GREEN SEA LOADS ON GENERAL CARGO SHIP

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Abstract

To develop a practical estimation method of ship motion and green sea loads when deck wetness occurs frequently, series of model tests in waves were conducted using the model of general cargo ship, which is finer than bulk carriers. Using the model of flooded waves, estimation method of ship motion and green sea loads, which is taken the momentum change of green sea into account, was proposed. Having compared estimated green sea loads with measured data, it was found that present method shows good agreement with measured data. It is verified that present method is useful for the estimation of ship motions and green sea loads in rough seas when deck wetness occurs frequently.

Probability density function of green sea loads were estimated by the use of prediction method, which was developed by the one of authors, in order to assess the validity of measured probability of green sea loads quantitatively. Having compared estimated distributions with measured ones, it was found that present method shows good agreement with measured distribution. It was verified that both estimated and measured distributions were reasonable results.

Experimental results for general cargo ship were compared with the ones for bulk carrier in order to examine the effect of ship type on green sea loads. Although the test conditions, such as the significant wave height, the mean wave period and the ship speed, of the two model tests conducted were different and severer for the general cargo ship, it is found that the green sea load on the deck of the general cargo ship are smaller than those of the bulk carrier. It was concluded that the difference of ship type should be taken into account for the determination of rational criteria of green sea loads.

1. INTRODUCTION

It is well known that deck wetness sometimes causes serious damage to the bow deck itself and structures on the deck. For the assessment of the effect of deck wetness on ship stability, it is very important to estimate the green sea load and water volume on deck exactly.

In the meanwhile, the revision work of International Convention on Load Lines (ICLL66) is carrying out in the International Maritime Organization (IMO) in recent years. Rational revision based on the technical background such as seakeeping theory is required. Revision work is carrying out gradually. At the present time, revision of regulation about minimum bow height and hatch cover [1-11] was carried out.

Many studies have been carried out on deck wetness before the revision work of ICLL66. Though they verified that the occurrence of deck wetness can be distinguished by the comparison of relative water height with freeboard and bow height, they provided little quantitative information of shipping water volume and green sea loads. In particular, only recent some studies, which were carried out with relation to the revision work of international convention [11-13] and domestic regulation of Japan[14][15] on Load Line, refer to the estimation method of green sea loads and its probability density function.

Based on these backgrounds, a series of free running tests using the model of a general cargo ship were conducted in regular and irregular waves in order to measure the green sea load due to deck wetness. For the examinations of effects of the ship forward speed on the green sea loads, the model tests in regular head seas were conducted at a ship speed of 6 knots, 4 knots and 2 knots. Tests in irregular waves were carried out in 12m significant wave height ($H_{1/3}$) and 10.4 seconds mean wave period (T_{01}), which is the severe condition for the longitudinal motion of this ship. Mean ship speed in irregular waves were set as 4 knots and 2 knots.

The model of flooded waves [16][14] were applied for describing the behaviour of green sea on deck by the one of authors[14][15]. It was found that this model gives good agreement with measured shipping water height distribution on the deck. Using the model of flooded waves, an estimation method of ship motion and green sea loads, which is taken the momentum change of green sea into account, was proposed. Having compared estimated green sea loads with measured data, it was found that present method shows good agreement with the measured data. It is verified that the present method is useful for assessing the ship motions, green sea volume and its loads in rough seas when deck wetness occurs frequently.

The probability density function of green sea loads were estimated by the use of the prediction method, which was derived based on the model of the flooded waves, in order to assess the validity of measured probability of the green sea loads. Having compared the estimated distributions with measured ones, it was found that the present method shows good agreement with the measured distribution. It was verified that both estimated and measured distributions were reasonable results.

Authors had carried out similar experiments for a bulk carrier[13]. For the examination of the effect of ship type on green sea loads, present results for a general cargo ship were compared with the results for a bulk carrier, present ICLL66 and unified requirement for the bulk carrier (UR-S21) by the International Association of Classification Society (IACS). Although the test conditions, such as the significant wave height, the mean wave period and the ship speed, of the two model tests conducted were different (Bulk carrier: $H_{1/3}$=10.6m, T_{01}=14.0 sec., ship speed=1.4kt, General cargo ship: $H_{1/3}$=12m, T_{01}=10.4 sec., ship speed=2kt) and severer for the general cargo ship, it is found that the green sea load on the deck of the general cargo ship are smaller than those of the bulk carrier. It was concluded that the difference of ship type should be taken into account for the determination of rational criteria of green sea loads.

2. EXPERIMENTS

2.1. Model and measuring instruments

Series of free running tests in waves were conducted, using the model of a general cargo ship, in order to measure green sea loads on deck. The tests were performed at the Square Basin (80m by 80m) of National Maritime Research Institute of JAPAN.

A model of general cargo ship was chosen for the present study. Principal Particulars of this ship are shown in Table 1. The model was constructed at a scale of 1:32.

The ship was assumed to be flush decked, with no sheer and no camber on the weather deck at center line. The ship was assumed to have no forecastle so that superstructure had no effective length.

Setup of measuring instruments is shown in Fig.1. Impact pressures on fore castle were measured by three pressure gauges (P1, P2 and P3). Green sea loads were measured at the position of No.1 hold and No2 hold (S.S.9 and S.S.8). Load cells were attached under the deck, which was separated from the main body of the model, in order to measure green sea load directly. The areas of separated decks are $0.11m^2$ respectively. An accelerometer was attached next to the load cell to exclude the effect of inertia of the separated bow deck plate. A video camera was attached to observe the behaviours of shipping water.

In addition to the green sea loads, ship motions, relative water height and vertical acceleration were measured. Relative water was measured at stem, S.S. 91/2, S.S. 7, S.S. 51/2 and S.S.3. Vertical accelerations were measured at F.P., S.S. 9 and S.S. 8.

2.2. Conditions

Series of regular wave tests were carried out to allow a comparison with analytical study. In addition, tests in irregular waves were also carried out. Waves were lasted the equivalent of about 1.5 hours in full scale

Experiment in regular waves was carried out in the head seas (χ=180 deg.). Mean ship speed in waves was set 6 knots (Froude number Fn=0.0585), 4knots (Fn=0.039) and 2knots (Fn=0.0195). In particular, the wave height was varied at the sever condition to longitudinal motion of ship (λ/L=0.8, 1.0 and 1.2 ; λ:wave length, L:ship length)

Experiment in irregular waves was carried out in the head seas. The ISSC spectrum was used for wave spectrum of irregular waves. The encounter waves were 500 in number. Mean wave period and significant wave height in ship scale were T_{01}=10.4 seconds, which is the severest to the longitudinal motion and green sea loads of this cargo ship, and $H_{1/3}$=12.0m respectively. Mean ship speed in waves was set as 4knots and 2knots.

Table 1. Principal particulars

	Ship	Model
L_{pp} (m)	160.0	5.0
Breadth (m)	24.13	0.75
Depth (m)	15.79	0.49
Draft (m)	9.58	0.30
Displacement (ton)	24546.32	0.75
GM (m)	3.03	0.09
Block coefficient C_B	0.66	0.66
Longitudinal Gyration(κ_y/Lpp)	260523.00	0.82

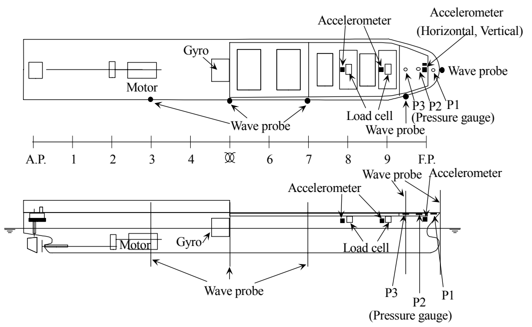

Fig.1 Setup of measuring instruments

3. CALUCULATION OF SHIP MOTIONS TAKING GREEN SEA LOADS INTO ACCOUNT

Equation of ship motions when deck wetness occurs frequently were derived in accordance with the methodology of time domain and non-linear strip method in which the effect of time-varying sectional hydrodynamic forces were taken into account [17].

Based on the balance of force and moment, total force F and moment Fx, which were taken the effect of green sea loads into account, can be expressed as

$$\int_{A.P.}^{F.P.} F dx = \int_{A.P.}^{F.P.} (F_i + F_r + F_{ma} + F_{mj} + F_{mj}^* + F_{imp} + F_{imp}^* + F_s + F_G) dx = 0 \quad (1)$$

$$\int_{A.P.}^{F.P.} F \times x dx = \int_{A.P.}^{F.P.} (F_i + F_r + F_{ma} + F_{mj} + F_{mj}^* + F_{imp} + F_{imp}^*) + F_s + F_G) x dx = 0 \quad (2)$$

where F_i is the inertia of ship, F_r is the hydrodynamic force due to wave damping, F_{ma} is the hydrodynamic force due to the added mass, F_{mj} and F_{mj}^* are the hydrodynamic force due to longitudinal variation of added mass in waves and in calm water respectively, F_{imp} and F_{imp}^* are the hydrodynamic force due to time-varying of the added mass in waves and calm water respectively, F_s is a static force and F_G is a force due to green sea. From eq.(1) and eq.(2), equation of longitudinal motion is expressed as

$$\begin{pmatrix} M + m_{33} & m_{35} \\ m_{53} & I_{55} + m_{55} \end{pmatrix} \begin{pmatrix} \ddot{Z} \\ \ddot{\theta} \end{pmatrix} + \begin{pmatrix} N_{33} & N_{35} \\ N_{53} & N_{55} \end{pmatrix} \begin{pmatrix} \dot{Z} \\ \dot{\theta} \end{pmatrix} + \begin{pmatrix} C_{33} & C_{35} \\ C_{53} & C_{55} \end{pmatrix} \begin{pmatrix} Z \\ \theta \end{pmatrix} = \begin{pmatrix} E_3 \\ E_5 \end{pmatrix} \quad (3)$$

where M is a mass, I_{55} is the inertia moment of pitch, m_{ij} (i,j=3,5) is the added mass coefficient, N_{ij} (i,j=3,5) is the damping coefficient, C_{ij} (i,j=3,5) is the restoring force coefficient, Z is the heave amplitude, θ is the pitch angle and E_i (i=3,5) is the wave exciting force.

With respect to sectional hydrodynamic forces and potential value, Integral equation method was used. Source and doublet are distributed at the origin of each section to avoid the irregular frequency in accordance with Ohmatsu's method [18].

Based on the study for FPSO [19] and study for the Japanese domestic ships[14], pressure due to green sea loads P ,which was taken momentum change of water into account, can be expressed by the given shipping water height h as follows

$$P = \frac{d(\rho h \cdot W)}{dt} + \rho g h \cos\tau = \rho\left(\frac{\partial h}{\partial t}\right) W + \rho\left(g\cos\tau + \frac{\partial W}{\partial t}\right) h \quad (4)$$

where ρ is a density of water, W is the vertical velocity of the deck, g is the acceleration of gravity, τ is the angle between keel line and surface of calm water and t is a time variable. W can be derived as

$$W = \dot{Z}\cos\tau - x\dot{\theta} \quad (5)$$

where x is the longitudinal distance from center of gravity. By substituting eq.(5) for eq.(4), P can be expressed as

$$
\begin{aligned}
P &= \rho\left(\frac{\partial h}{\partial t}\right)\left(\dot{Z}\cos\tau - x\dot{\theta}\right) \\
&\quad + \rho\left(g\cos\tau + \frac{\partial}{\partial t}\left(\dot{Z}\cos\tau - x\dot{\theta}\right)\right)h \\
&= \rho h\cos\tau \times \ddot{Z} - \rho hx \times \ddot{\theta} \\
&\quad + \rho\left(\frac{\partial h}{\partial t}\right)\cos\tau \times \dot{Z} - \rho\left(\frac{\partial h}{\partial t}\right)x \times \dot{\theta} \\
&\quad + \rho gh\cos\tau
\end{aligned}
\tag{6}
$$

By integrating pressure P, green sea load can be expressed as

$$
\int_{A.P.}^{F.P.} F_G dx = \int_{A.P.}^{F.P.} P \times B(x)dx \tag{7}
$$

where $B(x)$ is breadth of each section. It was assumed that shipping water height varies only along the longitudinal direction.

By substituting eq.(7) for eq.(1) and eq.(2), the hydrodynamic force of present method can be expressed by the use of them in the conventional method[17], which wasn't taken the effect of green sea loads into account, as

Integral calculus of green sea loads along the ship length in eq.(8), only fore part from S.S.8 was considered based on the experimental results.

$$
\begin{aligned}
m_{33} &= m_{33}(conventinal) + \int_{A.P.}^{F.P.} \rho h\cos\tau \times B(x)dx \\
m_{35} &= m_{35}(conventinal) - \int_{A.P.}^{F.P.} \rho hx \times B(x)dx \\
m_{53} &= m_{53}(conventinal) \\
&\quad + \int_{A.P.}^{F.P.} \rho h\cos\tau \times x \times B(x)dx \\
m_{55} &= m_{55}(conventinal) - \int_{A.P.}^{F.P.} \rho hx^2 \times B(x)dx \\
N_{33} &= N_{33}(conventinal) \\
&\quad + \int_{A.P.}^{F.P.} \rho\left(\frac{\partial h}{\partial t}\right)\cos\tau \times B(x)dx \\
N_{35} &= N_{35}(conventinal) - \int_{A.P.}^{F.P.} \rho\left(\frac{\partial h}{\partial t}\right)x \times B(x)dx \\
N_{53} &= N_{53}(conventinal) \\
&\quad + \int_{A.P.}^{F.P.} \rho\left(\frac{\partial h}{\partial t}\right)\cos\tau \times x \times B(x)dx \\
N_{55} &= N_{55}(conventinal) - \int_{A.P.}^{F.P.} \rho\left(\frac{\partial h}{\partial t}\right)x^2 \times B(x)dx \\
E_3 &= E_3(conventinal) + \int_{A.P.}^{F.P.} \rho gh\cos\tau \times B(x)dx \\
E_5 &= E_5(conventinal) + \int_{A.P.}^{F.P.} \rho gh\cos\tau \times x \times B(x)dx
\end{aligned}
$$

(8).

With regard to the shipping water height, the model of flooded waves[14], which was applied by the theory of the flooded waves[16] to shipping water, were used. By defining a coordinate system shown in Fig.2, shipping water height h at the position of x is derived as

$$
\begin{aligned}
h(x,t) &= \frac{B_0}{B(x)} \\
&\quad \times \frac{x}{2\sqrt{\pi D}} \int_0^t \frac{F(\xi)}{(t-\xi)^{3/2}} \exp\left\{\frac{-(x-\omega_0(t-\xi))^2}{4D(t-\xi)}\right\} d\xi
\end{aligned}
\tag{9}
$$

where $D= v_0\ h_0/2\ i_0$, $\omega_0=5\ v_0\ /3$, v_0 is a ship speed , h_0 is a bow height, i_0 is the slope of deck, $F(t)=f(t) - h_0$, $f(t)$ is the relative wave height at the stem, B_0 is an inflow breadth of shipping water and x is the longitudinal distance from stem.

Tasaki [20] reported that an inflow breadth of shipping water B_0 is in proportion to maximum value of exceeded height of relative water height δ ($=f(t)_{\max} - h_0$), based on the measured shipping water volume per an encounter period.

The one of authors determined it as B_0= =1.1 δ based on the measurement of both shipping water distribution and its load[14]. In this study, this relation is applied for the present method.

As to the slope of deck i_0, we assume that it is the same as $\sin\theta_{max}$ where θ_{max} is maximum angle between keel line and surface of calm water. Inflow of shipping water begins just after the relative water height becomes maximum value.

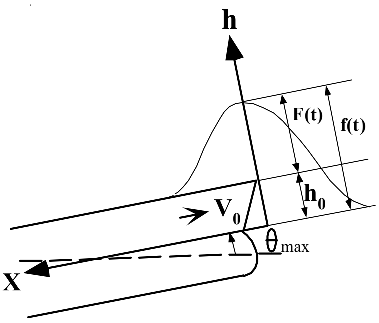

Fig.2 Model of the flooded waves

4. EXPERIMENTAL RESULTS AND COMPARISON WITH CALUCULATION

4.1. Vertical acceleration and relative water height

Verification of accuracy of estimated vertical acceleration and relative water height at stem is important to estimate green sea loads accurately. Vertical accelerations at F.P. and S.S.9 in head seas with various wave heights are shown in Fig.3 and 4 respectively. Fundamental frequency component of measured and estimated data a_a are divided by L/gζ (L:ship length, ζ:wave amplitude) respectively. Phase angle between pitch and vertical accelerations are shown in Fig.5 and Fig.6 respectively.

It was found that the wave height have much effect on the amplitude of vertical acceleration. Meanwhile, it is also found that phase angle of vertical acceleration wasn't affected by the wave height. Although estimated phase angle shows good agreement with measured one, it was found that the agreement in the small wave height is not always good. However, it is found that present method gives good agreement with measured amplitude in the large wave height. It is found that the estimated amplitude by the linear calculation such as strip method, which gives similar solution to the one in the small wave height by the present method, becomes much different from the measured amplitude.

It is confirmed that present method, which is taken green sea loads and time-varying sectional hydrodynamic forces into account, is useful for the estimation of acceleration in rough seas.

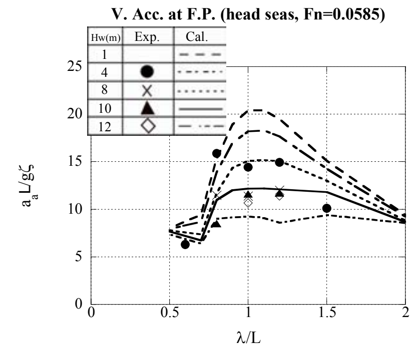

Fig.3 Amplitude ratio of vertical acceleration at F.P. (Head seas, Fn=0.0585)

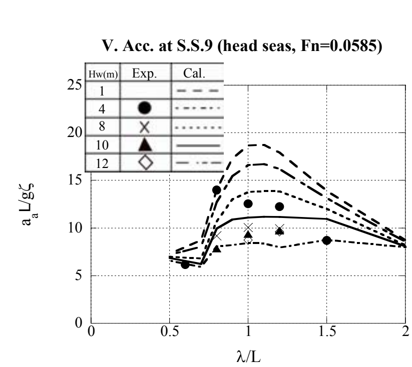

Fig.4 Amplitude ratio of vertical acceleration at S.S. 9 (Head seas, Fn=0.0585)

Relative water heights at stem with various wave heights at a ship speed of 6 knots and 4 knots are shown in Fig.7 and 8 respectively. Fundamental frequency component of measured and estimated value η_a are divided by wave amplitude ζ respectively. Phase angle between pitch and relative water height are shown in Fig.9 and Fig.10 respectively.

Similar to the results of vertical acceleration, it was found that wave heights have much effect on the amplitude of relative water height. Meanwhile, it was also found that phase angle of relative water height wasn't affected by the wave heights.

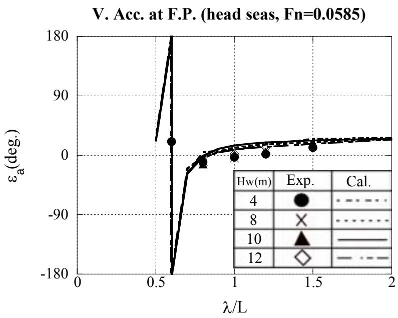

Fig.5 Phase angle between pitch and vertical acceleration at F.P. (Head seas, Fn=0.0585)

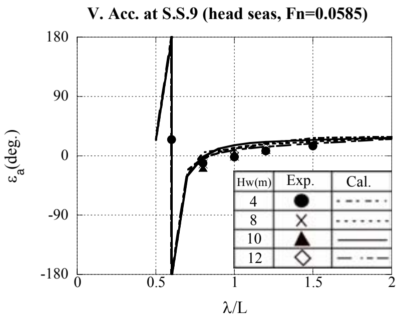

Fig.6 Phase angle between pitch and vertical acceleration at S.S. 9 (Head seas, Fn=0.0585)

It is found that estimated relative wave heights gives good agreement with measured data. With regard to the results in 4m wave height, there is some discrepancy between estimated and measured data. It is considered that reflected wave at bow effects on measured data. Though such a 3-D effect should be taken into account to modify the accuracy of estimation, it is found that present method gives good agreement with measured amplitude in the large wave height.

It is confirmed that present method is useful for the estimation of relative water height in rough seas when the deck wetness occurs frequently.

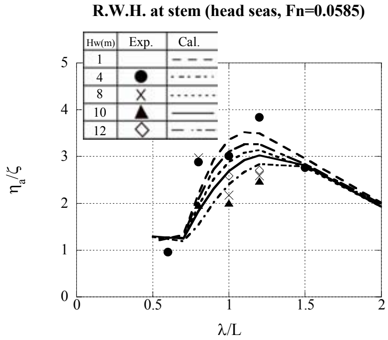

Fig.7 Amplitude ratio of relative water height at stem (Head seas, Fn=0.0585)

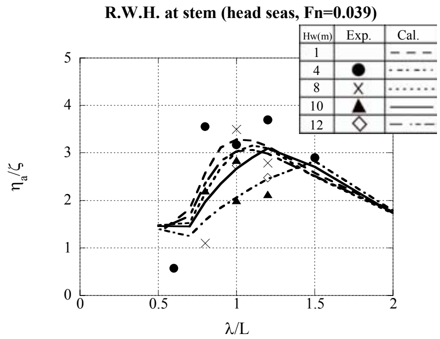

Fig.8 Amplitude ratio of relative water height at stem (Head seas, Fn=0.039)

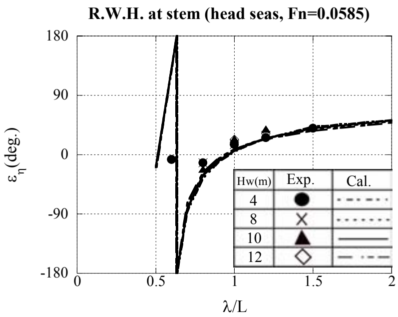

Fig.9 Phase angle between pitch and relative water height at stem (Head seas, Fn=0.0585)

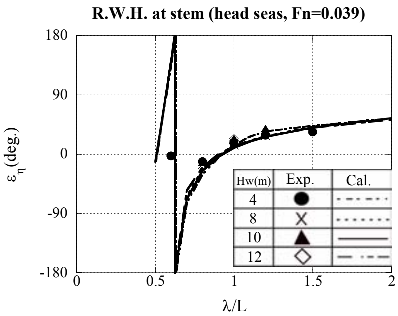

Fig.10 Phase angle between pitch and relative water height at stem (Head seas, Fn=0.039)

4.2. Green sea load

Sample of estimated and measured time histories of green sea loads are shown in Fig. 11 and Fig.12. For the comparison, it was assumed that the instant of maximum values of relative water height in estimated data was the same time as the one in measured data. Relation between the wave height and the peak value of green sea loads were shown in Fig. 13 and Fig.14. Both estimated and measured green sea loads were converted to those for full-scale ship using Froude's law.

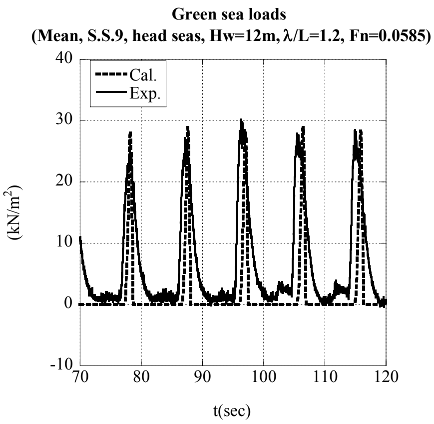

Fig.11 Time history of measured and estimated pressure due to green sea on fore deck(P3(S.S.91/2), Head seas, Hw=12m, λ/L=1.2, Fn=0.0585)

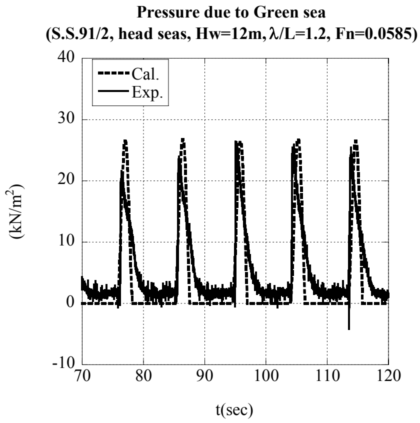

Fig.12 Time history of measured and estimated green sea loads on No.1 hatch position(S.S.9) (Head seas, Hw=12m, λ/L=1.2, Fn=0.0585)

It was found that present method gives good agreement with measured data. It is verified that the model of flooded waves describes green sea well.

In this study, it was found that there was small effect of green sea loads on ship motions. However, it is considered that its effect on small vessel can't be ignored. Though the model of pile of water on deck should be required separately, present method can be useful for such an examination.

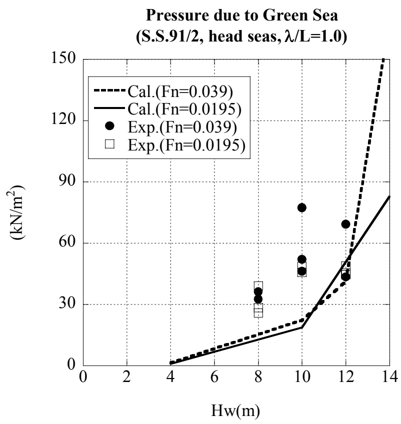

Fig.13 Effect of wave height on pressure due to green sea on fore deck (P3(S.S.91/2), Head seas, λ/L=1.0)

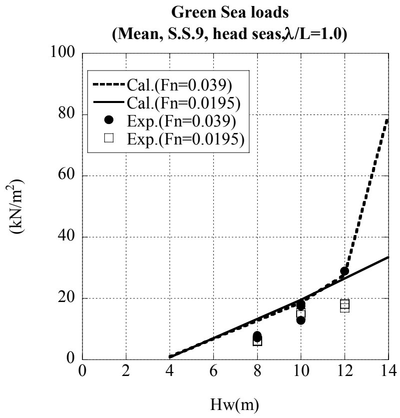

Fig.14 Effect of wave height on green sea loads on No.1 hatch position(S.S.9) (Head seas, λ/L=1.0)

4.3. Results in the irregular waves

Measured probability of exceedance of green sea loads at a ship speed of 4knots and 2knots were shown in Fig.15 and Fig.16 respectively. It was found that green sea load diminishes rapidly in the aft part on the deck in the head seas. It was also found that ship speed has much effect on green sea loads.

Measured probability of exceedance of green sea loads were verified by the comparison with estimated probability, which was derived by the one of authors[15].

It was reported that the estimated green sea loads using flooded waves were in good agreement with measured ones in not only the present study but also previous studies[14][15]. The model of flooded waves assumes that green sea at the stem flows with same height as maximum height over the bow top, and with a breadth which is proportional to the maximum height over the bow top. From these results, one of authors found a relation between the green sea loads and the square of the maximum height of the water over the bow top, δ_{max}. The relation between the maximum value of the green sea loads F_{max} and the maximum value of the relative water height η_{max} can be approximated by the expression

$$F_{max} = \alpha \rho g B \left(\eta_{max} - f\right)^2 = \alpha \rho g B \delta_{max}^2 \qquad (11)$$

where α is the coefficient, ρ is a density of water, g is the acceleration due to gravity, B is the breadth of the ship and f is the bow height at the stem. The relation between the green sea loads and the relative water height at a ship speed of 4 knots and 2knots are shown in Fig. 17 and Fig.18 respectively. The points in these figures indicate the experimental results. The values of the experimental data were converted to those for a full-scale ship using Froude's law. The coefficient α can be estimated by applying the eq.(11) to the experimental results. For the No.1 hatch position at the ship speed of 4knots and 2knots, it was 0.158 and 0.131 respectively. For the No.2 hatch position at the ship speed of 4knots and 2knots, it was 0.076 and 0.049 respectively. The approximation found using the eq.(11) is shown by the lines in Fig. 17 and Fig.18. It was found approximation is valid. Although the coefficient α can be changed by the type of ship and the ship's speed, etc., α can be estimated without experiments using the estimation method for green sea loads shown in the present paper.

Based on the relation between relative water height and green sea loads, probability density function of green sea loads $p_F(F)$ can be derived. Assuming that the probability density function of relative water height is given by the Rayleigh distribution, $p_F(F)$ can be described as

$$p_F(F) = \frac{f \cdot \sqrt{\alpha \rho g B} + \sqrt{F}}{2 \alpha \rho g B \sigma_\eta^2 \sqrt{F}} \cdot \exp\left\{ -\frac{\left(f \cdot \sqrt{\alpha \rho g B} + \sqrt{F}\right)^2}{2 \sigma_\eta^2 \alpha \rho g B} \right\} \qquad (12)$$

where σ_η is standard deviation of relative water height at stem. By the integral calculus of eq.(11), the exceedance of probability of green sea load $P(F>F_0)$ can be expressed as

$$P\ (F > F_0) =$$

$$\int_{F_0}^{\infty} p_F(F)dF = \exp\left\{-\frac{\left(f\cdot\sqrt{\alpha\rho g B}+\sqrt{F_0}\right)^2}{2\sigma_\eta^2 \alpha\rho g B}\right\} \tag{13}$$

Estimated distribution is shown in Fig.15 and Fig.16 as lines. It was found that the agreement with measured data is very well. It was verified that measured green sea loads is reasonable.

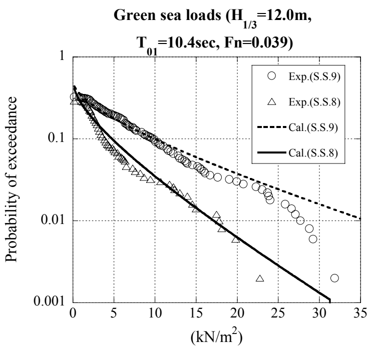

Fig.15 Probability of exceedance of green sea loads (Head seas, $H_{1/3}$=12.0m, T_{01}=10.4sec, Fn=0.039)

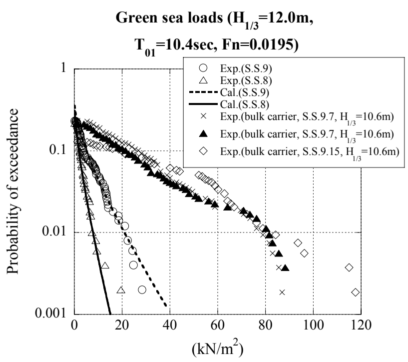

Fig.16 Probability of exceedance of green sea loads (Head seas, $H_{1/3}$=12.0m, T_{01}=10.4sec, Fn=0.0195)

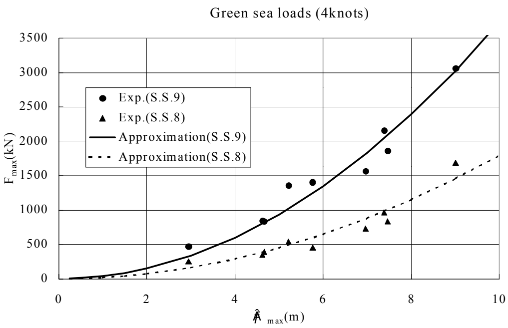

Fig.17 Relation between green sea loads and relative water height at stem (Fn=0.039)

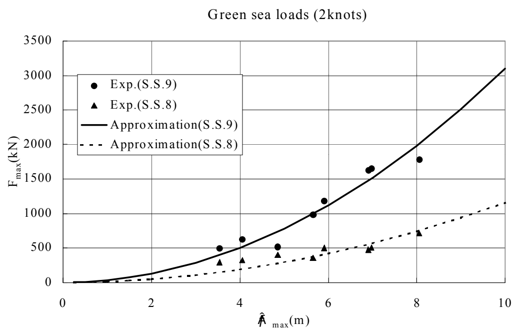

Fig.18 Relation between green sea loads and relative water height at stem (Fn=0.0195)

Measured green sea loads on bulk carrier, which was measured by the authors [5], was also shown in Fig.16. Although the test conditions, such as the significant wave height, the mean wave period and the ship speed, of the two model tests conducted were different (Bulk carrier: $H_{1/3}$=10.6m, T_{01}=14.0 sec., ship speed=1.4kt, General cargo ship: $H_{1/3}$=14m, T_{01}=10.4 sec., ship speed=2kt) and severer for the general cargo ship, it was found that the green sea loads on the general cargo ship are smaller than those of the bulk carrier. It is considered that the difference of ship type has effects on the probability density function of green sea loads.

4.4. Comparison with design load

Measured green sea loads were compared with criteria in ICLL66 and unified requirement for bulk carrier of IACS (UR-S21). Fig. 19 and Fig.20 show the longitudinal variation of measured green sea loads. The points in these figures indicate mean, 1/10 and 1/3 significant values, which are derived from experiments, respectively. The lines in the figures show green sea load criteria when the ICLL66 and UR-S21 were applied to the present cargo ship. Measured results for bulk carrier are also shown in Fig.20. Although it is difficult to directly correlate measured values with the criteria, mean values tend to be same level as the one in ICLL66. It was also found that the longitudinal distribution of green sea loads is deferent with the one in IACS UR-S21, which was constructed for the bulk carrier, and measured results on bulk carrier. It is considered that the difference of ship type should be taken into account for the determination of magnitude and longitudinal distribution of green sea loads.

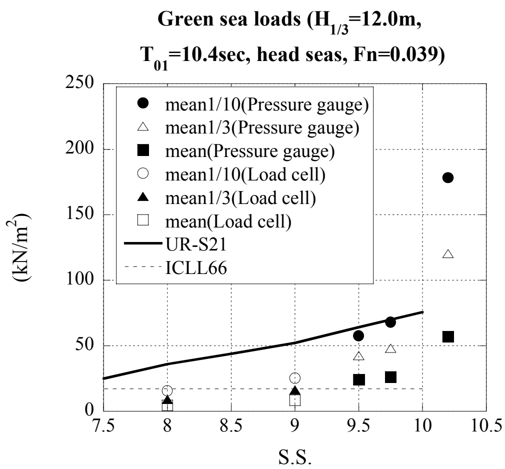

Fig.19 Longitudinal distribution of green sea loads (Head seas, $H_{1/3}$=12.0m, T_{01}=10.4sec, Fn=0.039)

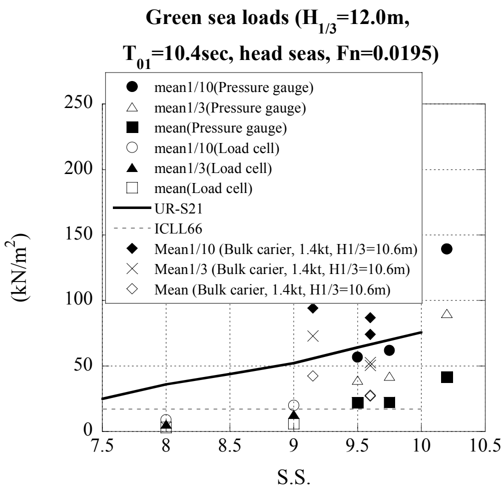

Fig.20 Longitudinal distribution of green sea loads (Head seas, $H_{1/3}$=12.0m, T_{01}=10.4sec, Fn=0.0195)

5. CONCLUSION

Series of free running tests in waves were conducted in order to measure the green sea loads. Estimation method of ship motion and green sea loads when deck wetness occurs frequently was proposed. It was concluded as

(1) It is found that estimated ship motion and green sea loads using the present method gives good agreement with measured data.
(2) It is clarified that estimation of green sea loads by the use of the model of flooded waves is useful.
(3) Probability density function of green sea loads can be estimated accurately by the present method.
(4) It is found that the green sea loads on the general cargo ship are smaller than the loads of the bulk carrier at the same probability of occurrence. It indicates that the difference of ship type should be taken into account for the determination of rational criteria of green sea loads.

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Japan.

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