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Application of fin system to reduce pitch motion

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Abstract

Container ships are prone to move at a greater speed compared to other merchant ships. The slenderness of the hull of container vessel is for better speed, but it leads to unfavorable motions. The pitch and roll are related and sometimes the vessel might be forced to parametric roll condition which is very dangerous. A fin attached to the ship hull proves to be more efficient in controlling the pitch. The fin is fitted at a lowest possible location of the hull surface and it is at the bow part of the ship. Simulations are done using proven software package ANSYS AQWA and the results are compared. Simulations are done for both regular and irregular seas and the effect of fin on ship motion is studied. P-M spectrum is considered for various sea states.

Keywords: Parametric roll; Pitch control; Fin systems; Sea states; Irregular sea

1. Introduction

The theory on the parametric roll initiation of commercial ships has been of interests to designers, analysts, ship operators and owners as well. Mainly such roll occurs when the ship is either in the following sea or head on sea. Sometimes the pitch motions which resonate with the sea waves might be responsible for a dangerous roll condition. Hence, a modification of the pitch behavior of the ship might help avoid such dangerous roll motions. The bow and stern part acceleration may also be undesirable parameter for slender commercial ships. The effects of fixed bow anti-pitching fin pairs on the sea keeping characteristics of ship are analyzed using proven software program. The present paper gives the results of analysis done in ANSYS AQWA. The result part consists of the effects of various fin configurations on the pitch and heave, speed loss, phase angles and vertical accelerations of a container ship in regular head seas. The operating conditions included a speed range corresponding to Froude numbers from 0 to 0.22, and a range of wave lengths corresponding to wave length-ship length ratios from 0.75 to 1.51. The results indicate that fixed bow fins produce maximum pitch reductions for ship-speed and wave-length combinations that correspond to near resonance conditions. For the particular container ship considered for this investigation, maximum pitch reductions up to 37 percent were obtained. The total plan area of the fin system considered was equal to 3.17 percent of the water plane area for the load water line of the ship.

The head sea parametric roll is a recently identified phenomenon relevant to very large containerships. Large roll angles more than 45° are likely to occur. Various authors show up different angles and claims up to 40° roll angle both sides. Such extreme roll angle varies from ship to ship and challenges the righting arm stability and safety based on the loading, cruising speed, environmental conditions, sea states etc. When the natural period of the roll is nearly twice the wave encounter period, resulting in two pitch cycles per roll,

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there is a chance of inception of such parametric roll. Here, the worst may be when the pitch motion is in resonance with incoming wave. In other words, parametric roll occurs when natural roll period is between 1.8 and 2.1 times the pitch periods. Here, there is likely chance of ship to pitch with the incoming waves in a head sea. The parametric roll can occur for the streamlined hull due to its low damping for roll besides the other reasons. The wave heights exceeding critical values can also excite parametric roll and it is true in view of the large flare in the fore and aft parts of ship hull.

It is the duty of the designer to avoid any unfavorable motions which will throw off stacked containers and cargo into the seas as mentioned by Shin et al. (2004). Such a condition will force the ship into a permanent list which is dangerous in the presence of a sudden gust wind or during a turn in a fast maneuver. France et al. (2001) made an investigation of head-sea parametric rolling and its influence on container lashing systems. The author emphasized the occurrence of parametric roll on container ship might impart high load on the containers and to their securing system. The author also added that Post-Panamax container ships were particularly prone to parametric roll. Surendran and Kiran (2006a) studied the feasibility to control roll motion using active fins. Surendran and Kiran (2006b) studied the control of ship roll motion by active fins using fuzzy logic. The authors suggested an activated the fin by electro-hydraulic mechanism based on the in-built intelligence using fuzzy logic control algorithm. Later, Surendran et al. (2007a) focused on the fin effect on roll motion and the fin was activated using PID controllers. Surendran et al. (2007b) also proposed a mathematical model to predict the beginning of the parametric roll. The authors adapted an algebraic expression based on Duffing's method to propose the solution for parametric roll initiation. Thomasa et al. (2009) described the avoidance of parametric roll in head sea. The authors studied the effect of bilge keel to reduce the roll motion induced by parametric roll. Galeazzi et al. (2012) investigated on early detection of parametric roll resonance on container ship. The authors stated that the parametric roll resonance on ships was a nonlinear phenomenon. When the waves encountered with twice the natural roll frequency could bring the vessel dynamics into a bifurcation mode and lead to extreme conditions of roll.

The investigations on ship motions and control were initiated decades ago. Abkowitz (1959) proposed that fins operated most effectively, and had minimal effect, at higher and lower frequencies. It was stated that the loss of speed due to fin was not excessive in calm water and fixed fin could even be designed resulting in a decreased resistance for a certain speed. Stefun (1959) conducted experimental investigation on anti-pitching fins. Heave and pitch motions for different aspect ratio and angle were studied and the possibility of speed reduction in waves also explored. Becker et al. (1959) stated that bow fins were subjected to ventilation and cavitation which led to excessive vibration when bubbles collapsed on the fin and the hull. Ochi (1961) focused on ships fitted with bow and stern fins. The author reported that there was an increase in resistance, of stern fins, two to three times that of bow fins. With bow fins a 10% reduction in pitch was achieved. Bhattacharyya (1978) suggested pitch motion reduction using fins fitted to underwater hull. The fin was fixed as low as possible to the ship's bow, as the emergence of fin caused serious operational problem. Slamming like forces are possible during the emergence of the fin and this must be considered in the structural design. The fin used for pitch stabilization was a hydrofoil section cantilevered to the hull surface in the bow of the ship. The fin was designed in such a way that the area of the fin is roughly 4.6% of the area of the load water line. Kaplan et al. (1984) studied the problem of pitch stabilization to commercial and military craft with stern and bow fin. The stern fins are less effective than the bow fin even when it is active. Bessho et al. (1985) described a methodology to choose fin size and location to reduce both heave and pitch motion. However pitch is usually the main concern and heave is rarely targeted for reduction. Avis (1991) studied the use of anti-pitching fin to reduce the added resistance of a yacht in waves. The author proposed a mathematical model to predict the effect of anti-pitching fin on ship motion and added resistance. The author validated his results with experimental investigation which claimed 22 percent reduction in pitch, 15 percent reduction in heave and 40 percent reduction in added resistance. Wu et al. (1999) investigated the effectiveness of the activated fins on reducing the pitch motion. The authors used a closed loop control system to activate the fin and a favorable pitch response could be achieved only in the linear domain. Shigehiro and Kuroda (2001) conducted an evaluation method of passenger comfort and its application to a ship with anti-pitching fins. The author studied the effect of anti-pitching fins on ship motion from the view of passenger comfort. Perez and Goodwin (2008) showed that the effectiveness of ship fin stabilizers was severely deteriorated due to dynamic stall. Dynamic stall could lead to complete loss of control action depending upon how much the fin exceeded the threshold angle.

A new system fitted to the underwater part of hull is to be evaluated in so many angles. The overall size, here the breadth-wise parameter of the fins should not project out of the prismatic frame size of the ship. As the hull is narrower at the bulbous bow region, the fin fitted with required span might be within the breadth of the vessel. The bulb interacts with the bow, and an optimum size is determined for a better fuel consumption also at higher speed. The fin was designed for both fixed and varying angles of tilt. The optimum fin dimensions are finalized based on operating speed of ship, ships breadth, incoming wave slope and restoring effect of ship.

1.1. Mathematical modeling of fin moment

The simplest anti-pitching imaginable is the hydrofoil section. This anti-pitching consists of a pair of hydrofoil section attached to the hull surface at the bow part of the ship. The fins should be fitted as low as possible to avoid emergence out of water. The lift produced by the anti-pitching fins can be used to explain the basic principle of pitch damping.

The idea is to reduce the pitch motion of the ship as to give the most beneficial effect on the heave and roll motion of the ship. To do this, the strategy is to make the vertical orbital velocity around the fin surface to the maximum and the ship should move at its maximum forward speed so that the stabilizing moment generated by the fin reduces effect of the external excitation moment by the wave. The ship profile with the anti-pitching fin is shown in Fig. 1.

At zero fin angle an angle of attack "α_f" is induced on the fin which depends on the Heave velocity($\dot{z}$), Pitch angular velocity ($\dot{\theta}$), Pitch angle (θ), Ship speed (V_s), Vertical orbital velocity of the wave particle at the fin (υ). The various components of angle of attack are shown in Fig. 2.

The angle of attack "α_f" is given by

$$\alpha_f = \theta + \frac{-\dot{z} - \dot{\theta} l + \upsilon}{V_s}. \tag{1}$$

For small pitch angular velocity

$$\dot{\theta} = q.$$

The angle of attack for small pitch angular velocity is given by

$$\alpha_f = \tan^{-1}\left(\frac{ql}{V_s}\right). \tag{2}$$

The angle of attack at the fin with fin angle (φ) is denoted by (α)

$$\alpha = \alpha_f + \varphi. \tag{3}$$

Where

α_f is the angle of attack at zero degree fin angle
φ is the fin angle

All angles should be in radians and the angle of attack is then changed to degrees to enter the curve for lift coefficient versus angle of attack. The lift force on the fin is given by

$$L_f = \frac{1}{2}\rho V_s^2 A C_L(\alpha). \tag{4}$$

Where A is the area of the fin and $C_L(\alpha)$ is the lift coefficient at an angle of attack α.

The lift produced by angular velocity on the fin is expressed by

$$L_f = \left(\frac{\partial C_L}{\partial \alpha}\right)\alpha_f \frac{1}{2}\rho A\left[V_s^2 + (ql)^2\right]. \tag{5}$$

The drag on the fin is expressed as

$$D_f = C_D \frac{1}{2}\rho A\left[V_s^2 + (ql)^2\right]. \tag{6}$$

The fin moment (M_f) is given as the product of the vertical component of the lift force and the distance from the center of the fin to the CG of the ship (l).

$$M_f = -L_f l \cos\alpha - D_f l \sin\alpha. \tag{7}$$

The moment component due to the vertical distance between the Y-axis and the fin is neglected because of small force component and small moment arm. The most significant part of the fin angle of attack is due to pitch angular velocity ($\dot{\theta}$) and if the lift coefficient versus the angle of attack curve is linear then $\partial C_L/\partial\alpha$ is constant, therefore the equation of lift force becomes

$$L_f = (\alpha_f + \varphi)\frac{\partial C_L}{\partial \alpha}\frac{1}{2}\rho V_s^2 A.$$

$$L_f = \left(\theta + \frac{-\dot{z} - \dot{\theta} l + \upsilon}{V_s} + \varphi\right)\frac{\partial C_L}{\partial \alpha}\frac{1}{2}\rho V_s^2 A \tag{8}$$

Where φ is the fin angle

The major component of this force is

$$-\dot{\theta}\left[\frac{l}{V_s}\frac{\partial C_L}{\partial \alpha}\frac{1}{2}\rho V_s^2 A\right].$$

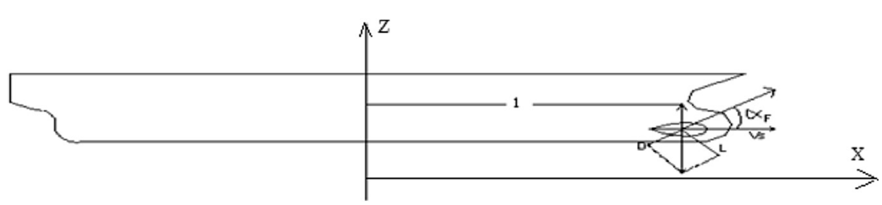

Fig. 1. Ship profile with anti-pitching fin-no fin angle.

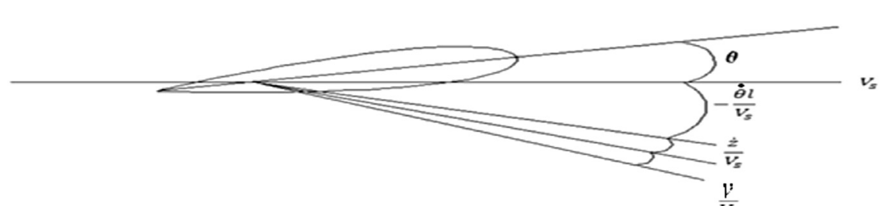

Fig. 2. Components of angle of attack on the fin.

This is a constant times $\dot{\theta}$ and acts in the same way as the term "b$\dot{\theta}$" in the pitch equation of motion and can be considered as an extra damping. Therefore the effect of the fin is mainly to increase the damping forces, which are significant in resonant condition. Substituting for the lift force and the drag force in equation (7), the equation of moment becomes

$$M_f = -\frac{1}{2}\rho A l V_s^2 \left[1 + \left(\frac{ql}{V_s}\right)^2\right]^{1/2} \times \left[\left(\frac{\partial C_L}{\partial \alpha}\right)\tan^{-1}\left(\frac{ql}{V_s}\right) + C_D\left(\frac{ql}{V_s}\right)\right]. \tag{9}$$

If we are expressing the square root term in Binomial expansion and the inverse tangent is expressed in power series

$$M_f = -\frac{1}{2}\rho A l V_s^2 \left\{\left(\frac{\partial C_L}{\partial \alpha}\right)\left[\left(\frac{ql}{V_s}\right) + \frac{1}{6}\left(\frac{ql}{V_s}\right)^3 - \frac{11}{120}\left(\frac{ql}{V_s}\right)^5\right] + C_D\left[\frac{ql}{V_s} + \frac{1}{2}\left(\frac{ql}{V_s}\right)^3 - \frac{11}{8}\left(\frac{ql}{V_s}\right)^5\right]\right\}. \tag{10}$$

(ql/V_s) is less than unity and their higher power terms will have a very small value, hence the higher power terms are omitted. It can be seen that the effect of the fin is to indirectly increase the damping force in the pitch equation of motion.

The damping coefficient due to the fin is given by

$$M_f = b_f \frac{d\theta}{dt}. \tag{11}$$

or

$$b_f = \left(\frac{\partial M_f}{\partial \theta}\right)_{\dot{\theta}=0} = -\frac{1}{2}\rho A V_s l^2 \left[\left(\frac{\partial C_L}{\partial \alpha}\right) + C_D\right].$$

For small fin angle the drag forces induced by the fin will be small therefore the equation can be reduced to

$$b_f = \left(\frac{\partial M_f}{\partial \theta}\right)_{\dot{\theta}=0} = -\frac{1}{2}\rho A V_s l^2 \left(\frac{\partial C_L}{\partial \alpha}\right) \tag{12}$$

The value of $\partial C_L/\partial \alpha$ depends on the aspect ratio of the hydrofoil section. The mass of the fin can be neglected in the motion calculation, but the added mass is taken into account. The fin added mass is considered for heave motion, the fin added mass times l^2 is added to the virtual mass moment of inertia of the ship.

1.2. Pitch equation of motion

The pitch equation of motion of a ship without anti-pitching fin is given by

$$a\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} + c\theta = M_0 \cos \omega_e t. \tag{13}$$

The various components of the pitch equation of motions are

$$\text{Inertial moment} = a\frac{d^2\theta}{dt^2}$$

Where "a" is the virtual mass moment of inertia and it is a function of radius of gyration and mass distribution of the vessel. $d^2\theta/dt^2$ is the angular acceleration of pitching.

$$\text{Damping moment} = b\frac{d\theta}{dt}$$

Here "b" is the damping moment coefficient and $d\theta/dt$ is the pitch angular velocity. The damping moment is linearly proportional to the angular velocity.

$$\text{Restoring moment} = c\theta$$

"c" is the restoring moment coefficient and it is a function of longitudinal metacentric height. θ is the angular displacement in pitching.

The solution of the pitch equation of motion is given by

$$\theta = \frac{\theta_{st}}{\sqrt{\left(1-\Lambda^2\right)^2 + 4k^2\Lambda^2}} \sin(\omega_e t - \varepsilon_2). \tag{14}$$

The equation of motion of the ship fitted with anti-pitching fin is given by

$$a\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} + c\theta = M_0 \sin \omega_e t - M_f. \tag{15}$$

Substituting the equation (11) in (15)

$$a\frac{d^2\theta}{dt^2} + \left(b + \frac{1}{2}\rho A V_s l^2 \left(\frac{\partial C_L}{\partial \alpha}\right)\right)\frac{d\theta}{dt} + c\theta = M_0 \sin \omega_e t. \tag{16}$$

Equation (16) shows that the energy under the external excitation is to be balanced by inertial, damping and restoring moments. "a" includes the fin added mass + ship added mass. Kindly note that the added mass term "a" is different in equation(13) and (16).

1.3. Response amplitude operator

The response amplitude operator (RAO) describes how the response of the vessel varies with the frequency. These are normally non-dimensional quantities and are achieved by dividing the response with wave height (ζ_0) or wave slope ($K\zeta_0$) for linear and angular motions respectively.

It may be seen that the RAOs tend to unity at low frequency; this is where the vessel simply moves up and down with the wave. At high frequency, the response tends to zero since the effect of very short waves cancel out ever the length of the vessel. The vessel will also have peak of greater than unity, this occurs close to the vessel's natural period. The peak is due to the resonance. The RAO value greater than unity indicates the vessel response is greater than the wave amplitude (or slope).

Heave RAO

$$RAO_z = \frac{Z_0}{\zeta_0}. \tag{17}$$

Pitch RAO

$$RAO_\theta = \frac{\theta_0}{K\zeta_0}. \tag{18}$$

1.4. Response spectrum

The vessel RAOs depend only on the vessel's geometry, speed and heading. Once the RAOs have been calculated the response of the vessel in a particular sea state can be calculated as follows,

1. Calculate the wave spectrum S_ζ (ω).
2. Obtain encounter spectrum S_ζ (ω_e) of the vessel.
3. Obtain transfer function RAOz (ω_e) and square it.
4. Multiply the wave spectrum by the square of the RAOs to get the response spectrum.

$$RAO_Z(\omega_e) = \frac{Z_0(\omega_e)}{\zeta_0(\omega_e)}. \tag{19}$$

$$S_z(\omega_e) = (RAO_z(\omega_e))^2 S_\zeta(\omega_e) \tag{20}$$

Table 1
Vessel particulars.

Item	Value
LBP	313.64 m
B	36.64 m
Depth	24.1 m
Draught	14.5 m
Displacement in tonnes	103292
L/B	8.56
B/T	2.53
C_b	0.622
K_{yy}/L_{pp}	0.27

Average pitch amplitude is given by

$$= 1.253 {m_0}^{1/2} \times \left(1 - \varepsilon^2\right)^{1/2} \tag{21}$$

where m_0 is the 0th moment of the response spectrum and ε is the correction factor.

$$\varepsilon = \frac{m_0 m_4 - m_2^2}{m_0 m_4}. \tag{22}$$

The mean of one-third highest pitch amplitude is

$$= 2.00\, {m_0}^{1/2} \times \left(1 - \varepsilon^2\right)^{\frac{1}{2}}. \tag{23}$$

The mean of one-tenth highest pitch amplitude is

$$= 2.54\, {m_0}^{1/2} \times \left(1 - \varepsilon^2\right)^{\frac{1}{2}}. \tag{24}$$

The mean of one-hundredth highest pitch amplitude is

$$= 3.336\, {m_0}^{1/2} \times \left(1 - \varepsilon^2\right)^{\frac{1}{2}}. \tag{25}$$

2. Vessel particulars

The main particulars of a Post-panamax containership are shown in Table 1.

The body plan of the ship is shown in Fig. 3. The vessel is modeled using a computer package program. The service speed of 25 knots is taken for analysis. A trend in the speed, as observed from the operations of such vessel, is found to be around 20 knots. Here higher speeds are considered for academic interest to control pitch motion.

2.1. Fin design and analysis

A suitable fin of hydrofoil section is selected for anti-pitching fin. Three sets of aspects ratios are taken for study and the same has been tested for efficiency. The span of the fin is selected in such a way that the fin does not project out of the ship's hull region. The aspect ratios of the fin, having a chord length of 15.9 m, are shown in Table 2.

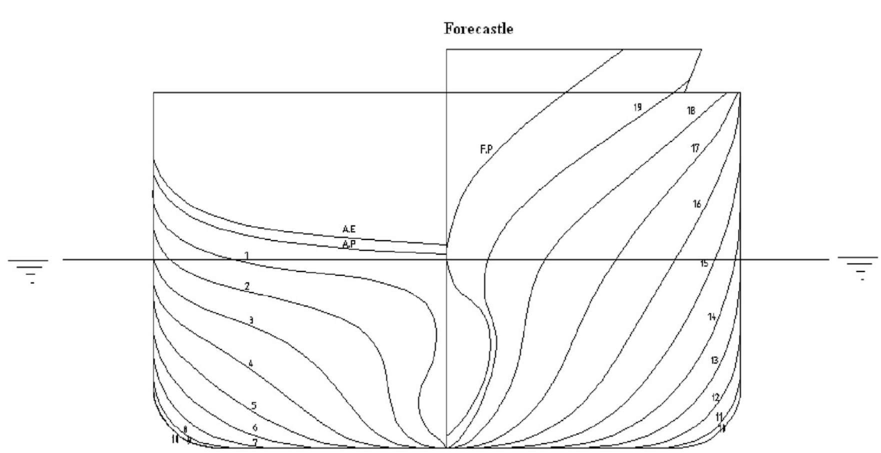

Fig. 3. Body plan of the ship.

Table 2
Fin particulars.

Span (m)	Aspect ratio
8	0.50
10	0.63
12	0.75

NACA 0018 is taken for study. From literature it is observed that the fin should not project out of frame of the hull. Therefore the maximum span that a fin can be is fixed. Chord of the fin is fixed based on the bow form. The fin angle is optimized in as a way the fin should be working in a region much below the dynamic stall angle.

The fin is fitted as close to the hull surface to form an integral part of the ship so as to generate a three dimensional flow around the surface and doubles the geometric aspect ratio of the fin. Fig. 4 shows the profile view of the fin with the ship's bow part as background. The proximity of the fin to the hull will increase the effectiveness of the fin. The fin encounters with waves with a relative velocity in addition to water particle velocity. Fig. 5 shows the plan of the fin fitted on the hull.

2.2. Computer simulation for fin action

Bhattacharyya (1978) relied upon equilibrium stabilization to control the pitch motion of the ship. The effectiveness of the stabilization depends upon the fin location, the fin angle and the fin aspect ratio. A computer model is prepared using ANSYS AQWA WORK BENCH module. It is shown in Fig. 6. The fin is given various tilt angle and the values of pitch angle obtained from simulation using actual ship size are shown in Fig. 7. Incoming regular waves of 1 m–5 m amplitude are considered. At five degree fin angle the lift force generated by the fin is predominant to control the pitch motion while the drag force has lesser influence on the ship hull. An automatic fine mesh is generated in ANSYS AQWA which generates a smooth refined mesh sufficient to solve the problem. The mesh details are already provided in Table 3.

3. Results and discussion

Since the drag force is less the resistance offered by the fin to the ship motion should also be less. This can be justified by calculating the resistance of the ship with and without fin. The meshing details are given in Table 3. Fig. 7 is for head sea and the bow fin is with an aspect ratio of 0.75. The simulation shows at 5° fin angle the fin effect is more predominant hence 5° fin angle is taken into account for further study. As already mentioned, a tilt of 5° found to be effective. The matrix of parameters considered for the simulation is shown in Table 4. The fin is found to be more effective at higher ship speed and proves to be effective in the frequency range of 10–12 s wave

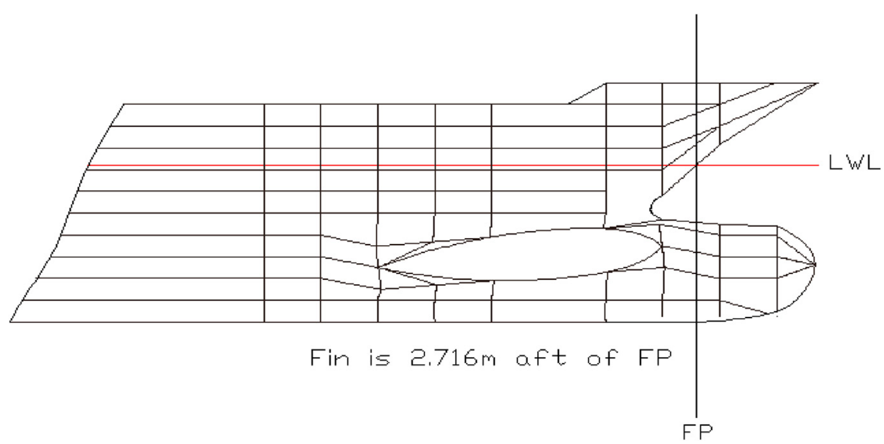

Fig. 4. Profile of bow part with the fin.

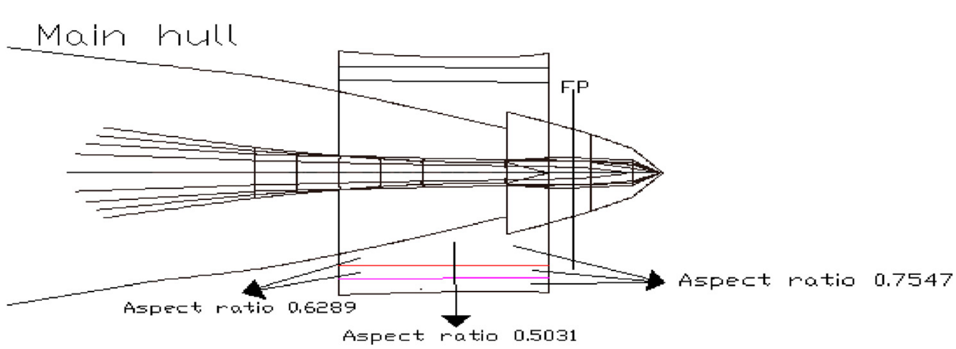

Fig. 5. Plan view of bow part of the ship with fin.

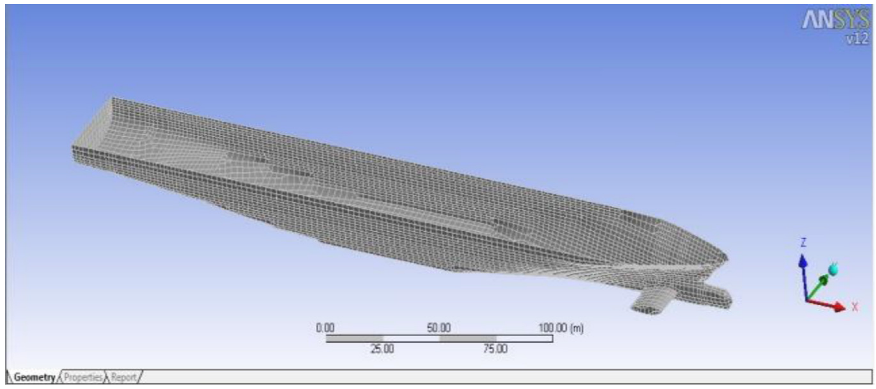

Fig. 6. Meshed model in ANSYS AQWA of actual ship.

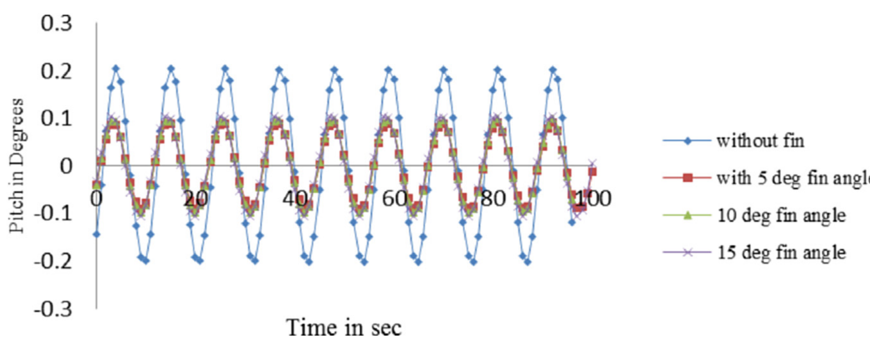

Fig. 7. Effect of anti-pitching fins for wave amplitude 1 m and period of 10 s.

Table 3
Meshing details of container ship with fin and without fin.

Sl.no	Mesh details	Without fin	With fin
1	No. of nodes	5312	6091
2	No. of elements	5251	6043
3	Defeaturing tolerance(m)	2 m	2 m
4	Max element size(m)	5 m	5 m
5	Meshing type	Program control	Program control

period and numerical simulation are done in these frequency ranges for wave amplitude of 2–4 m.

Computer simulations in regular sea are carried out for various speeds and amplitudes in head sea condition. Under the wave amplitudes of 2 m for 10 s wave period the anti-pitching fin gives a reduction of 39.4%, for a speed of 25 knots and it is shown in Fig. 8. Fig. 9 shows the result for a 3 m wave amplitude, 10 s wave period and 25 knots ship speed head on condition. The reduction in pitch is 38.6%. Fig. 10 shows the pitch response with 35.3% reduction in pitch, in head sea at 25 knots and wave amplitude of 4 m. Fig. 11 is for 5 m wave amplitude. Fig. 12 is for 6 m wave amplitude. These are all for the academic interest and in real situation such occurrence may be rare. But in all case a significant reduction is seen in the value of pitch. Figs. 13 and 14 are for the heave response of the ship with and without fin for wave amplitudes of 5 and 6 m respectively for different wave periods. The result shows there is reduction in heave amplitude over particular range of frequency and within this wave period the anti-pitching fin is efficient in controlling the ship motion. The heave is also important since most cases a coupling between heave and pitch takes place during ship motion.

The RAO of the ship with and without fin at various speeds are found out from simulations. Fig. 15 is for 20 knots speed. Fig. 16 is for 25 knots, which is the usual design speed of a container vessel. Pitch RAO is found much lesser for ship with fins fitted.

The RAO of heave motion achieved from the regular wave condition is shown in Fig. 17. No much effect due to fin is visible. The lift force generated by the fin combines with the antipitching lever (distance from LCF to the centroid of the fin) have a large value to form the antipitching moment which much sufficient to reduce the pitch motion. But in case of the heave motion the heave damping force is very large and the fin force alone is considered for the additional heave damping which very small compare to heave damping. Hence there is no significant change in the heave motion.

Table 4
Conditions and parameters for ship simulation.

Ship speed (knots)	5, 10, 15, 20, 25
Fin aspect ratio	0.75, 0.63, 0.5
Draft (meters)	14.5
Fin angle (degrees)	5, 10,15
Without fin	For required cases
Wave period (sec)	10, 10.5,11,11.5,12
Wave amplitude (meters)	2, 3, 4 and 5

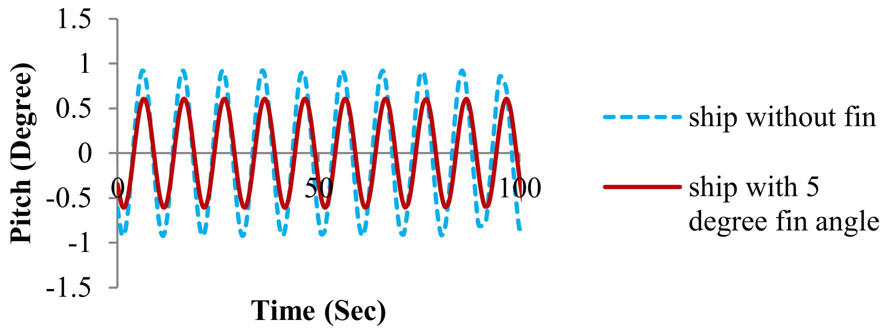

Fig. 8. Pitch for 2 m wave amplitude and wave period of 10 s.

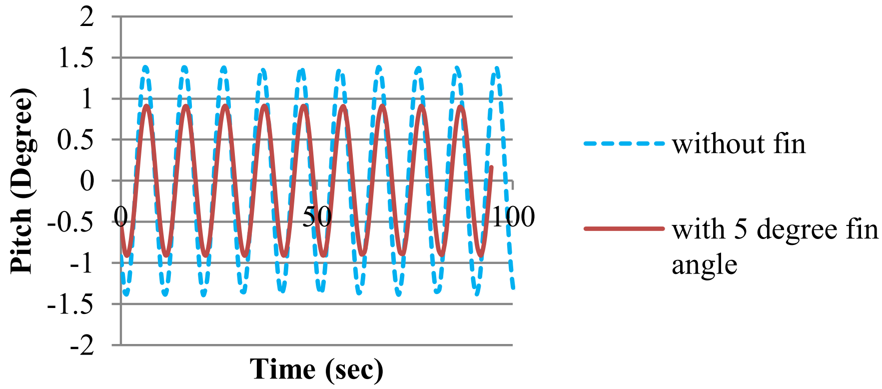

Fig. 9. Pitch for 3 m wave amplitude and wave period of 10 s.

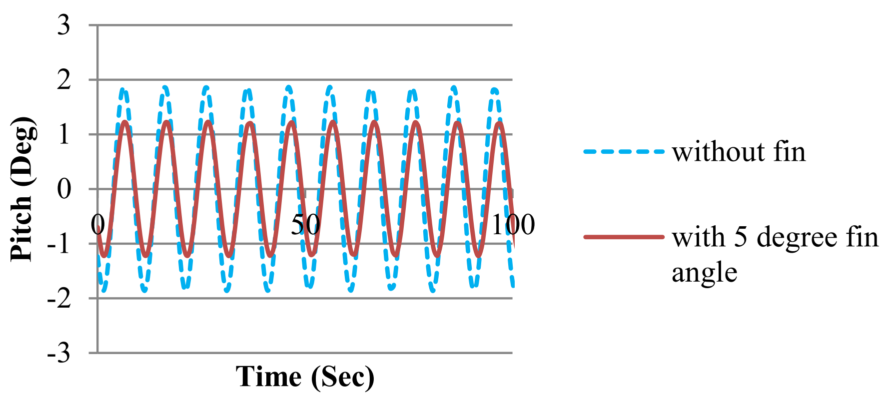

Fig. 10. Pitch for 4 m wave amplitude and wave period of 10 s.

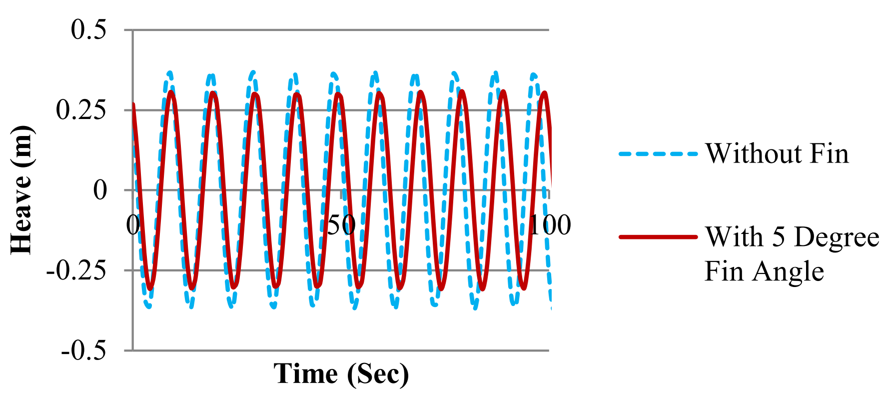

Fig. 11. Heave for 5 m wave amplitude and wave period of 10 s.

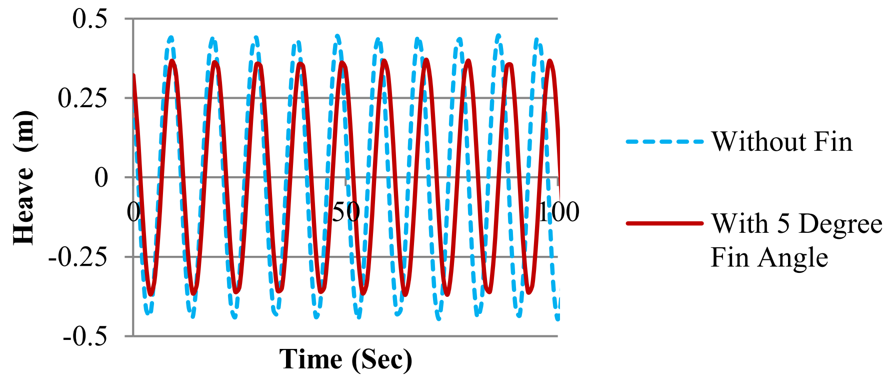

Fig. 12. Heave for 6 m wave amplitude and wave period of 10 s.

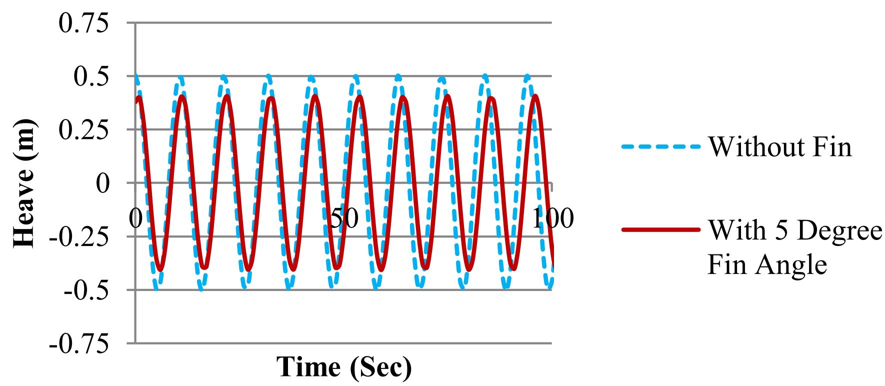

Fig. 13. Heave for 5 m wave amplitude and wave period of 10.5 s.

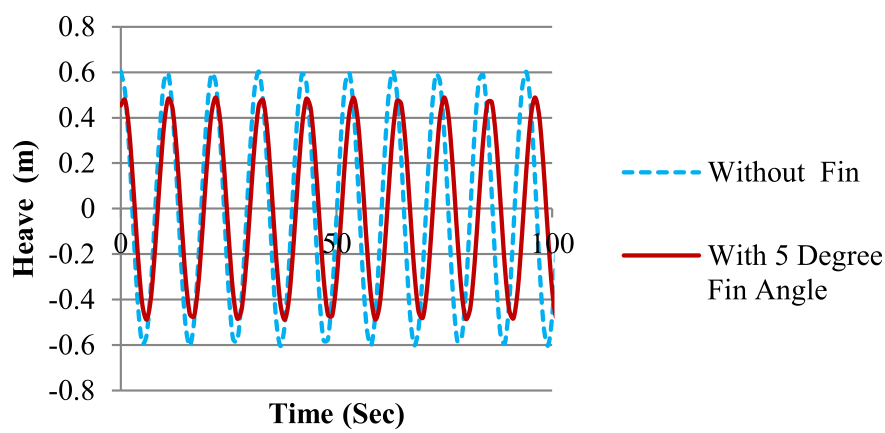

Fig. 14. Heave for 6 m wave amplitude and wave period of 10.5 s.

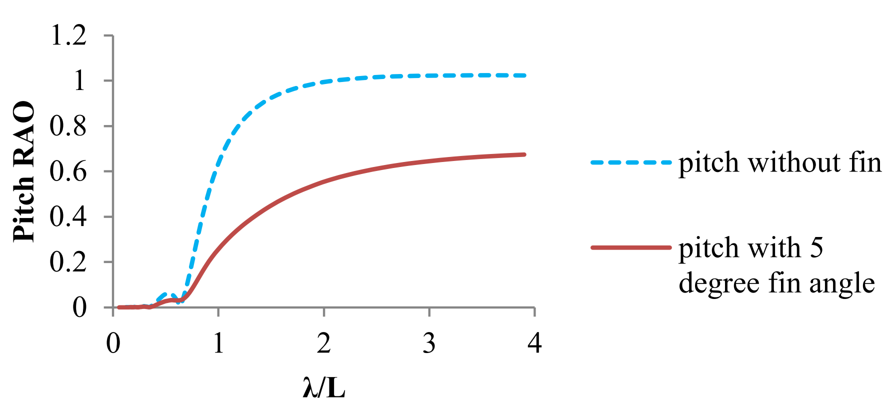

Fig. 15. Pitch RAO at 20 knots in head sea.

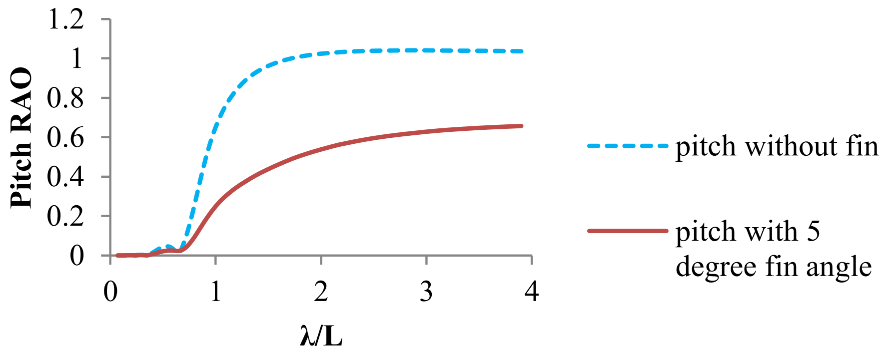

Fig. 16. Pitch RAO at 25 knots in head sea.

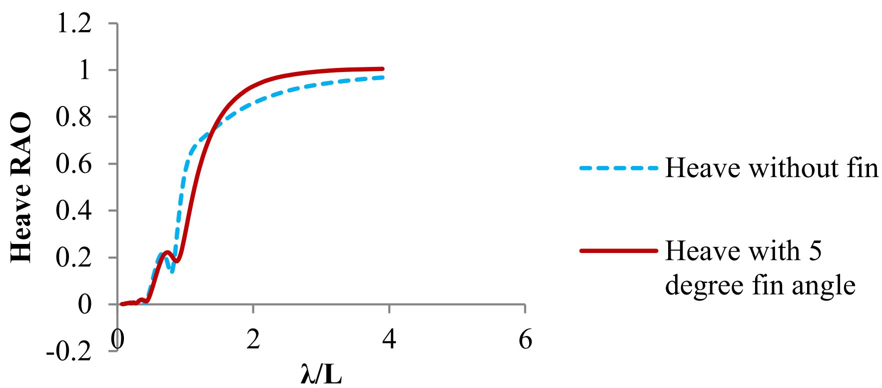

Fig. 17. Heave RAO at 25 knots in head sea.

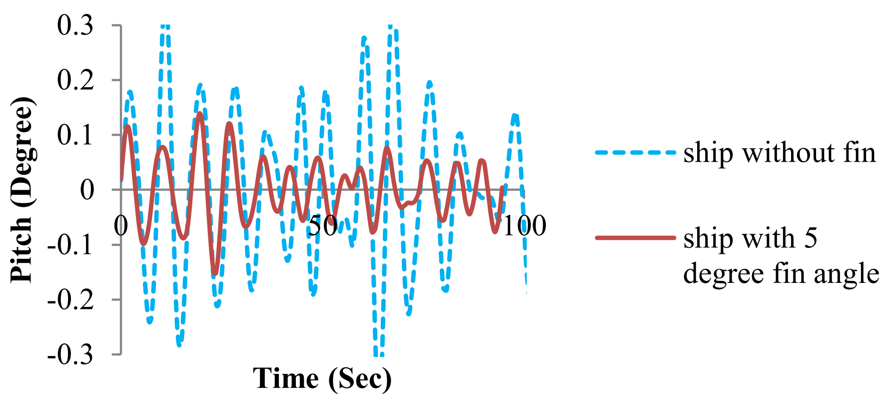

Fig. 18. Pitch for Sea state 5 without fin and with 5° fin angle at 25 knots head sea.

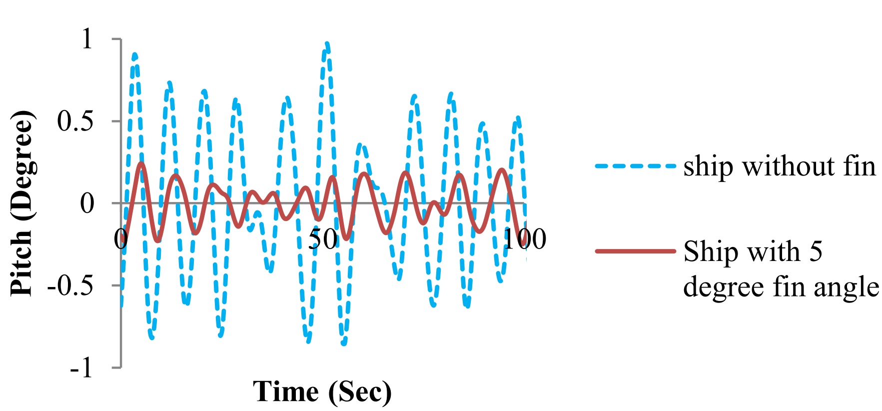

Fig. 19. Pitch for Sea state 6 without fin and with 5° fin angle at 25 knots head sea.

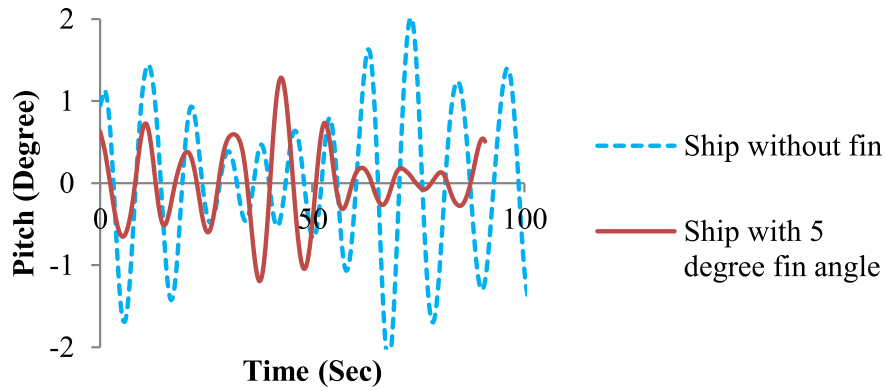

Fig. 20. Pitch for Sea state 7 without fin and with 5° fin angle at 25 knots head sea.

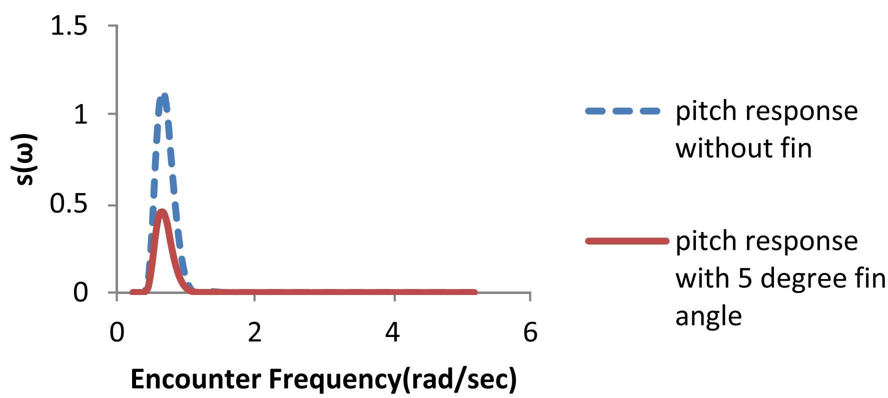

Fig. 21. Pitch response spectrum in sea state 5 in head sea and ship speed of 5 knots.

Time domain response of the ship with and without fin in irregular sea is shown in Fig. 18 for a sea state of 5 and ship speed 25 knots. P-M spectrum is assumed for the incoming wave in a particular sea state. In the past, it was tried by many researchers to give a fixed tilt angle to the fins system, which was related to the incoming wave slope in that sea state. For a continuously moving fin using a feedback from the ships response and desired response, the pitch control would have been much more efficient. Although the fabrication for such system was done in the laboratory, there was breakdown in the wave maker system. It was decided to tilt the fins manually. Fig. 19 is for sea state 6 and Fig. 20 is for sea state 7. The speed is assumed as 25 knots.

As per Fig. 18 the ship with fin angle of 5° is giving an average pitch reduction 40.3%. As per Fig. 19, the fin is responsible for an average pitch reduction of 28% in sea state 6. Fig. 20 shows the pitch response of ship fitted with fin and without fin. An average pitch reduction of 37% using the fin systems is achieved for a sea state of 7. A number of simulations are done for irregular sea. The effectiveness of the fin depends on the depth of immersion of the fin, ships forward speed, heading angle, encounter frequency and fin angle. The

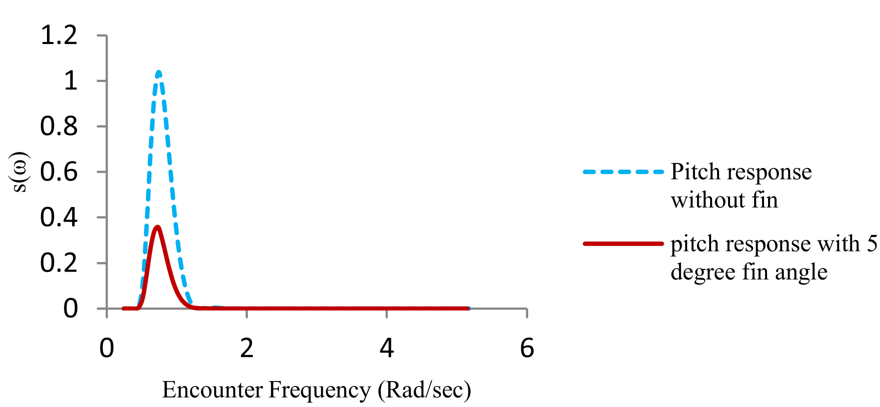

Fig. 22. Pitch response spectrum in sea state 5 in head sea and ship speed of 10 knots.

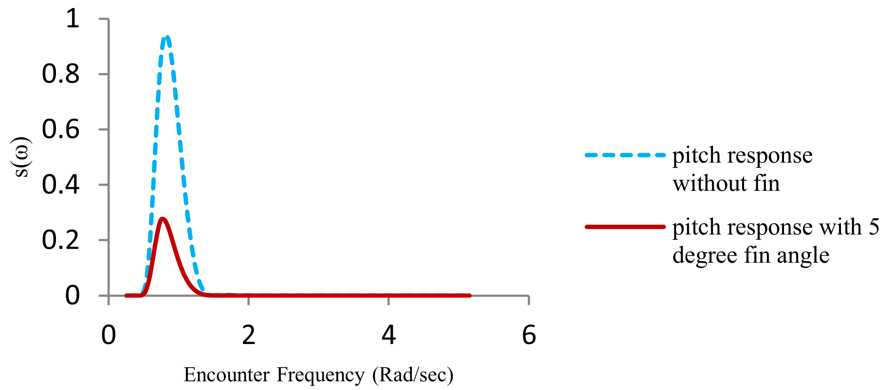

Fig. 23. Pitch response spectrum in sea state 5 in head sea and ship speed of 15 knots.

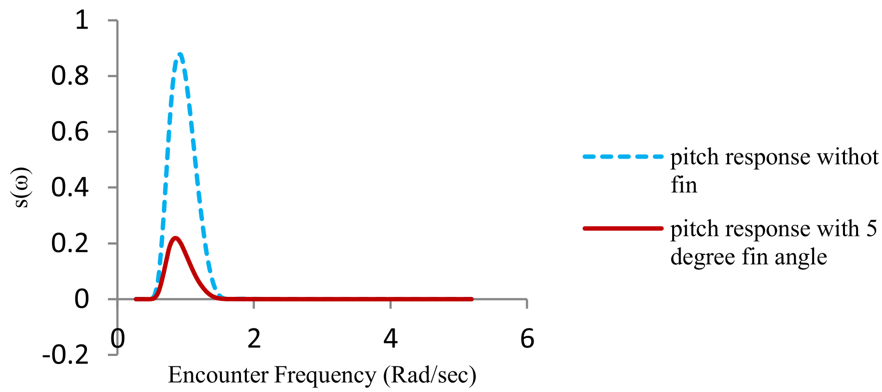

Fig. 24. Pitch response spectrum for sea state 5 in head sea and ship speed of 20 knots.

effect of wave steepness is responsible for the ship pitch motion and this should be countered by the fin action. In case of fixed fin system the pitch angle, pitch velocity and heave velocity are responsible for the induced angle of attack on the fin. The total angle of attack consist of the components of induces angle of attack plus the fin angle. Based on the ship response in the irregular sea, the fin can be used effectively in open sea to control the motion parameters. Although, initially the fin system was designed and fabricated for controlling the fin position on a continuous basis during a test series in a towing tank, later it was decided to limit the continuous motion by fixing the fin angle to a fixed value matching a particular sea state model. Only the computer simulation part is discussed in this paper. The spectral response and the area under the spectrum is a measure of the performance of the vessel.

Fig. 21 shows the response spectrum for sea state 5 in head sea condition for ship with and without fin at 10 knots. The average pitch value at 25 knots is 0.811° for ship without fin in sea state 5 and for ship with fin is 0.366°. The energy for pitch motion under the action of fin is reduced by 58%. Similarly the reduction for pitch was 68% for speed of 10 knots, as per

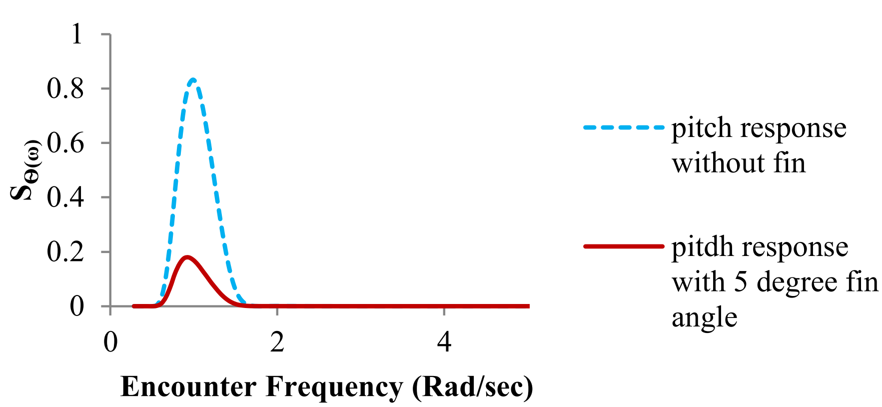

Fig. 25. Pitch response spectrum in sea state 5 in head sea and ship speed of 25 knots.

Table 5
Response spectrum characteristics for sea state 5 for various speeds.

Parameters	5 knots		10 knots		15 knots		20 knots		25 knots	
	Without fin	With fin	Without fin	With fin	Without fin	With fin	Without fin	With fin	Without fin	With fin
m_0 (Deg^2)	0.34	0.135	0.369	0.118	0.391	0.104	0.411	0.094	0.425	0.086
m_2 (Deg^2-sec^2)	0.177	0.065	0.238	0.0718	0.310	0.076	0.391	0.082	0.473	0.088
m_4 (Deg^2-sec^4)	0.103	0.0362	0.177	0.0500	0.283	0.065	0.425	0.082	0.601	0.103
Correction factor (ε^2)	0.128	0.118	0.13	0.130	0.129	0.135	0.126	0.135	0.121	0.131
Average pitch amplitude (degree)	0.732	0.457	0.755	0.427	0.777	0.401	0.797	0.380	0.811	0.366
Mean of one-third highest pitch amplitude	1.169	0.73	1.2	0.683	1.241	0.641	1.272	0.608	1.294	0.584
Mean of one-tenth highest pitch amplitude	1.14	0.92	1.53	0.869	1.579	0.816	1.618	0.773	1.647	0.743
Mean of one-hundredth highest pitch amplitude	1.95	1.21	2.01	1.139	2.070	1.070	2.121	1.014	2.159	0.974

Fig. 22. For 15 knots the reduction in pitch is by 72% and for 20 knots it is 74%. Figs. 23 and 24 show the areas under the spectra. At 25 knots the area under pitch with fin angle is reduced to 20% or 80% reduction due to fin action (see Fig. 25).

4. Conclusion

The fixed bow fin system in waves serves as good controller for pitch motion and heave motion can also be controlled in certain cases. The results show the fixed fin is very effective in a frequency range of 9−11 s wave period. In irregular seaway, an activated fin system may be more effective. By controlling the pitch motion the pitch motion characteristics of the ship is changed. It might be helpful in avoiding the parametric roll which is very much inherent with container ships with slender hull. For a cruising speed of 25 knots, the rms value of the response for that particular seastate is achieved using the area under the pitch spectral curve. If area under the pitch curves is based, the fin action gave 58%−80% of reduction in the pitch motion for a speed range of 5−25 knots in sea state 5. Maximum reduction in the pitch angle with the effect of fin system is also calculated from simulations. Such reduction in pitch motion save a lots of money for the owner and also provide safety to the crew members. Various spectral values are discussed and shown in Table 5. The study can be taken as bench mark for application of fins and use of in a feedback control system of ship motion.

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