A Study on the Characteristics of Roll Damping of Multi-hull Vessels

Toru Katayama, Masanori Kotaki and Yoshiho Ikeda

Department of Marine System Engineering, Graduate School of Engineering,
Osaka Prefecture University

ABSTRACT

In this study, for a catamaran and a trimaran as multi-hull vessels, the characteristics of the roll damping are investigated experimentally. A free roll decay test and a forced roll motion test with and without forward speed are carried out. The results show that the roll damping of them is much larger than that of conventional mono-hull vessels, and the component created by side-hull accounts for a significant rate for trimaran. Especially, at the condition without forward speed, the interference of waves created by hulls are significant, the measured roll damping values by different experiments are different on the basis of different water surface condition created by hulls. Moreover, the simplified prediction method is proposed.

KEYWORDS

Catamaran, Trimaran, Roll damping, Wave making component, Eddy making component

INTRODUCTION

They are very important to understand the characteristics of the roll damping for any kind of vessels and to estimate it adequately, because it is significantly affect on the occurrence of parametric rolling, the amplitude of resonances and so on. However, it is very complicated to calculate the roll damping theoretically, because of significant viscous component depending on vortex shedding.

It is known that there is a prediction method of the roll damping proposed by Ikeda (one of authors) for conventional displacement type of mono-hull vessels, barge ships and a small hard chine fishing boat. It is composed of wave making, friction, transverse lift and eddy making prediction component those are developed with theoretically and experimentally backgrounds based on the hydrodynamic characteristics of the roll damping for the above-mentioned types of vessels. Therefore, it is difficult to apply the method to the resent vessels that have large different hull form from above-mentioned types of vessels.

In this study, for catamaran and trimaran as multi-hull vessels, the characteristics of the roll damping are investigated experimentally. And based on the results, the simplified prediction method is proposed.

MODELS

The photographs of two model ships are shown in Figs. 1 and 2, and their principle particulars are shown in Tables 1 and 2. The model of catamaran in Fig.1 is wave piercing type high-speed craft, and its loading conditions are decided by based on over-100m class wave piercing catamaran. On the other hand, the model of trimaran in Fig.2 is stabilized slender mono-hull type high-speed craft, and its distributions of displacement for main-hull and side-hulls are decided by based on a real high speed vehicle-passenger trimaran ferry.

Fig. 1: Model of catamaran.

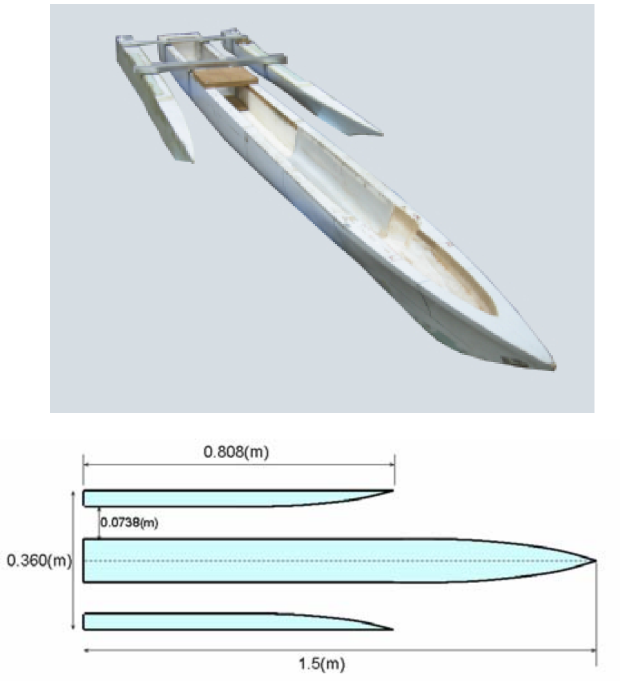

Fig. 2: Model of trimaran and its hull arrangement.

Table 1: Principal particulars of trimaran.

	main-hull	side-hull
L/B	12	10.2
L_{OA} (m)	1.5	0.888
L_{pp} (m)	1.42	0.808
breadth (m)	0.125	0.0874
depth (m)	0.1	0.07
draft (m)	0.037	0.012
displacement (N)	30.8	0.778×2
GM (m)	0.163	
T_n (sec)	1.04	

Table 2: Principal particulars of catamaran.

Scale	1/80
L_{OA} (m)	1.408
L_{PP} (m)	1.32
breadth(m)	0.38
depth (m)	0.07
draft (m)	0.04
displacement (N)	20.9×2
GM (m)	0.85
T_n (sec)	0.46

CHARACTERISTICS OF ROLL DAMPING WITHOUT FORWARD SPEED

In order to investigate the characteristics of roll damping of the models, at first, a free roll decay test is carried out without forward speed. In this test, for model, heaving, pitching, rolling, swaying and yawing are free, and it is initially heeled by fixing only rolling at arbitrary angle. From the condition with which model's attitude is balancing, motions are measured after freeing rolling.

The measured damping curves of rolling for each model are shown in Figs.3 and 4. The result for trimaran in Fig.3 seems to continuously damp, on the other hand, the result for catamaran in Fig.4 shows that the damping curve has some different periods and it damps irregularly.

Therefore, in this study, the results of the free roll decay test with catamaran, only the first swing is analyzed. And the results of the same test with trimaran are analysed for the first swing and other swings separately.

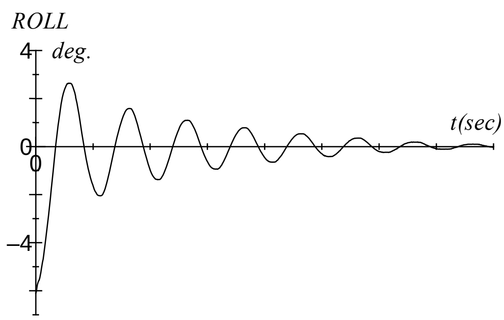

Fig. 3: Time histories of roll motion of the trimaran.

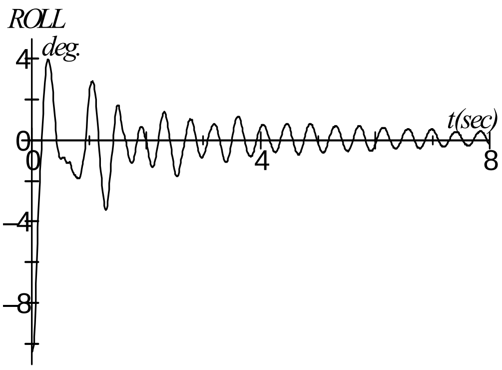

Fig. 4: Time histories of roll motion of the catamaran.

As another measurement of the roll damping, a forced roll motion test is also carried out. In the analysis, one degree of freedom of rolling motion equation is used, in which nonlinear terms are replaced by equivalent linear terms,

$$(I_{44}+a_{44})\ddot{\phi}+B_{44}\dot{\phi}+C_{44}\phi=M_R \qquad (1)$$

where $(I_{44} + a_{44})$, $B_{44,}$ C_{44} and M_R denote the inartia term, damping term, restoring term and roll excitation moment, respectively. In this test, model is forced to sinusoidal rolling around the center of gravity as $\phi=\phi_a \sin \omega t$. The measured roll moment is represented with Fourier series. Using the Fourier coefficient of the fundamental period for measured M_R, the amplitude M_{RF} in phase of roll angular velocity of measured M_R is obtained, and B_{44} is written as follows.

$$B_{44}=\frac{M_{RF}}{\phi_a \omega} \qquad (2)$$

where ω and ϕ_a are roll circular frequency and amplitude. The roll damping coefficient B_{44} can be represented by Bertin's N-coefficient on the condition that the energy losses of them in one period are equal,

$$B_{44}=2g\rho\nabla\frac{GM\ \phi_a}{\pi\ \omega}N \qquad (3)$$

where ∇ is displacemental volume, and the unit of ϕ_a is degree. And B_{44} is non-dimensionalized as follow.

$$\hat{B}_{44}=\frac{B_{44}}{\rho\nabla B^2}\sqrt{\frac{B}{2g}} \qquad (4)$$

where B is breadth of vessel.

In Fig.5, the relative positions of the models to the water surface when the model has heel angle. In the free roll decay test, the initial heel angles, where hull of model is not exposed the air, are selected. And the experimental conditions in forced roll motion test are shown in Table 3.

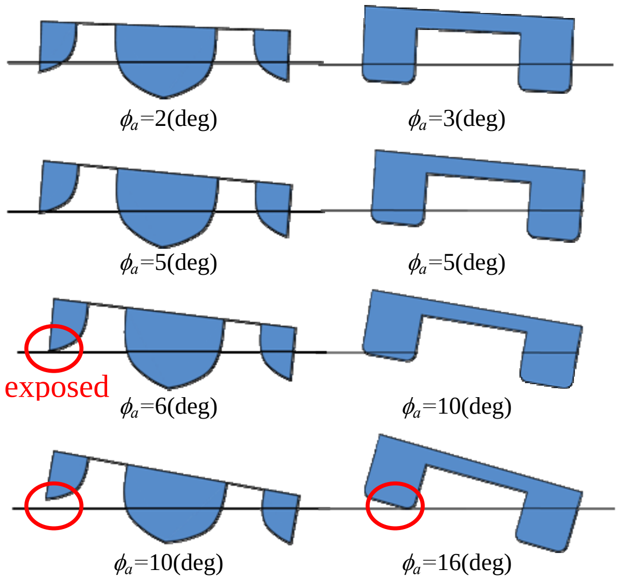

Fig. 5: Relative position of the heeling model to the water surface.

Table 3: Experimental conditions in forced roll motion test.

	trimaran	catamaran
center height of roll motion (m)	0.163	0.85
trim angle (deg)	0	0
forced rolling period: T (sec)	0.4, 0.8, 1.04, 1.3	0.3, 0.46, 0.7, 1.0
roll amplitude: ϕ_a (deg)	2, 5, 10	3, 5, 10

In Figs.6 ~ 9, B_{44} and N-coefficient for two models are shown. From the results of N-coefficient for both models in Figs.6 and 7, it is confirmed that their roll damping are sensuously large in comparison with it for common mono-hull vessels and the N_{10} is about 0.08. On the other hand, from the results of B_{44}, the effect of amplitude is observed. And, from Figs.8 and 9, the effect of roll period is also clearly found.

On the comparisons among different tests and analysis, quantitatively slightly different results are obtained. The results for trimaran show that the results of the first swing of the free roll decay test indicate lager value than those of the other swing of the same test and the forced roll motion test. For the results for catamaran, the same tendency is also observed. As a reason of this, it is supposed that the free surface conditions in these tests are different and there is the disturbed water surface by previous swing excepting the results of the first swing of free roll decay test.

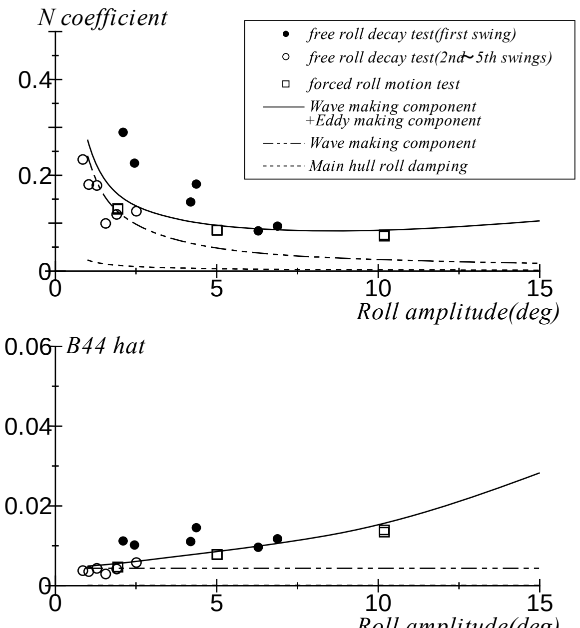

Fig. 6: Roll damping of the trimaran.

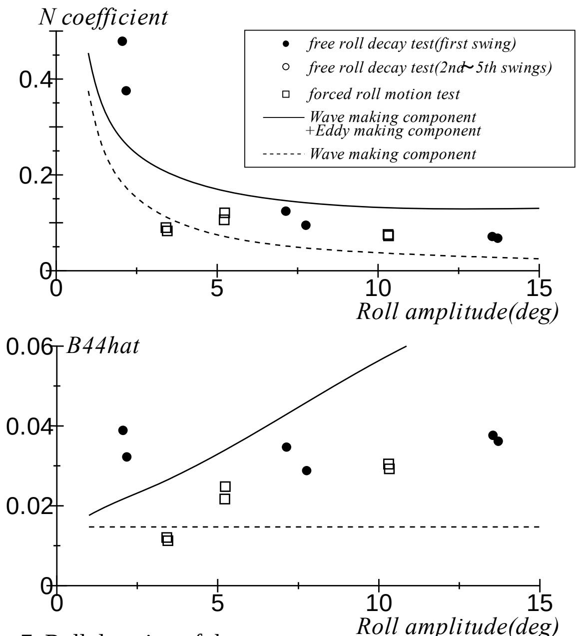

Fig. 7: Roll damping of the catamaran.

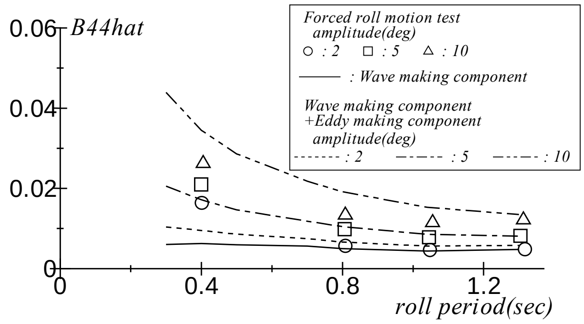

Fig. 8: Roll damping of the trimaran.

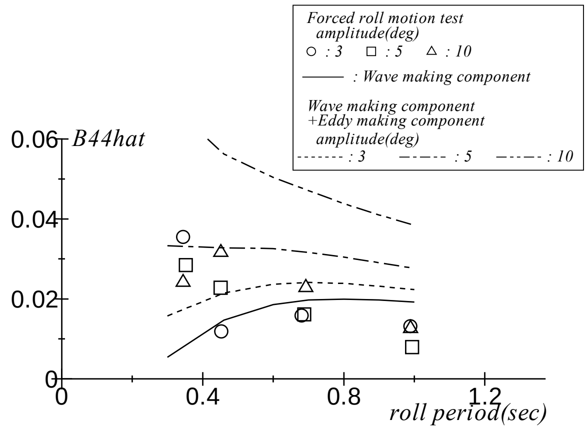

Fig. 9: Roll damping of the catamaran.

As reasons for the effect of amplitude on B_{44}, the nonlinearity of wave component caused by large amplitude motion, the interference of wave among hulls and the viscosity effects are occurred to. In Figs.8 and 9, the effect is also clearly observed for small amplitude. Therefore the viscosity component is considered in this study.

Fig.10 shows significant roll damping components acting on catamaran. One of them is the wave making component B_W which is created by the almost vertically oscillating demi-hull. This component can be roughly estimated by using the heave potential damping of demi-hull B_{33} as following equation.

$$B_W\dot{\phi} = B_W\omega\phi_a = 2l\ B_{33}\ l\omega\phi_a = 2l^2\ B_{33}\dot{\phi} \quad (4)$$

where l is the distance of demi-hull from the centre line shown in Fig.10. It is noted that the B_{43} is not include the interference of wave among hulls, in this study. Another component is the eddy making component and this component acts on the demi-hull moving upward shown in Fig.10. This component can be expressed by using drag coefficient C_{DA}.

$$
\begin{aligned}
B_E\dot{\phi} &= \frac{1}{2}\rho S C_{DA}(l\omega\phi_a)^2 \\
&\cong l^2 \frac{8\omega\phi_a}{3\pi}\rho S C_{DA}(\omega\phi_a) \qquad (5) \\
&= l^2 \frac{8\omega\phi_a}{3\pi}\rho S C_{DA}\dot{\phi}
\end{aligned}
$$

where ρ is density of fluid, S is hull projected area from below. In this study, C_{DA} is obtained from the data in Fig.11 and following equation.

$$C_{DA} = C_D - C_{DF} \qquad (6)$$

In Fig.11, C_D is the total drag coefficient of a 2-D section for a c/t, and C_{DF} and C_{DA} are the drag coefficients acting on forward-body and aft-body of the 2-D section, respectively. And C_{DF} is the drag coefficient at $c/t=\infty$. Moreover, C_{DA} is including roughly KC number effects by using the ratio of C_D for a KC number shown in Fig.12. In this study, KC number is assumed the following equation.

$$KC = \frac{2\pi l\phi_a}{\omega b}\left(Rn = \frac{2\pi l\phi_a d}{\nu}\right) \qquad (7)$$

where b is the breadth of cross section of demi-hull. For catamaran, the total roll damping is calculated by adding these two components. On the other hand, for trimaran, the total roll damping is calculated by adding these two components and the main-hull's roll damping calculated by Ikeda's prediction method[1)].

In Figs.6 ~ 9, the estimated B_{44} is also shown as lines. The estimation can express the effects of roll amplitude and period for the trimaran, however, can not always for the catamaran. As one of reasons for the difference, it is supposed that the interference of waves among hulls is significant for the catamaran.

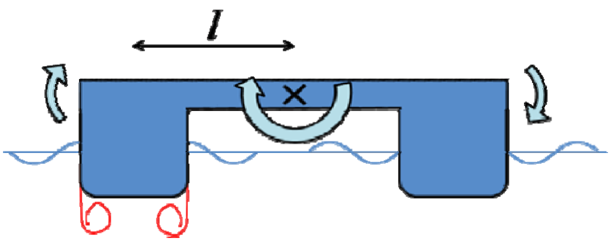

Fig. 10: Roll damping components for catamaran.

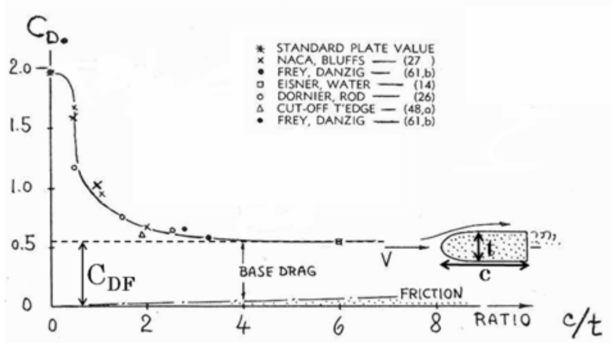

Fig. 11: Drag coefficients of 2-D section with several aspect ratio c to t. In this study, c is draft and t is breadth of demi-hull. (S. F. Hoerner, 1965)

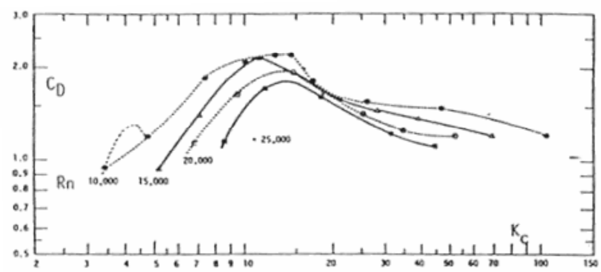

Fig. 12: KC number's effects of drag coefficient for cylinder. (Kuelegan G.H., Carpenter L.H., 1958)

CHARACTERISTICS OF ROLL DAMPING WITH FORWARD SPEED

In order to investigate the characteristic of the roll damping with forward speed, the forced roll motion test is carried out. In this test, the cases of forward speed are decided by based on the maximum speed of some real multi-hull high-speed craft. The experimental condition is shown in Table 4.

Table :4 Experimental conditions in forced roll motion test.

	trimaran	catamaran
Fn	0.148, 0.296 0.443, 0.591	0.136, 0.272 0.407, 0.543
trim angle (deg)	0	0
forced rolling period: T (sec)	0.4, 0.8 1.04, 1.3	0.3, 0.46 0.7, 1.0
roll amplitude: ϕ_a (deg)	2, 5, 10	3, 5, 10

In Figs.13 and 14, B_{44} for two models are shown, and their forced roll periods are their roll natural periods, respectively. For the results of the trimaran in Fig.13, the effect of forward speed on B_{44} is small. On the other hand, for the catamaran in Fig.14, the effect is significant.

In Figs.15 and 16, the effects of roll period on B_{44} for two models are shown, and their *Fn* are their service speed, respectively. The result of the trimaran in Fig.15 shows the same tendency as the results at *Fn*=0. On the other hand, the result of the catamaran in Fig.16 shows the different tendency from the results at *Fn*=0.

CONCLUSIONS

In this study, in order to investigate the characteristics of the roll damping for multi-hull vessel, the roll damping of a catamaran and a trimaran is measured. And Some conclusions can be remarked as follow.

1. In the result of free roll decay test, time histories of roll motion of the catamaran damp irregularly. This is caused by the interference of waves created by hulls.
2. The roll damping for the multi-hull has the effects of roll amplitude and period. The effects for the trimaran can be expressed by the eddy making component created by the demi-hull moving upward. However, it is not enough for the catamaran and it may be necessary to consider the interference of waves created by hulls.
3. The effect of forward speed on the roll damping for trimaran is small. On the other hand, the effect for the catamaran is significant, and the characteristics for the catamaran is different from that at *Fn*=0.

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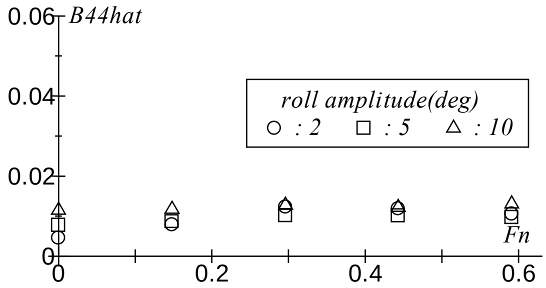

Fig.13: Roll damping of the trimaran at the roll natural period.

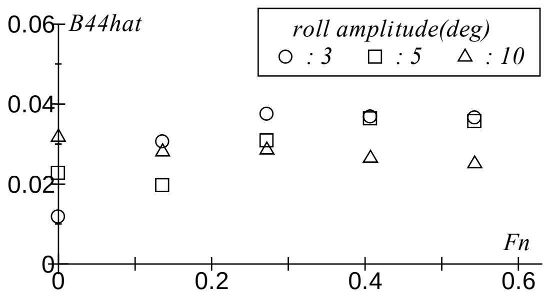

Fig.14: Roll damping of the catamaran at the roll natural period.

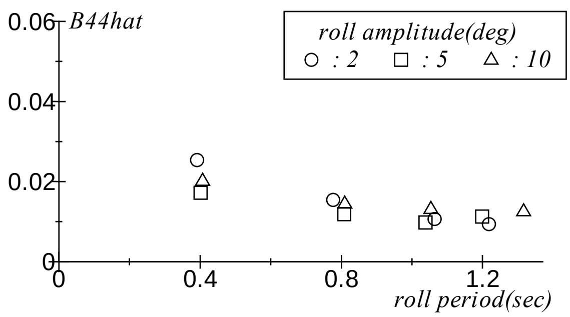

Fig. 15: Roll damping of the trimaran at *Fn*=0.591.

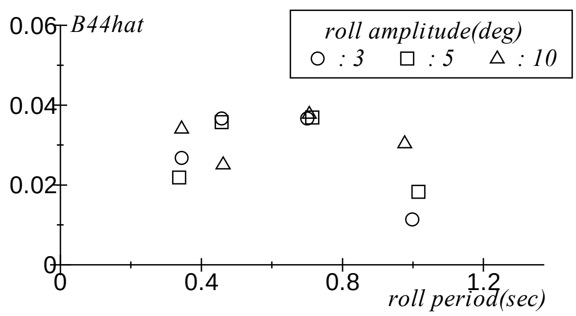

Fig. 16: Roll damping of the catamaran at *Fn*=0.543.