ISSN 2615-3114

INTERNATIONAL SEMINAR ON MARINE TECHNOLOGY

SENTA 2016

"Marine Technology for Fulfilling Global Maritime Axis"

PROCEEDING

Faculty of Marine Technology
December, 15th-16th 2016
website: senta.its.ac.id

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Effects of Application of a Stern Foil on the Seakeeping Performance: A Case Study of Orela Crew Boat

Ketut SUASTIKA[1,a*], Bonaventura D. PRASETYO[1,b], Soegeng RIYADI[2,c]

[1]Department of Naval Architecture and Shipbuilding Engineering, ITS Surabaya, Indonesia

[2]PT. Orela Shipyard, Ujung Pangkah, Gresik, Indonesia

[a]k_suastika@na.its.ac.id, [b]bonaventuradanis@gmail.com, [c]soegeng.riyadi@orela.co.id

*corresponding author

Keywords: Crew boat, laboratory experiments, numerical simulations, seakeeping, stern foil.

Abstract. Effects of application of a stern foil on the seakeeping performance are investigated by considering the Orela crew boat as a case study. Experiments were performed to determine the heave and pitch RAO's for the cases with and without stern foil. The experimental results are used to verify the results obtained from numerical simulations. The stern foil improves the seakeeping performance of the boat. Using a stern foil, the heave and pitch significant heights in a sea state with H_s = 2.0 m decrease 6.3% and 9.8%, respectively.

Introduction

A well-known application of a stern foil is the so-called hull vane®, invented by van Oossanen in 1992 and patented in 2002, which is a fixed hydrofoil attached to the ship at the stern below the transom. The mechanism of the hull vane® consists of generating a force in the forward direction (additional thrust), reducing the running trim (generating a bow-down moment), reducing the transom wave, reducing the pitching motion and reducing the added resistance in waves [1]. Shortly, it reduces the ship resistance and the ship motions, resulting in a reduced fuel consumption and a higher comfort level for the crew and passengers.

The working principle of the hull vane® and its applications to different vessels are reported in [1-4]. In [2], effects of the hull vane® on the motions of ferries and RoPax vessels are reported. It was found that the hull vane® reduced the pitch motion but its effect on the heave motion depended on the wave frequency and the resulting phase shift between the heave and the pitch motions.

Effects of the hull vane® on the fuel consumption and seakeeping performance are reported in [3]. CFD simulations were performed where the hull vane was applied to a 108-m Hollands-class ocean-going patrol vessel (OPV) of the Royal Netherlands Navy. At the speed where most fuel was consumed (17.5 knots), fuel saving of 15.3 % was reported (compared to the case without vane). On yearly basis and for all speed ranges, a reduction of 12.5% fuel consumption was achieved. Considering the seakeeping, the vertical acceleration (on the helicopter deck) and the pitching motion were reduced, consistent with the results reported in [2].

A study utilizing computational fluid dynamics (CFD), which compared the performance of hull vane®, interceptors, trim wedges and ballasting, is reported in [4]. The devices and ballasting were applied to a 50-m patrol vessel at speeds between 8.6 and 34.4 knots ($0.2 < Fn < 0.8$). At Froude number $Fn < 0.2$ (relatively low speed) the hull vane® results in an increase of the ship resistance, as expected. At Froude number $0.2 < Fn < 0.4$ the hull vane results in a bow-down running trim. In all the Froude-number ranges being considered, the hull vane® reduces the bow-up running trim. It was concluded that among all the trim correction devices considered, the hull vane® was the most efficient device in reducing the ship resistance and in reducing the pitch motion ($0.2 < Fn < 0.8$).

The effectiveness of the vane/foil in reducing the ship resistance and ship motions depends on the optimum effects it makes on the magnitude and orientation of the generated lift, the running trim, the stern waves and the added resistance in waves. Furthermore, the dimension of the optimum foil depends on the dimension and type of ship being considered and the type of foil being used.

The purpose of the present study is to investigate the use of NACA 64(1)212 foil as stern foil applied to a crew boat. The focus is on the effects of the stern foil on the seakeeping performance. Its effects on the ship resistance are reported in [5]. Results of the present study can enrich the literature on the application of a stern foil/hull vane® as a fuel-saving device, which additionally can increase the level of comfort for the crew and passengers.

A crew boat usually brings a crew and/or logistics from the shore to an offshore platform and later picks them back from the platform to the shore. It has a relatively high-dense and regular schedule and, therefore, usually has a relatively high speed. (The ship's speed and fuel consumption are of great concern.) The Orela crew boat is considered, which is a semi-planing boat with a target top speed of 28 knots (Froude number $Fn = 0.73$). (See e.g. [6] for a discussion of the seakeeping behaviour of high speed crafts.) The principal dimension of the boat is summarised in Table 1.

The optimum foil size with maximum lift-to-drag ratio is obtained from CFD-simulations of foil alone. In the simulations, the foil's span is fixed (8 m; the same as the boat's beam). It is found that the optimum chord length is 1.2 m (aspect ratio of 6.67).

The foil is attached to the ship's hull at the transom by using two struts, which are NACA 0010 symmetrical foils with chord length of 1.2 m (the same as that for the stern foil), at a submerged position of 0.853 T = 1.45 m below the water line (T is the draft).

Table 1. Principal dimension of the orela crew boat.

Length overall (L_{oa})	40.00 m
Length between perpendiculars (L_{pp})	39.90 m
Beam (B)	8.00 m
Height (H)	4.40 m
Draft (T)	1.70 m
Displacement (Δ)	242.72 ton

Method

To study the seakeeping performance of the boat, experiments were performed at the Hydrodynamic Laboratory of the Faculty of Marine Technology, ITS Surabaya, Indonesia. The dimension of the towing tank is as follows: length = 50.0 m, breadth = 3.0 m and water depth = 2.0 m. The experimental results are used to verify the results obtained from numerical simulations.

I. Experiments

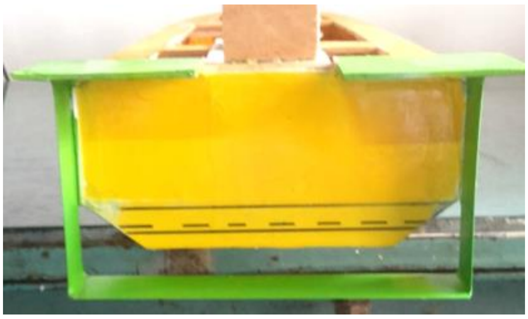
A scaled model of the boat was made from a fibre-glass reinforced plastics (FRP) with a geometrical scale of 1:40 (Froude-similarity). Tests with regular waves were conducted to determine the heave and pitch RAO's of the boat with zero-speed and with 22-knots speed in a heading sea (180° heading angle). The ship model is shown in Fig. 1. The measuring instruments (load cell, transducer) were calibrated before running a test. The heave and pitch motions were recorded for boat with and without stern foil. The seakeeping test parameters are summarised in Table 2.

The heave and pitch RAO's are then determined. For tests with a moving ship, the frequency axis is the frequency encounter, which is calculated as follows:

$$\omega_e = \omega\left(1 - \frac{\omega V_s}{g}\cos\mu\right) \tag{1}$$

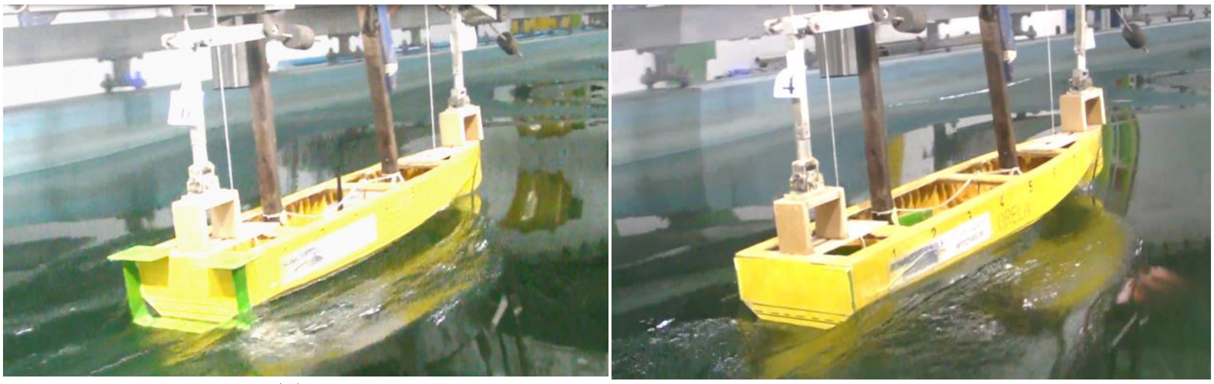
where ω_e is the encounter frequency, ω is the wave frequency, V_s is the ship speed, g is the gravitational acceleration and μ is the wave heading.

(a)



(b)

Figure 1. Model of the crew boat with stern foil (scale 1:40): (a) side view and (b) aft view.



(a) (b)

Figure 2. Seakeeping test with wave amplitude a = 1.2 cm (full-scale = 0.48 m) and wave period T = 1.1 s (full-scale =7.0 s): (a) with stern foil and (b) without stern foil.

Table 2. Seakeeping test parameters.

Wave Period [s]	**Wave Amplitude [cm]**	**Heading Angle [deg]**	**Ship Speed [knots]**
0.5	1.2	180	0
0.7			
0.9			22
1.1			
1.3			

II. Numerical simulations

The experimental heave and pitch RAO's are compared with those obtained from numerical simulations based on potential theory. The simulations were done in a stand-alone computer with Intel® Core (TM) i5-2450M CPU @ 2.50 GHz processor, 4.00 GB RAM using 64-bit Windows 10 Pro© OS. To ensure independency of the results from the number of cells (elements) used in the simulations, tests were performed to comply with the grid-independence criterion. This is defined as that the difference between two subsequently calculated area under the RAO curve is less than 2 % where the number of cells in the latter simulation is approximately twice of that in the former.

To determine the ship response in irregular waves, the calculated RAO from the numerical simulation is utilised with the sea waves modeled using ITTC spectrum [7]. The significant heave and pitch heights are calculated for different sea states utilising the response spectrum:

$$R_s = 4.0\sqrt{m_{0;r}} \tag{2}$$

where R_s is the significant response height, and $m_{0;r}$ is the area under the response spectrum.

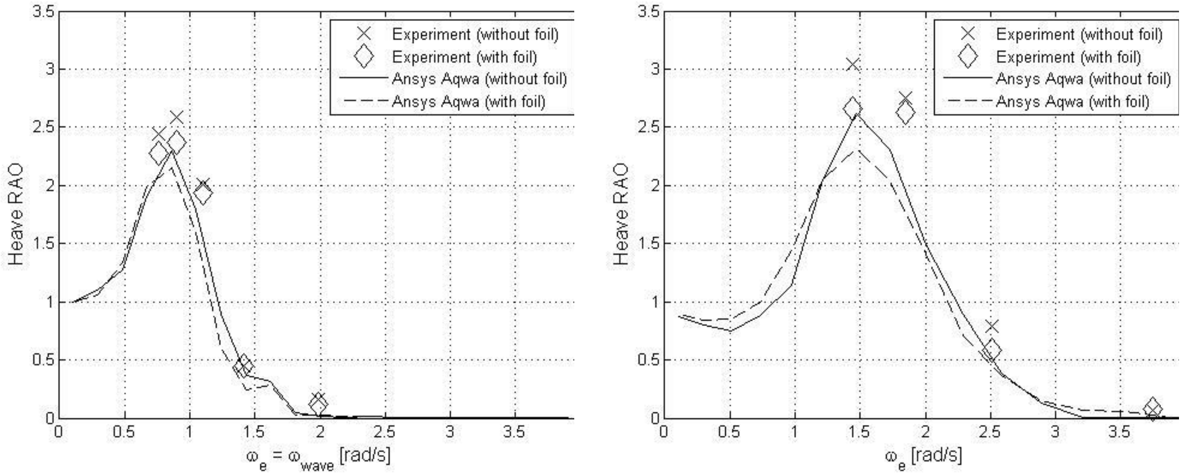
Results and Discussion

I. Heave and pitch RAO's

Figure 3a shows a comparison of heave RAO's for zero-speed ship with and without stern foil obtained from experiments and numerical simulations. The frequency with maximum RAO-value is approximately 0.96 rad/s. Figure 1 shows that the addition of a stern foil results in a decrease of the heave RAO in the frequency range with significant response ($0.8 < \square_e <$ 1.5 rad/s). The RAO-values obtained from the numerical simulations are generally smaller than those obtained from the experiments, ascribed to overestimation of damping effect in the numerical model.

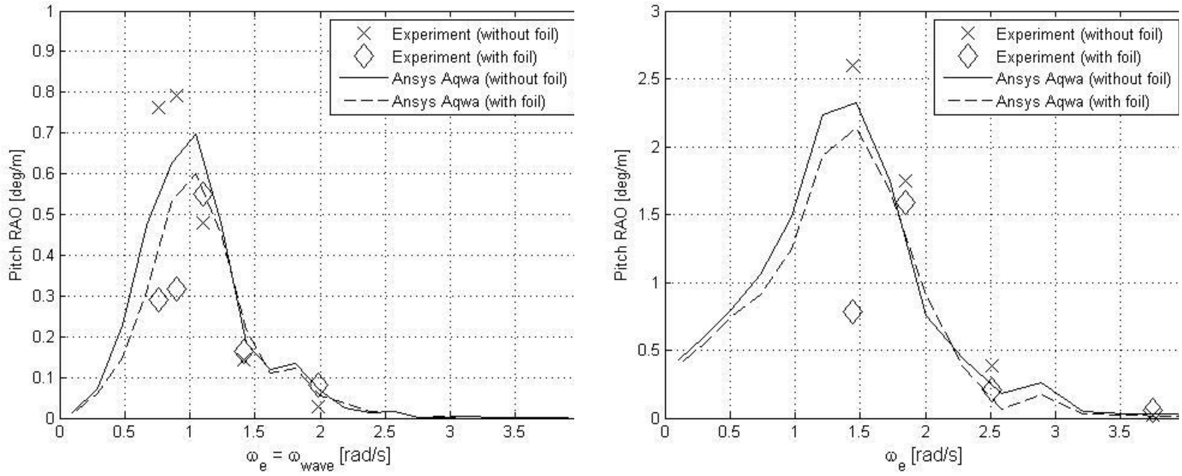
Figure 3b shows similar plots as shown in Fig. 3a for ship speed of 22 knots (Froude number Fn = 0.572). The frequency with maximum RAO-value is approximately 1.46 rad/s, which is larger than that for zero-speed, as expected. As for the case of zero speed, the installation of the stern foil results in a decrease of the heave RAO in the frequency range with significant response. However, because of the use of spectral analysis, no information about the phase shift between the heave and pitch motions can be reported to compare the result with that obtained in [2]. In addition, due to the ship speed (ship moving in a head sea), the magnitude of the heave RAO increases and the frequency range with significant response becomes broader compared to that with zero-speed ship.

Results for the pitch RAO can also be presented in a similar way as for the heave response (see Figs. 4a and b). The addition of the stern foil results in a decrease of the pitch RAO, consistent with the results reported in [1-4].



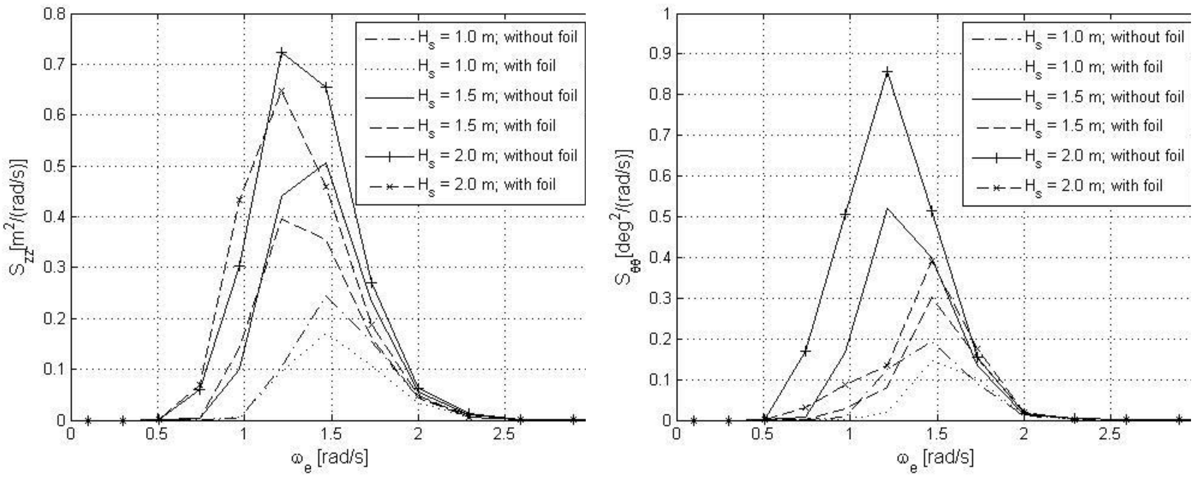
(a) (b)

Figure 3. Heave RAO's for zero speed (a) and 22-knots ship speed (b).



(a) (b)

Figure 4. Pitch RAO's for zero speed (a) and 22-knots ship speed (b).



(a) (b)

Figure 5. Heave (a) and pitch (b) spectra for 22-knots ship speed (Froude number *Fn* = 0.572).

Table 3. Significant heights of heave and pitch for different sea states.

H_s [m]	Significant heave height [m]		Significant pitch height [deg]	
	Without foil	With foil	Without foil	With foil
0.5	0.432	0.361	0.307	0.308
1.0	1.63	1.42	1.44	1.20
1.5	2.55	2.32	1.80	1.62
2.0	3.17	2.97	1.84	1.66

II. Heave and pitch spectra

The decrease of heave and pitch responses due to the stern foil can be illustrated by calculating the heave and pitch spectra for different sea states (see Fig. 5). To characterize the responses, the significant heights of the heave and pitch motions can be calculated from the heave and pitch spectra (see Eq. 2).

Table 3 summarises the significant heights of heave and pitch motions for different sea states. It is shown that, as the significant wave height increases, the significant heights of the heave and pitch also increase, as expected. The application of the stern foil results in a decrease of the significant heights of the heave and pitch motions. For example, in a sea state with H_s = 2.0 m (the highest sea state being considered), the significant heave is 3.17 m for the case without stern foil and 2.97 m for the case with stern foil, showing a decrease of approximately 6.3%. In the same sea state, the significant pitch decreases 9.8%.

Conclusions

Application of a stern foil results in better heave and pitch characteristics of the Orela crew boat. The significant height of heave in a sea state with significant wave height H_s = 2.0 m is 3.17 m for boat without stern foil and 2.97 m for boat with stern foil. The decrerase of the significant height of heave due to the stern foil is approximately 6.3%. Furthermore, the significant height of pitch in the same sea state is 1.84 degrees for boat without stern foil and 1.66 degrees for boat with stern foil. The decrease of significant height of pitch is approximately 9.8%.

Acknowledgement

This research project was financially supported by the Indonesian Ministry of Research, Technology and Higher Education (RISTEKDIKTI), under the grant: Penelitian Kerjasama Industri 2017 with contract no. 562/PKS/ITS/2017.

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