EVALUATION METHOD OF RIDE CONTROL SYSTEM FOR FAST CRAFT FROM THE VIEWPOINT OF PASSENGER COMFORT

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SUMMARY

The design of the ride control system for a fast craft presents special problems due to the need to optimize power of actuator in order to maintain safety and high-speed capabilities. In addition, the effect of this system sometimes gives a different reputation among the shipbuilder, operator and passenger. The main reason is that they do not have a common long measure related to seasickness.

In this paper, a new evaluation method of the ride control system for fast craft has been proposed from the viewpoint of passenger comfort. The method evaluates the amplitude of accelerations, their frequencies and the influence of exposure duration. Meanwhile, the boarding time of most fast craft is up to three hours. The point about the development of this method takes into account the influence of exposure duration during the boarding time. It is important for a fast craft to evaluate the influence of exposure duration during the boarding time as the function of time on the process of transient phenomena from the viewpoint of passenger comfort. In the evaluation method, the effect of ride control system is quantitatively discussed among the shipbuilder, operator and passenger.

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1. INTRODUCTION

Seasickness has always been a serious issue for people prone to motion sickness. Obviously if passenger comfort could be improved, they would easily get on board such as a car. As mentioned above, the boarding time of most fast craft is up to three hours. It is important for the fast craft to consider the influence of exposure duration during the boarding time.

Previous studies of passenger comfort began with shipboard surveys. Kempf (1940)[1)] recommended the allowance of rolling period from the viewpoint of passenger comfort. Tomi (1961)[2)] discussed the influence of jerk (the derivative of acceleration with respect to time), further, he recommended the limited value of 1.0 m/s^3 in rolling motion. Meanwhile, experimental studies were conducted in laboratory by O'Hanlon and McCauley (1974)[3)] using a three-axis motion generator, produced a model for frequency and magnitude dependence of motion sickness for vertical z-axis sinusoidal motion. The most sensitive frequency range was found to be from 0.17 to 0.33Hz. Hosoda et al. (1993)[4)] have developed a ship-motion simulator to carry out many experiments under the same conditions. They have tried to make clear the relationship between the feelings and the facial appearance to evaluated the feelings of seasick persons. On the other hand, in terms of the relationship between ship motions and seasickness, Lawther and Griffin (1986)[5)] discussed the influence to exposure duration based on surveys from 17 voyages of up to 6 hours duration. It took up to 3 hours for the participants to feel unwell under ship motions. Ikeda et al. (1990)[6)] discussed the effect of anti-pitching fins at the bow reduced by 10%, the ratio of vomiting was reduced by 20%. Shigehiro (2001)[7)] proposed the new evaluation method of passenger comfort that consists of vertical acceleration and lateral acceleration and exposure duration.

The purpose of this study is to propose an evaluation method of passenger comfort for fast craft. The method evaluates the vertical accelerations, lateral accelerations and the influence of exposure duration. Meanwhile, the boarding time of most fast craft is up to three hours. The point about the development of this method takes into account the influence of exposure duration during the boarding time as the function of time on the process of transient phenomena from the viewpoint of passenger comfort. From this method, a ride control system for the fast craft is objectively evaluated from the viewpoint of passenger comfort among the shipbuilder, operator and passenger.

2. EVALUATION METHOD OF PASSENGER COMFORT FOR FAST CRAFT

The passenger comfort depends on ship motions, smells, illuminations and the conditions of passenger. In this study, the authors have focused on the influence of ship motions, because ship motions are a dominant factor of seasickness. The motions excited in the ship are mainly due to the wave disturbance. In effect, the wave disturbance is the ‘input’ to ship and the resulting ship motions are the ‘output’. The relationship could be placed on a black box. If the black box could be assumed to be a linear system, since the wave disturbance could be treated probability, the relationship of ‘input’ and ‘output’ is also treated probabilistic. On this assumption, the evaluation method is also treated in probability phenomenon.

The evaluation method of passenger comfort is consisted of vertical accelerations, lateral accelerations and exposure duration as follows:

$$K = (C_z + C_y - C_z \cdot C_y)\,\eta(m) \qquad (1)$$

where C_z is the function of vertical accelerations and C_y is the function of lateral accelerations, and $\eta(m)$ is the function of exposure duration. The value of C_z , C_y and $\eta(m)$ varies from 0 to 1. Accordingly, K is also varies from 0 to 1.

The relationship of C_z and C_y is shown in Fig. 1. In this model, if C_z would be a large value (as represented in head seas), the influence of C_y is small one. On the other hand, if C_z would be a small value (as represented in beam seas), influence of C_y would be a dominant term. The details of C_z, C_y and $\eta(m)$ are discussed below.

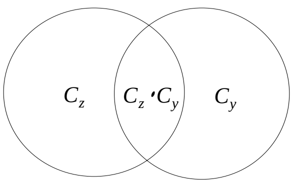

Fig. 1 Venn diagram showing C_z and C_y

2.1 VERTICAL ACCELERATION

The function of vertical acceleration is consisted of amplitude of vertical acceleration and frequency of vertical acceleration as follows:

$$C_z = g(\ddot{z}) \cdot T(\omega_z) \qquad (2)$$

where $g(\ddot{z})$ and $T(\omega_z)$ are given by

$$g(\ddot{z}) = 1 - e^{-\alpha \ddot{z}} \qquad (3)$$

$$T(\omega_z) = e^{-\frac{|1-\omega_z|}{3}} \qquad (4)$$

where $\ddot{z}$ is the amplitude of vertical acceleration in units of a gravity acceleration and ω_z is a circular frequency of vertical acceleration.

The constant α is assumed to be 6 on the basis of experimental data from the measurements of ship motions and survey of passenger comfort in 1998 and 2000. The seasickness conditions of the trainees were surveyed by questionnaires. The numbers of trainees were 10 females and 16 males in 1998, 7 females and 23 males in 2000. The questionnaires were made in simple format as shown in Table 1, so the seasick persons could answer easily. The trainees checked the questionnaires at each mealtime. Persons who checked in the grades of No. 2 (I feel unwell) and No. 3 (I vomited) in the Table 1 are regarded to be seasick persons. The ratio of seasickness is obtained as follows:

$$\textit{The ratio of seasickness} = \frac{\textit{Seasick persons}}{\textit{Number of participants}} \qquad (5)$$

Table 1 Items of questionnaire

Q.1	What have you been doing?	1 Watch 2 Deck work 3 Rest time
Q.2	How do you feel now?	1 I fee all right 2 I feel unwell 3 I vomited

Fig. 2 shows the relationship between vertical accelerations and ratio of seasickness. In this figure, the vertical accelerations measured only within 5〜6 s of period in the first three days on each sailing are plotted. This was done to exclude the influence of frequency and exposure duration.

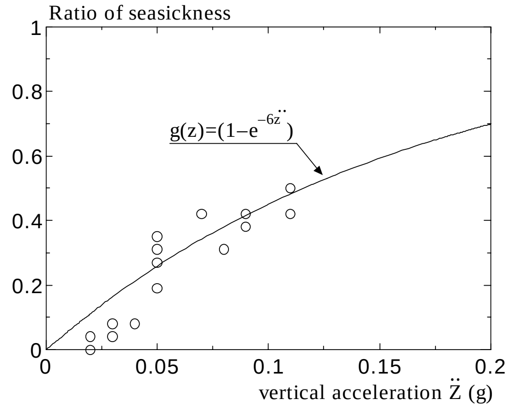

Fig. 2 Ratio of seasickness versus vertical acceleration measured.

In addition, the influence of frequency of vertical acceleration, $T(\omega_z)$ is assumed to be an exponential function with the maximum at $\omega_z = 1$ (period:2π sec.) as shown in Fig. 3. This is because of the experimental data of O'Hanlon et al. (1974) where the severest period for passenger comfort was found to be 6 s.

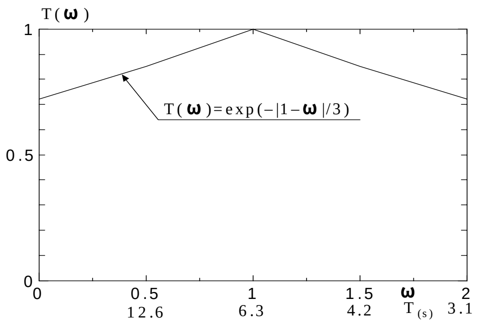

Fig. 3 Function of frequency for seasickness.

2.2 LATERAL ACCELERATION

The David W. Taylor Naval Ship Research developed criteria of lateral acceleration for human under the auspices of US Navy. William (1986)[8) has discussed the relationship influence of vertical and lateral accelerations. He showed the criteria for the fatigue decreased proficiency levels of the vertical and lateral accelerations in low frequency. The limit of lateral acceleration is approximately equivalent to that of vertical acceleration in low frequency. The authors assumed that each weight of vertical and lateral accelerations could be even in this stage. Therefore, the function of lateral acceleration is the same model of vertical acceleration.

$$C_y = g(\ddot{y}) \cdot T(\omega_y) \tag{6}$$

where $g(\ddot{y})$ and $T(\omega_y)$ are given by

$$g(\ddot{y}) = 1 - e^{-\alpha \ddot{y}} \tag{7}$$

$$T(\omega_y) = e^{-\frac{|1-\omega_y|}{3}} \tag{8}$$

where $\ddot{y}$ is the amplitude of lateral acceleration in units of a gravity acceleration and ω_y is a circular frequency of lateral acceleration. The constant α is 6 in this study.

2.3 EXPOSURE DURATION

The boarding time of most fast craft is up to 3 hours. It is important for the fast craft to consider the influence of exposure duration on the boarding time. The authors evaluate the influence of exposure duration on the process of transient phenomena.

The influence of exposure duration $\eta(m)$ is determined using a model of charge and discharge, as a resistance and condenser (R-C) circuit. In this R-C circuit, the response function is denoted by a first linear differential equation. *E(a)* is zero or unity(1) as a step function which is an input, as shown in Fig. 4.

Variable 'm' indicates the minutes in the boarding time. From this, the following function $\eta(m)$ can be readily obtained if we work out the first linear differential equation:

$$\eta(m) = \left\{ \eta(m-1) - E(a) \right\} e^{-\beta} + E(a) \tag{9}$$

where *E(a)* is given by:

$$E(a) = 0 \qquad (a \le 0.03\,g)$$
$$= 1 \qquad (a > 0.03\,g) \tag{10}$$

$$a = \ddot{z} \vee \ddot{y} \tag{11}$$

where the symbol of $\vee$ means that we select the large term between $\ddot{z}$ or $\ddot{y}$, and g is the gravity acceleration. $\ddot{z}$ and $\ddot{y}$ are also average value in a minute. The constant β in the function is determined to be 0.05 on the basis of our survey data. The inverse of β corresponds to a time constant of an R-C circuit. As an initial condition, $\eta(0)$ is given to be zero. For example, the variations of $\eta(m)$ are shown in Fig. 5.

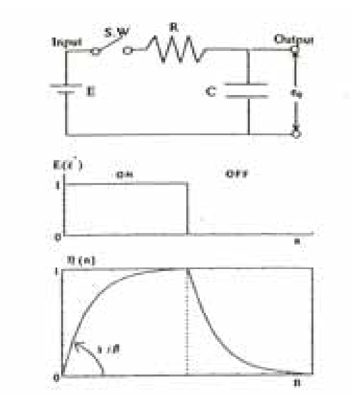

Fig. 4 Model of exposure duration $\eta(m)$

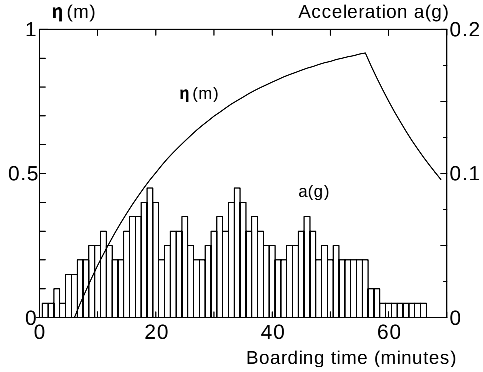

Fig. 5 Example of the variation of $\eta(m)$

3. EVALUATION OF RIDE CONTROL SYSTEM

The present method is applied to a foil-assisted catamaran and a mono-hull ship to evaluate the ride control system form the viewpoint of passenger comfort. In the case of the foil-assisted catamaran, flaps of hydrofoils are controlled for pitching and rolling motions. The mono-hull ship has anti-pitching fins with bow and stern.

3.1 FOIL-ASSISTED CATAMARAN

The foil-assisted catamaran is about 30m long with a maximum speed of 40 knots. The hull is a hybrid design consisting of both a catamaran and fully submerged foils as shown in Fig. 6. The lift provide by the hydrofoils supports more than 80 percent of ship's weight with the rest being supported by the vertical force of the catamaran itself. The design also gives great longitudinal stability by balancing the moments of the hydrofoils and the catamaran. The hull's design enables to use a simple control system, and this simplicity increases control system reliability. The ride control system consists of flaps and ailerons on the hydrofoils as shown in Fig. 7. The flap angles (δ) are as follows:

$$T_e \dot{\delta} + \delta = K_p \theta + K_d \dot{\theta} \tag{12}$$

where θ : pitch angles (deg.), $\dot{\theta}$: pitch rates (deg./sec)

T_e: time constant of flap's element, K_p , K_d : constant

The elements of the control system are:

1) Two flaps on the fore hydrofoil to control vertical motions, and compensate for changes in the center of gravity due to fuel consumption and passenger.
2) Two ailerons on the aft hydrofoil to control rolling motion

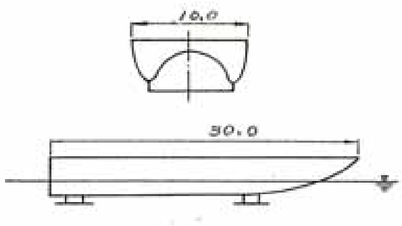

Fig. 6 Outline of the foil-assisted catamaran

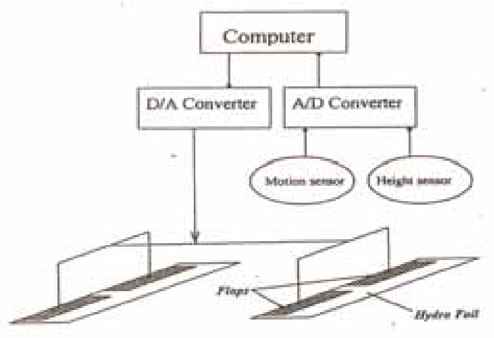

Fig. 7 Schematic illustration of ride control system

The foil-assisted catamaran of pitching and heaving motions are very small in head seas, but are larger in following seas. For this reason, following seas are considered a severe condition for the hybrid-design ship.

Fig. 8 shows the results of a simulation at a speed of 34 knots in following seas. The conditions of simulation are a wave heights of 2.5m and wave length ratio (λ / L) of 2.5. As can be seen, the pitching motions on control are far smaller than those off control. But, the heaving motions are a slight improvement on control.

The time constant of the flap depends on power of actuator. When it is a small value, the actuator is need to a large power. Fig. 9 shows the result of simulation study to change the time constant. From these results, the time constant of 0.5 is a reasonable value. If it would be less than 0.5, even though the power of actuator is larger, the passenger comfort is a slight improvement.

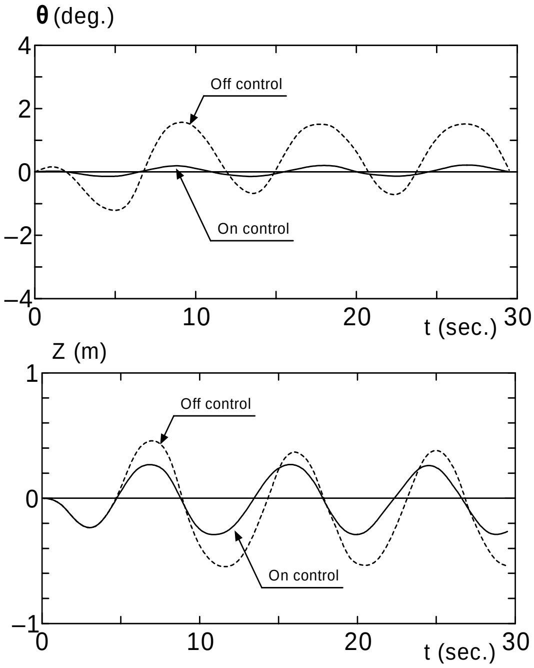

Fig. 8 Time histories of pitching and heaving in following seas (λ / L =2.5, Hw=2.5m)

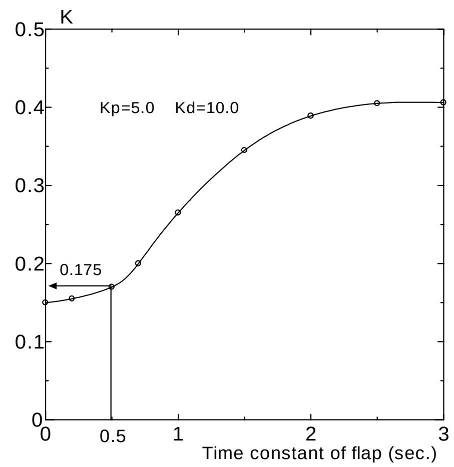

Fig. 9 Evaluation result of time constant of flap angle from the viewpoint of passenger comfort

3.2 MONO-HULL SHIP

Motions of mono-hull ship are different from the foil-assisted catamaran. In this case, the ship is named Kagoshima-maru of Kagoshima University as shown in Fig. 10. When a ship moves in waves, accelerations are exerted on it as a consequence of ship motions. The ship motions of mono-hull have been easily obtained from strip theory in regular waves. If wave spectra are known in irregular seas, the spectral density of ship motions could be estimated in the linear system. By using both the present method of passenger comfort and spectral density of ship motions, passenger comfort could be evaluated in irregular seas in generally.

It is well known that a wave spectrum density function of I.S.S.C. is defined as follows:

$$[f(\omega)]^2 = \frac{0.01}{\omega_o}\left(\frac{\omega}{\omega_o}\right)^{-5} e^{-0.044(\omega/\omega_o)^{-4}} \cdot H^2 \qquad (13)$$

Were H is a significant wave height and ω_o is a mean circular frequency. For example, the wave spectra densities are shown in Fig. 11.

The directional function of waves could be assumed $\cos^2\chi\ (-\frac{\pi}{2} \le \chi \le \frac{\pi}{2})$, thus the wave spectrum density function is

$$[f(\omega,\chi)]^2 = \frac{2}{\pi}\cos^2\chi\,[f(\omega)]^2 \qquad (14)$$

$$\omega_e = \omega - \frac{\omega^2}{g}V\cos\chi \qquad (15)$$

The standard deviation of acceleration σ is defines as follows:

$$\sigma^2(\psi) = \frac{2}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\int_0^{\infty}[f(\omega,\chi)]^2[A(\omega,\psi-\chi)]^2 d\omega\, d\chi \qquad (16)$$

$$A(\omega,\psi-\chi) = |\ddot{z}(\omega,\psi-\chi)|\ or\ |\ddot{y}(\omega,\psi-\chi)| \qquad (17)$$

Where ψ is heading of the ship.

The maximum value of the acceleration agrees quite closely with the Rayleigh's probability density function. The expected value are given by

$$\text{Mean value} = 1.25\sigma$$
$$\text{(1/3) Significant Value} = 2.00\sigma \qquad (18)$$

The mean period of ship motions is defined as follows:

$$\bar{T}_o = \frac{2\pi}{\omega_o} = 2\pi\sqrt{\frac{\sigma}{\sigma_2}} \qquad (19)$$

Where

$$\sigma_2{}^2(\psi) = \frac{2}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\int_0^{\infty}\omega^2[f(\omega,\chi)]^2[A(\omega,\psi-\chi)]^2 d\omega\, d\chi \qquad (20)$$

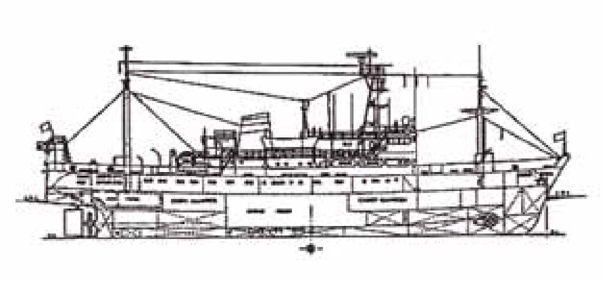

Fig. 10 Side profile of the Kagoshima-maru

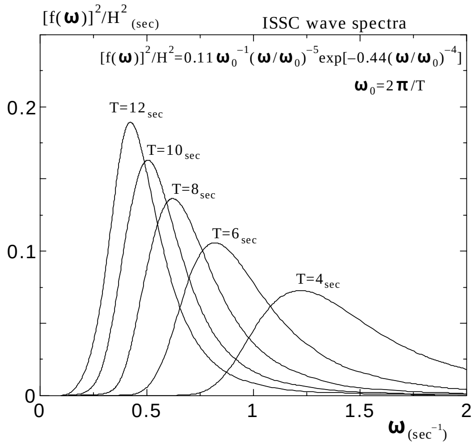

Fig. 11 Example of wave spectrum by ISSC

The significant values of amplitude of accelerations are obtained from Eq. (18). Also, the mean periods of ship motion are obtained from Eq. (19). Meanwhile, the ratios of seasickness K are obtained Eq. (1). By using both the spectral density of ship motions and the evaluation method of passenger comfort, the ratio of seasickness K is generally predicted in irregular seas. The results of predicting K are shown in Fig. 12. As can be seen, the ratio of seasickness K of bow seas (χ =120 ° ∼150 °) and beam seas (χ =90 °) are severe conditions, however, K is a slight in following seas (χ =0 °). Furthermore, when the boarding time is up to 30 minutes, the estimated value is reduced about a half as shown in Fig. 5.

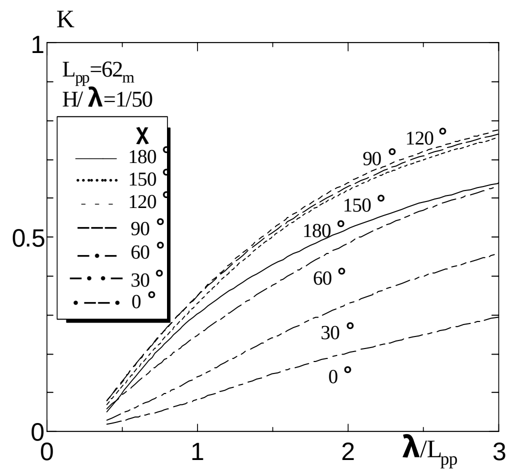

Fig. 12 Ratio of seasickness K change in wave directions

3.3 OPTIMIZATION OF FIN'S AREA

The anti-pitching fins are able to reduce the pitching motions such as a small mono-hull ship. In this study, the area of anti-pitching fin is optimized from the viewpoint of passenger comfort. The model experiments using a 1/31 scale model of the Kagoshima-maru were conducted to evaluate the effect of anti-pitching fines on ship motion in waves. The model arrangement is shown in Photo. 1. In this model, the ship has two fines with fore and aft part. The results of experiments of vertical acceleration at the bridge section are shown in Fig. 13.

The ratio of seasickness K is obtained from the results of model test to change in the area of fines. The results are shown in Fig. 14 in which the *x*-axis (A_F/A_W) is the ratio of the area of the fin to water plane area of the ship at the design draft. By increasing the area, K decreases rapidly at first, and then decreases gradually over A_F/A_W of 4%.

It can be safely said that the most suitable anti-pitching fins for the Kagoshima-maru are the bow and stern fins, each with area of 4% of the water plane area, and with these about 30% improvement in the passenger comfort can be achieved.

Photo.1 Model arrangement

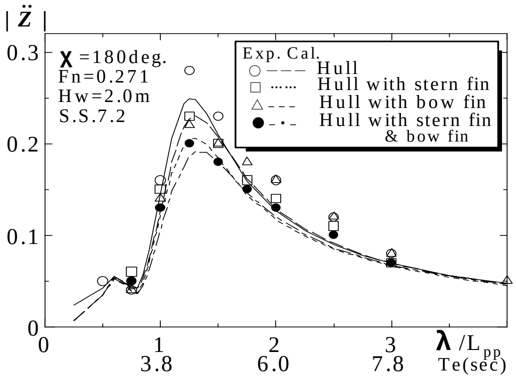

Fig.13 Estimation of vertical acceleration

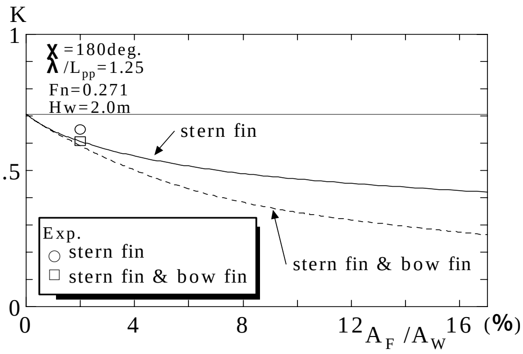

Fig. 14 Variation of K due to changes in area of fins

4. CONCULUSIONS

On the basis of this study, the evaluation of ride control system for a fast craft is discussed quantitatively from the viewpoint of passenger comfort. The following conclusions are drawn:

1) A new method is proposed to evaluate passenger comfort for a fast craft that consists of the influence of exposure duration on boarding time.
2) The time constant of a flap on hydrofoil is evaluated from the viewpoint of passenger comfort.
3) The optimum area and location of the anti-pitching fin is determined for the Kagoshima-maru from the viewpoint of passenger comfort.

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