Characteristics of Seakeeping Performance of Philippine Outrigger Craft

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Abstract

The Core-University Scientific Corporation Program has started between Philippines and Japan from 1998. The project of fishing craft is conducted to improve the performance of Philippine outrigger craft. Most fishing craft of the Philippines are constructed in the double outrigger form with a main hull and floats at both sides. Generally, a float and its beam are made of bamboo.

In this paper, the characteristics of ship motions are experimentally investigated to clarify dangerous sea conditions for the craft in waves. A computer program has been developed to calculate ship motions of the craft. The accuracy of this computer program is checked by measurement of ship motions in waves. Furthermore, results of the calculation are in good agreement with the measured ones. From these results, the outriggers increase heaving and pitching motions in head seas at the short wave length, although significantly decrease heaving and rolling motions in beam seas.

1. Introduction

An outrigger craft is the most traditional and popular fishing craft in the Philippines. In resent years, many persons engaged for fishery working on such outrigger craft have died in sea disasters. The main cause of the accidents is regarded that supporting arms of the outriggers were damaged due to large load in severe seas. In order to prevent such accidents, it should be clarified the relation between wave conditions and maximum load on the supporting arms. Aguilar (1997)[1) 2)] measured and recorded the technical characteristics of the outrigger crafts and to build a database, which can be used for analysis and further studies. However, there are a few studies on seakeeping performance of the outrigger craft.

The purposes of this study are to develop a calculation method to estimate ship motions of the craft in waves and to clarify the characteristics of seakeeping performance of them. A computer program to calculate ship motions of the craft is developed based on a strip method (F. Tasai and M. Takagi. (1969))[3)], in which Froude Krylov force, hydrostatic forces and inertia forces acting on the outriggers are added. Furthermore, the accuracy of the developed computer program is checked by model experiments.

By using the computer program, the ship motions of the craft are compared with without outrigger's (called center-hull) ones. From these calculations, the influence of the outriggers on ship motions is discussed quantitatively.

2. Calculation Program of Ship Motions of Outrigger Craft

2.1 Method of Calculation

A computer program is based on strip method that called Ordinary Strip Method (OSM), in which Froude-krylov force, hydrostatic forces and inertia forces acting on the outriggers are added [4)], and the other forces are abbreviated on the assumption that they are negligible small. The point about the development of this program is taken into the effect of the outriggers. Fig. 1 shows the coordinate systems in this calculation program. The formulas of these forces and moments are explained under the below.

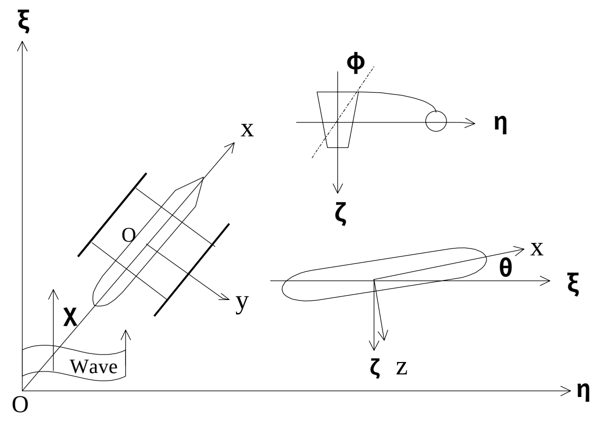

Fig. 1 Coordinate systems.

2.2 Vertical Forces of Outrigger

Froude-Krylov force

Froude-Krylov force means integrated value of hydrodynamic pressure acting on wetted surface induced by wave. The pressure is defined as follows:

$$p = \rho g \varsigma_w e^{-kz} \cos(k^* x - ky \sin\chi - \omega_e t) \\ k^* = k \cos\chi \tag{1}$$

where ρ, g, ς_w, k, χ and ω_e are the density of fluid, acceleration of gravity, wave amplitude, wave number ($k = 2\pi/\lambda$), direction of incident wave and encounter frequency, respectively.

The sectional vertical force is obtained from integrating the vertical component of the pressure around the girth length of the section. The sectional vertical force and moment are described as follows:

$$\left.\begin{aligned} dF_h^w &= \rho g \varsigma_w e^{-kz} \left\{ \int_{y_{in}}^{y_{out}} \cos\left(k^* x - ky \sin\chi - \omega_e t\right) dy \right. \\ &\quad \left. + \int_{-y_{out}}^{-y_{in}} \cos\left(k^* - ky \sin\chi - \omega_e t\right) dy \right\} dx \\ &= 2\rho g \varsigma_w e^{-kz} \frac{\sin\left(ky_{out}\sin\chi\right) - \sin\left(ky_{in}\sin\chi\right)}{k \sin\chi} \\ &\quad \left(\cos k^* x \cos\omega_e t + \sin k^* x \sin\omega_e t\right) dx \\ dM_p^w &= -x_L dF_w dx \\ x_L &= x - x_G \end{aligned}\right\} \tag{2}$$

where y_{out}, y_{in} are distance between the center line of center-hull and the location of outside/inside of an outrigger. x_G is the location of the center of gravity. z equals to draft of the outrigger.

Hydrostatic force

Hydrostatic forces and moment of the outrigger can be defined as follows:

$$\left.\begin{aligned} dF_h^b &= -\rho g \int_L B(x)\left(\varsigma - x_L \theta\right) dx \\ &= -\rho g \left\{ \varsigma \int_L B(x) dx + \theta \int_L B(x) x_L dx \right\} \\ dM_p^b &= -\rho g \int_L B(x)\left(x_L \varsigma - x_L^2 \theta\right) dx \\ &= -\rho g \left\{ \varsigma \int_L B(x) x_L dx + \theta \int_L B(x) x_L^2 dx \right\} \end{aligned}\right\} \tag{3}$$

where $B(x)$ is the function of the outrigger's section.

Inertia force

Inertia force associates with acceleration of the body mass. Inertia force of the outrigger can be defined as follows:

$$dF^I = -\frac{w(x)}{g}(\ddot{\varsigma} - x_L \ddot{\theta}) dx \tag{4}$$

where $w(x)$ is the function of the outrigger's weight.

2.3 Transverse Forces of Outrigger

Lateral motion of the outrigger craft is calculated by the same method as vertical motion. Froude-Krylov force acting on the outriggers in transverse direction is obtained from Eq.2. The component of y-direction is integrated over the sections of the outrigger.

Hydrostatic forces and moments acting on the outriggers are defined as follows:

$$dF_y^h = 0 \\ -dM_\phi^h = w(x) GM \theta dx \tag{5}$$

where GM is the transverse metacentric height.

Inertia force and moment acting on the outriggers are defined as follows:

$$-dF_y^I = \frac{w(x)}{g}\left(\ddot{\eta} + x_L \ddot{\varphi}\right) dx \\ -dM_\phi^I = \frac{w(x)}{g} \kappa_{xx} \ddot{\phi} dx \tag{6}$$

where κ_{xx} is the radius of gyration.

As mentioned above, the coefficient of each term can be added to corresponding the coefficient of hydrodynamics forces in the equation of ship motions in OSM.

2.4 Measurement of Ship Motions in Waves

In order to check the accuracy of the calculation method, the experiments were carried out at the model basin (60 m in length, 25 m in width, water depth 3.2 m) of the National Research Institute of Fisheries Engineering in Hasaki. The model is a 1/4-scale, and its body plan and its principal particulars are shown in Fig. 2 and Table 1. The cross section of the outriggers is a circular. In this model, distance between the outriggers is able to change from 1.36 m to 1.76 m as shown in Fig. 2.

Forward speed is *Fn*=0.3 (6 knots for the full scale ship). The towing point is adjusted to the center of gravity of the model. In this speed condition, the model is free to heave, pitch and roll. Meanwhile, advance speed of zero is carried out to measure the rolling motion in beam seas. In this condition, the model is free to heave, pitch, roll and sway.

Wave slop is a constant of 1/30 $(H/\lambda = 1/30)$ in this measurement. Wave lengths are changed systematically as shown in Table 2. Also the directions of incident wave are changed from 0 degree (following seas), 45 degrees, 90 degrees, 135 degrees and 180 degrees (head seas).

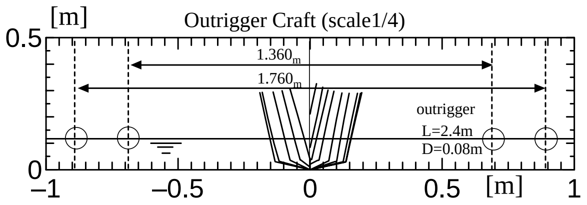

Fig. 2 Body plan of model.

Table 1 Principal particulars of the model.

Items	model
L_{OA} (m)	3.022
L_{PP} (m)	2.735
B (m)	0.314
d_m (m)	0.117
L_{CG} (m) (aft+)	-0.049
Distance between outriggers (m)	1.36, 1.76
Length of outrigger (m)	2.4
Diameter of outrigger (m)	0.08

Table 2 Experimental conditions.

Forward speed: $F_n = U / \sqrt{gL_{pp}}$	0, 0.30
Wave slop: H / λ	1/30
Wave length: λ / L_{pp}	0.5 ～ 3.0
Direction of incident wave: χ (degrees)	0, 45, 90 135, 180

2.5 Comparison of Calculated Results with Experimental Results

The comparisons of heaving and pitching amplitude in head seas between the calculated and measured results are shown in Fig. 3 and Fig. 4. The heaving and rolling motions in beam seas are also shown in Fig. 5 and Fig. 6. As can be seen, the calculated results agree fairly well with the measured ones. In head seas, the influence of the distance between outriggers is rather slight in heaving and pitching motions.

On the other hand, in beam seas, the influence of it is observed in heaving amplitude. It should be noted that the calculated results of heaving amplitudes have a remarkable peak at the short wave length (λ/L_{pp} =0.3). Meanwhile, λ/L_{pp} =0.3 is nearly equal to the distance of between the center-hull and the outrigger. Accordingly, the center-hull and both outriggers are just on the peak of waves.

The comparisons of rolling amplitudes at *Fn*=0.0 between the calculated and measured results are shown in Fig. 6.The roll amplitude gradually approach to the value of 1.0 in long wave length. Because the transverse metacentric height (GM) is very large for the outrigger craft, the wave length is very short to resonate with rolling motion. Moreover, the calculated results are in fairly good agreement with the results of measured.

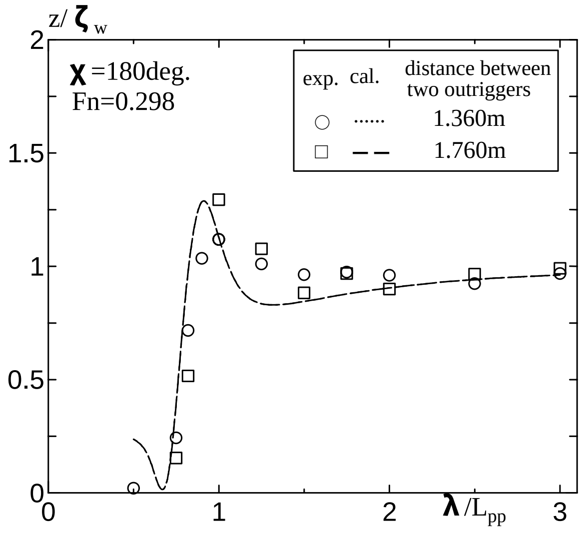

Fig. 3 Heaving amplitude in head seas.

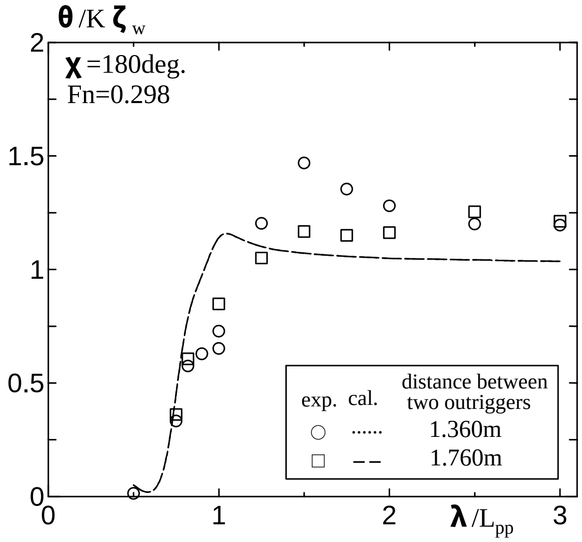

Fig. 4 Pitching amplitude in head seas.

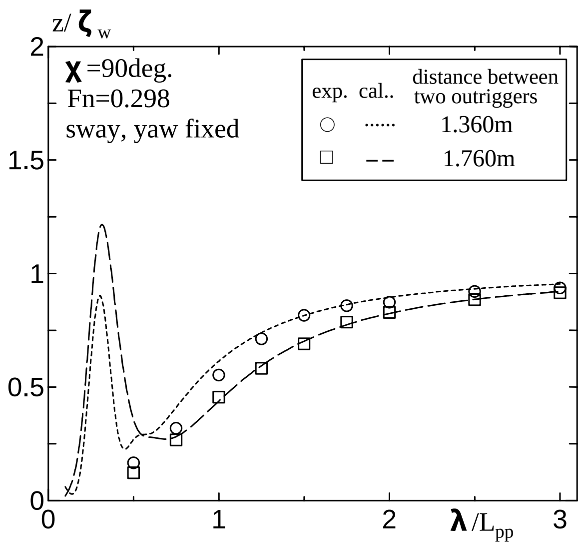

Fig. 5 Heaving amplitude in beam seas.

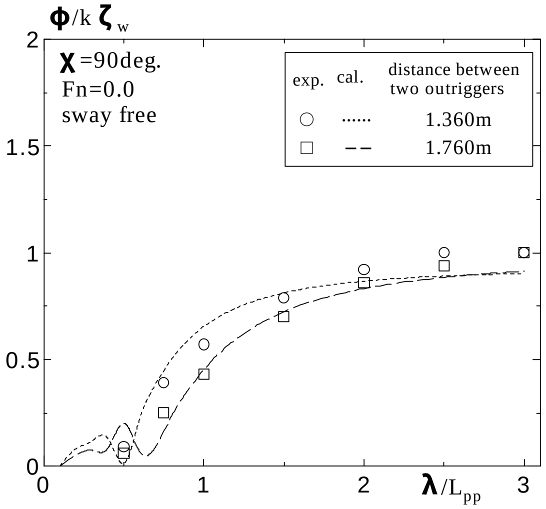

Fig. 6 Rolling amplitude in beam seas.

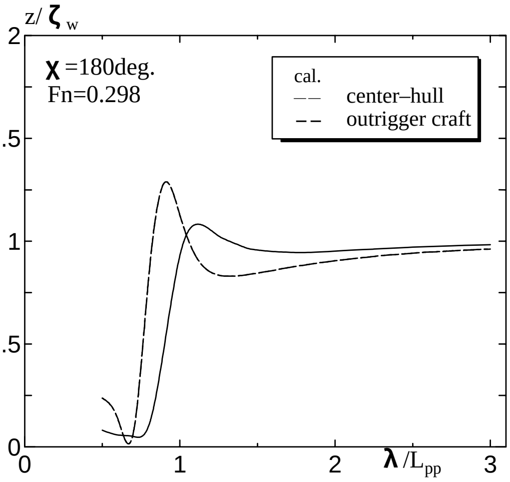

Fig. 7 Comparison of heaving amplitudes between center-hull and outrigger craft in head seas.

3. Characteristics of Ship Motions of Outrigger Craft

3.1 Ship Motions

The comparisons of calculated results between the center-hull and the craft with the outriggers of 1.76 m distance are shown in Figs. 7-10. The solid lines show the calculated results of center-hull by OSM, and the broken lines are also the outrigger craft. In calculation of the center-hull's condition, the position of the center of gravity is equal to the model's one, and pitching inertia moment is obtained from an empirical formula for a conventional mono-hull ship. In head seas, the outriggers make the peak of heaving and pitching motion shift to short wave length and increase heaving and pitching amplitudes at short wave length (λ/L_{pp} <1.0) as shown in Figs. 7, 8. In this wave condition, as the encounter frequencies of motion are so high frequencies, the inertia force is a dominant factor for the supporting arm. The heaving and the pitching amplitudes of the outrigger craft gradually approach the center-hull's ones in long wave length.

On the other hand, in beam seas, as mentioned in the previous chapter, heaving amplitudes of the outrigger craft have a remarkable peak at the short wave length and its values are larger than the center-hull's ones. However, the outrigger craft rapidly decrease heaving amplitudes after the peak as shown in Fig. 9. After that, heaving amplitudes of the outrigger craft gradually approach the center-hull's ones in long wave length. The outriggers considerably decrease heaving amplitudes at 0.5< λ/L_{pp} <2.0 in beam seas.

The calculated results of rolling amplitude in beam seas at Fn = 0.0 are shown in Fig. 10. In this calculation, the roll natural period T_R of the center-hull is assumed to be 1.84 seconds. The roll natural period of the model's T_R is 0.5 seconds by a free decay test. The outriggers significantly decrease rolling amplitudes in beam seas. These outrigger craft's characteristics of rolling motion in beam seas can be explained two ways. One is that the roll damping moment of an outrigger craft is very large. Another is the roll natural period of an outrigger craft is very short because the outriggers increase the rolling restoring moment.

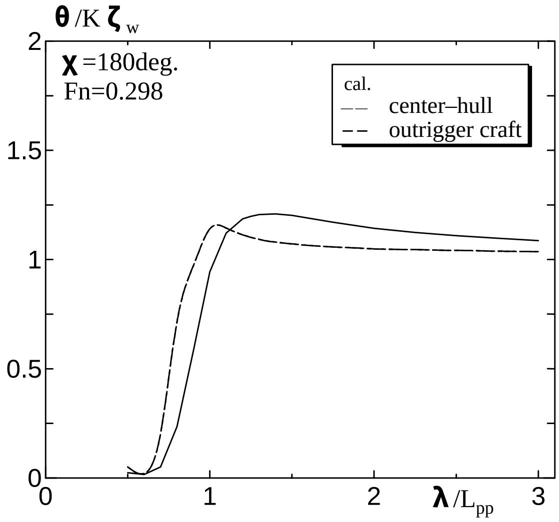

Fig. 8 Comparison of pitching amplitudes between center-hull and outrigger craft in head seas.

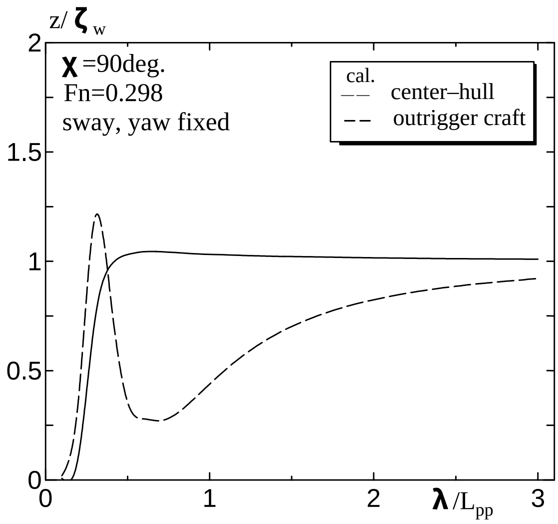

Fig. 9 Comparison of heaving amplitudes between center-hull and outrigger craft in beam seas.

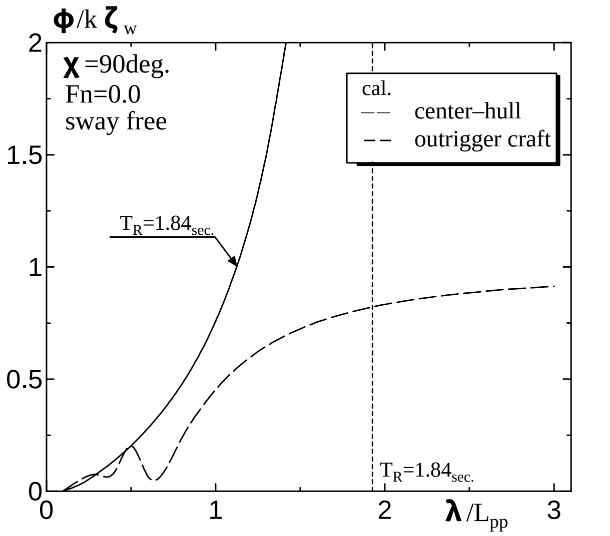

Fig. 10 Comparison of rolling amplitudes between center-hull and outrigger craft in beam seas.

3.2 Transverse Stability

The transverse static stability curve (*GZ*-curve) of the model ship is shown in Fig. 11. The solid line shows the *GZ*-curve of the center-hull, and the broken line is also the outrigger craft. The height of center of gravity *KG* is assumed 0.117m ($KG = d_m$). The calculated *GZ*-curve demonstrates that outriggers significantly increase the roll restoring moment. In addition, the sinkage and the trim for the outrigger craft are larger than the center-hull's ones as shown Fig. 12. Consequently, the roll natural period of the outrigger craft becomes shorter (T_R=0.5s.) compared with the center-hull's one (T_R =1.84 s.).

It was found from these calculated results that the outriggers decrease not only heaving amplitude but also rolling amplitude in beam seas.

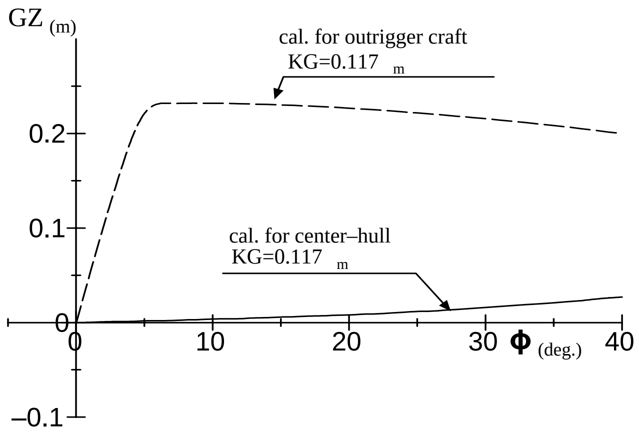

Fig. 11 Comparisons of GZ-curves between the outrigger craft and only center-hull.

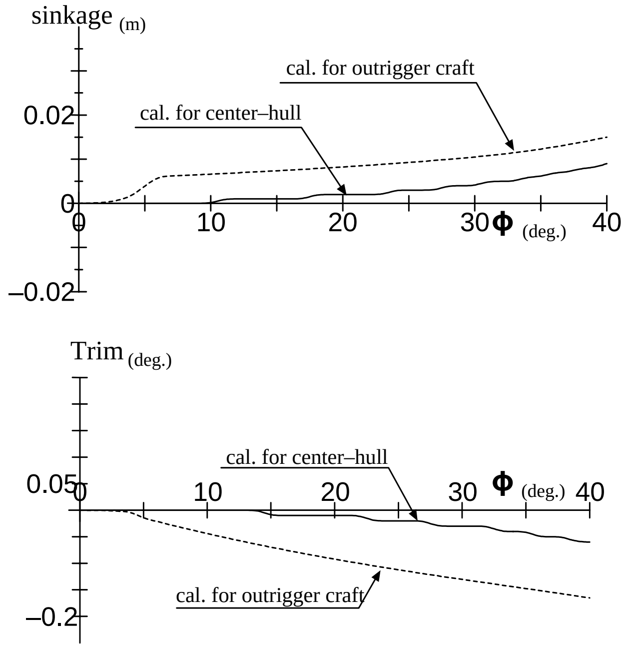

Fig. 12 Comparisons of the trim and the sinkage between outrigger craft and only center-hull.

4. **Wave Loads on Outriggers**

4.1 Model Arrangement

Wave loads on the outriggers are experimentally investigated to clarify the maximum load and twist moments in waves. The loads are measured by strain gages that are attached to the supporting arms of 0.58m from center of an outrigger as shown in Fig. 13. The model of beam is a cantilever. The bending moment is described as follows:

$$MB = F \cdot \ell \qquad (7)$$

where F is the vertical force acting on outrigger, ℓ is the lever from center of an outrigger to the strain gage. The positive direction of vertical force is downward in this measurement.

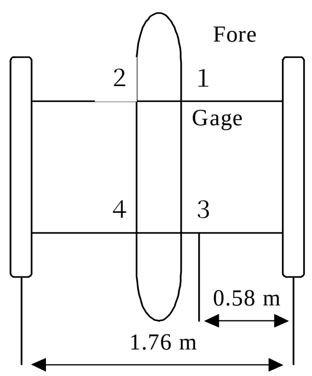

Fig. 13 Model arrangement.

4.2 Results and Discussion

The maximum bending moments are shown in Figs. 14 -17. The largest value is the condition of head seas, and ratio of wave length is 1.25 at the peak. As can be seen, the bending moments at the peaks are getting small to change the wave direction. For instance, the peak of beam seas is about half of one in head seas (see Fig. 15).

Furthermore, the time histories of measurements are shown in Figs, 18-20. In head seas, the peaks of starboard side (No.1) and port side (No.2) are almost closed. Meanwhile, in quartering seas ($\chi = 45$) , the phase of vertical forces is inversed. The phenomenon demonstrates that the twist moment will be getting larger than head seas of one.

In this stage, the matter of the strength will be given careful consideration to prevent the capsizing for the Philippine outrigger craft. For instance, materials, operations for fishermen and the condition of waves near the Philippines. These are the future studies for us.

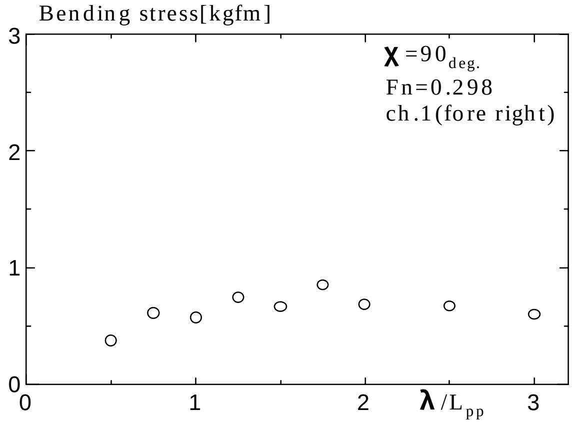

Fig. 16 Maximum bending moment on the supporting arm of outriggers in beam seas ($\chi = 90$).

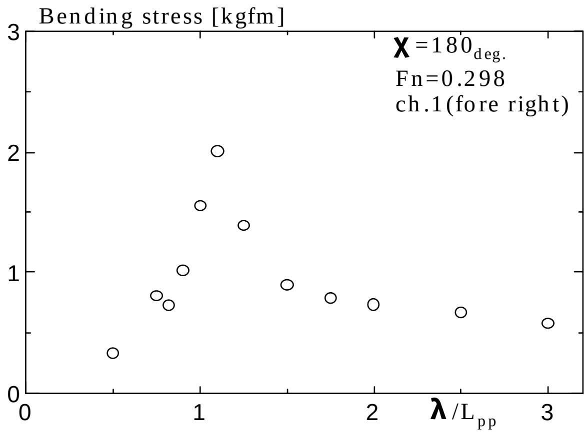

Fig. 14 Maximum bending moment on the supporting arm of outriggers in head seas ($\chi = 180$).

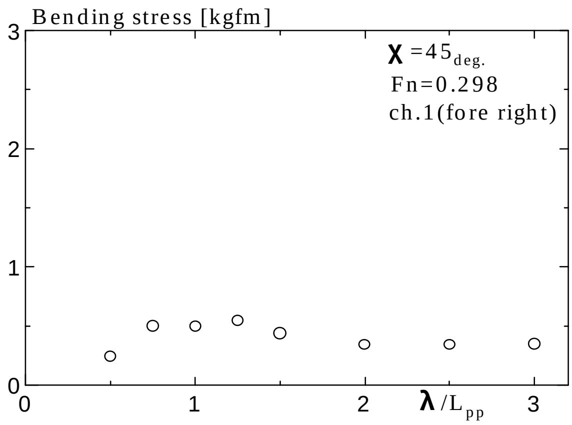

Fig. 17 Maximum bending moment on the supporting arm of outriggers in quartering seas ($\chi = 45$).

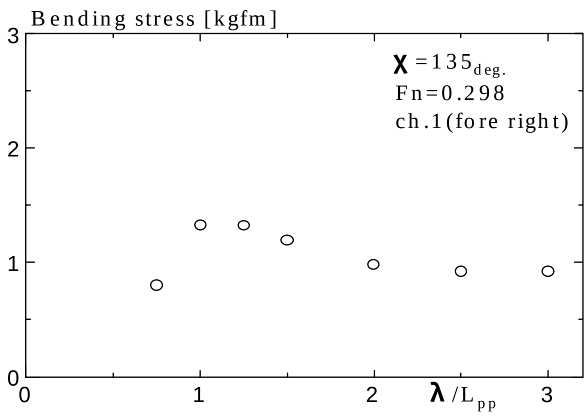

Fig. 15 Maximum bending moment on the supporting arm of outriggers in bow seas ($\chi = 135$).

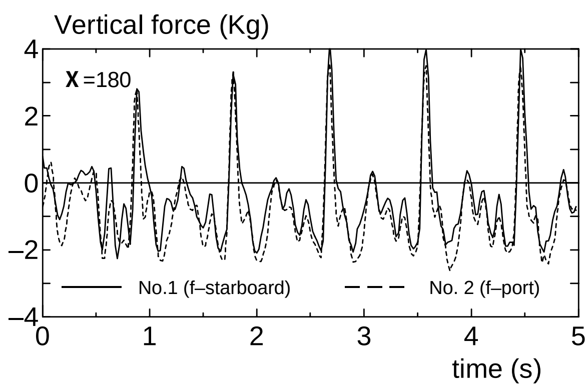

Fig. 18 Time histories of vertical forces on outriggers of starboard and port side in head seas ($\chi = 180$) .

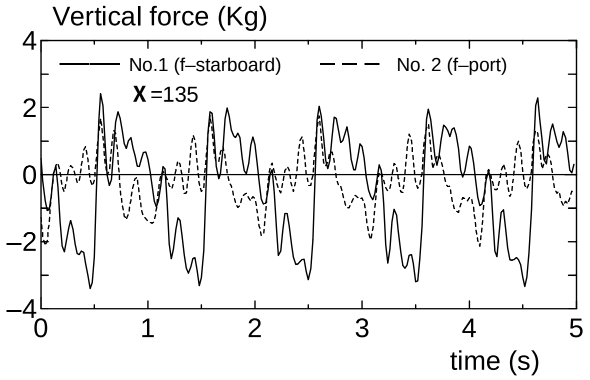

Fig. 19 Time histories of vertical forces on outriggers of starboard and port side in bow seas $(\chi = 135)$.

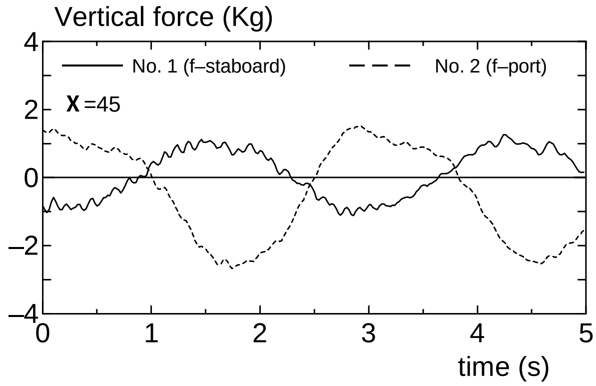

Fig. 20 Time histories of vertical forces on outriggers of starboard and port side in quartering seas $(\chi = 45)$.

5. **Conclusions**

On the basis of the experimentally studies, characteristics of seakeeping performance of Philippine outrigger craft are discussed. The following conclusions are as follows:

1) A computer program to calculate ship motions of the outrigger craft is developed based on an Ordinary Strip Method (OSM). The accuracy of this program is adequate to consider the safety of the outrigger craft in the Philippines.
2) In Head seas, the outriggers make the peak of heaving and pitching motion shift to short wave length and increase heaving and pitching amplitudes at short wave length (λ/L_{pp} <1.0).
3) In beam seas, heaving amplitudes of the outrigger craft have a remarkable peak at the short wave length (λ/L_{pp} =0.3). This is because that phase of heave exciting forces acting on the center-hull and two outriggers agree, as λ/L_{pp} =0.3 is nearly equal to the distance of between the center-hull and the outrigger.
4) The outriggers significantly decrease rolling amplitudes in beam seas. This is because that the outriggers significantly increase transverse static stability and the roll natural period becomes shorter.

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