important in the higher period range typically after 10 seconds, for obtaining the transfer function characteristics. Based on these considerations and the mean of the highest wave occurrence during the annual period, a constant wave height of 0.12m was fixed for all experiments in regular waves in stationary condition. By choosing a constant wave height of 0.12m for all experiments it was possible to obtain the maximum motion responses and the dynamic effects wherever they occurred. The wave steepness ranged from $H/\lambda = 0.12$ for T=5.8s to $H/\lambda = 0.04$ for T = 10s. For the values from T=10s to T=14.6s, responses were mostly quasi-static in nature and therefore the relatively mild slopes of the exciting waves are in order. Figure 4 shows the typical test setup in wave basin. The wave steepness parameter (H/λ) where H is the wave height and λ is the wave length, is given in Table 2.

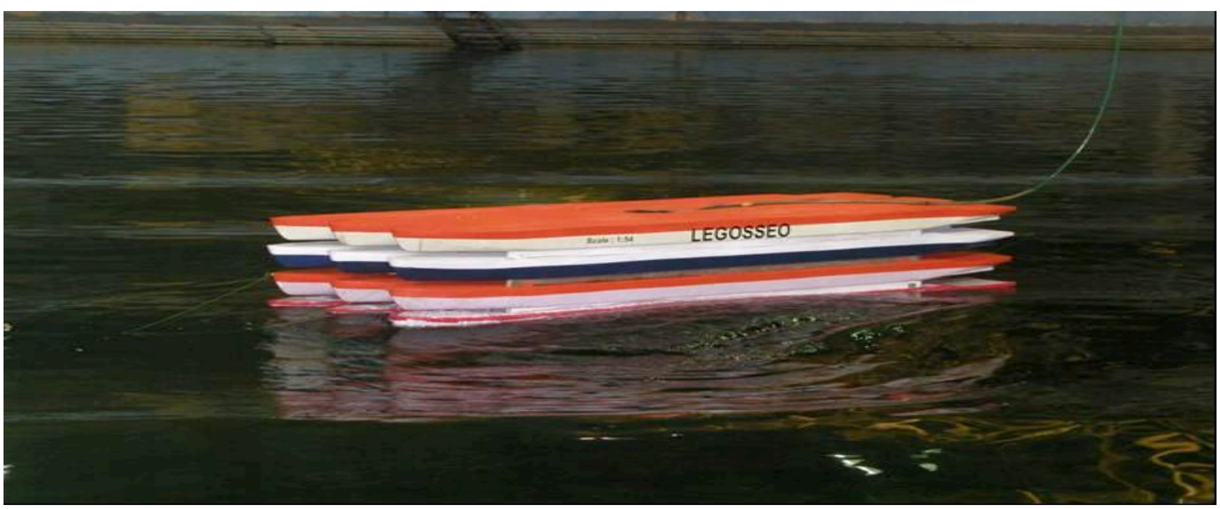


Fig.4. Typical test set up in the Wave Basin

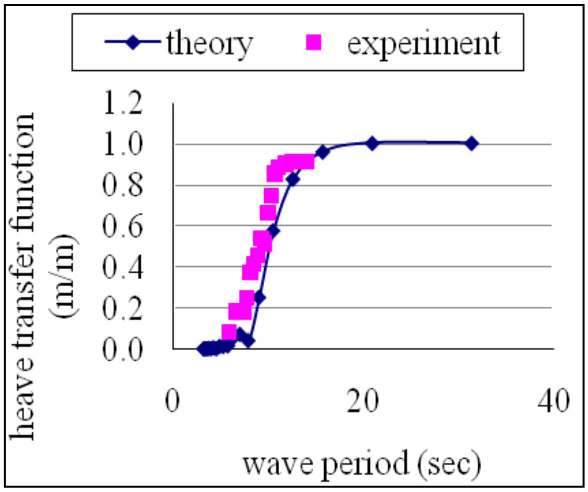
Table 2. Experimental wave conditions

Sl no.	Prototype wave period(sec)	Deep water wave length(m)	Wave length / ship length	Wave steepness (for constant wave height H=6.48)
1	5.8	52.48	0.397	0.123
2	6.6	67.95	0.50	0.095
3	7.3	83.13	0.62	0.08
4	7.7	92.49	0.69	0.07
5	8.1	102.35	0.76	0.06
6	8.4	110.07	0.82	0.058
7	8.8	120.80	0.89	0.054
8	9.2	132.03	0.98	0.049
9	9.5	140.79	1.04	0.046
10	9.9	152.89	1.13	0.042
11	10.2	162.30	1.2	0.04
12	10.6	175.28	1.30	0.036
13	11.1	192.20	1.42	0.034
14	11.7	213.54	1.58	0.03
15	12.4	239.86	1.78	0.027
16	13.2	271.81	2.01	0.024
17	13.9	301.40	2.23	0.021
18	14.6	332.53	2.5	0.02

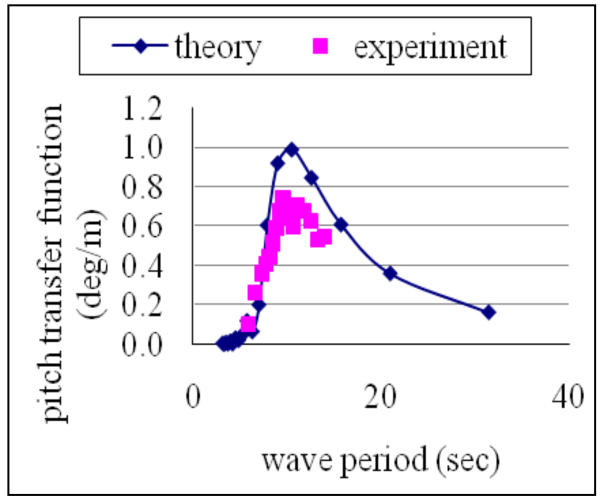
RESULTS

Vessel motions – Numerical and Experimental comparisons

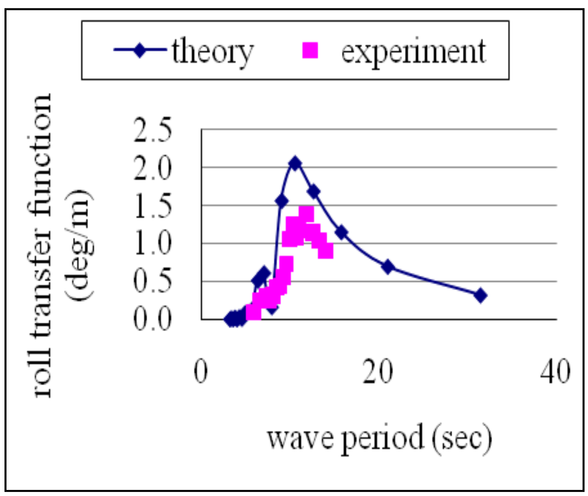
The heave, pitch and roll transfer functions obtained from the model tests carried out in the sea-keeping basin (at IIT Madras) for regular waves in head sea, bow-quartering sea and beam sea for zero speed case are compared with the numerical results, obtained using the strip method for zero speed case. Results for bow-quartering sea condition are shown in Figure 5.



(a) Heave transfer function



(b) Pitch transfer function

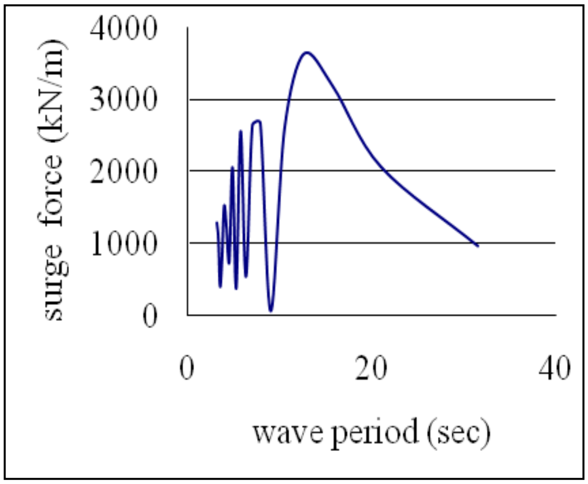


(c) Roll transfer function

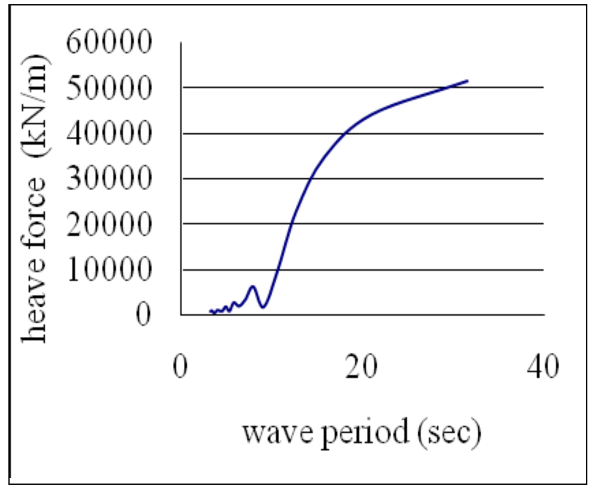
Fig.5. Vessel motions in bow-quartering sea condition (μ=135 deg)

Wave loads on the carrier vessel

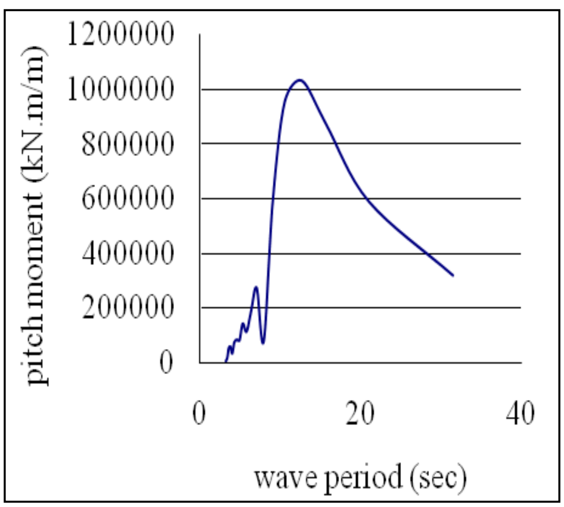
The wave exciting forces and moments on the carrier vessel in zero speed condition are estimated using strip theory. The wave exciting forces for surge, sway and heave and the wave exciting moment on the whole vessel are obtained by integrating the two-dimensional values over the vessel length. The wave exciting moment for pitch is obtained by integrating two-dimensional surge and heave contributions into the pitch moment. The wave exciting moment for yaw is obtained by integrating two-dimensional sway contributions into the yaw moment. The wave exciting forces and moments per unit wave amplitude (transfer function) on the vessel in head sea condition are shown in Figure 6.



(a) Surge excitation force



(b) Heave excitation force



c) Pitch excitation moment

Fig.6. Wave excitation forces and moments in head sea (μ=180 deg)

CONCLUSIONS

Results for the vessel motions presented shows that the numerical and experimental ones compare fairly well for heave motion. The theory over-predicts the roll and pitch motion considerably due to the absence of appropriate viscous damping factor in the theoretical model, but the trend and order are same. These observations are true for all the three sea directions (head, bow-quartering and beam seas) considered here for analysis. The computationally obtained wave exciting forces and moments on the carrier vessel for different sea directions, such as following, stern-quartering, beam, bow-quartering and head sea, are presented. Table 3 gives the maximum values of wave exciting forces and moments per unit wave amplitude, which when multiplied by the known wave amplitude gives the corresponding wave excitation forces and moments. The heave excitation force is an order above the surge and sway exciting forces, which obviously is due to the broader form of the carrier vessel. Roll moment is insignificant in following and head seas, whereas it is large in beam seas followed by quartering seas. Pitch moment is considerable in head and following seas and also comparable in quartering seas. Due to vessel symmetry about longitudinal vertical central plane the yaw moment is insignificant in head and following seas, and it is maximum in quartering seas.

Table 3. Maximum values of wave exciting forces and moments for 1.0m wave amplitude

Sea Direction	Surge Force [kN/m]	Sway Force [kN/m]	Heave Force [kN/m]	Roll Moment [kNm/m]	Pitch Moment [kNm/m]	Yaw Moment [kNm/m]
Following	3640	---	51600	---	1030000	---
Stern-Quartering	3360	6240	52000	87200	948000	242000
Beam	---	10400	52300	138000	127000	14500
Bow-Quartering	3520	6270	52000	88400	941000	245000
Head	3640	---	51700	---	1030000	---

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