Development of Expression for Estimating Bow Freeboard and Assessment of the 1966 Load Line Convention

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Summary

This paper deals with development and application of the new regression equation for the bow freeboard which consists of the various parameters indicating the ship's principal particulars and the hull form features. The response characteristics of relative bow motion are first obtained for 67 existing ships in regular waves based on the strip theory. Using these response characteristics of 67 existing ships, a regression equation is introduced to express the magnitude of the relative bow motion in irregular waves. By using the regression equation, the relation between bow freeboard and deck wetness probability can be easily derived under any given sea conditions. This method is used for assessment of the current formula of the 1966 Load Line Convention and the Chinese formula which is recently proposed at SLF/IMO. Finally we discuss the future works necessary for the revision work of the convention.

1. Introduction

The bow freeboard is one of the most important factors from a view point of a safety of ship. The 1966 Load Line Convention (ICLL 66) has functioned for the world maritime community over the past 25 years as the level of safety for monohull displacement ships, as it has been evaluated the basic freeboards for vessels over 100 m in length. However, it has some problems such that it is not based on the seakeeping theory, and it does not contain the various parameters indicating the ship's principal particulars and hull form features but only the length of ship and the block coefficient. It has been, therefore, confirmed that the current formula is different from the method of ship design based on the modern seakeeping theory. In recent years, the development in modern seakeeping theory has enabled to assign the bow freeboard through the direct calculation or the model experiments under the progress in marine engineering. This is the reason why the SLF Sub-Committee is now discussing the possible revision of ICLL 66.

A great number of studies on the ship motion theory have been carried out in Japan. As the pioneering research for the deck wetness, Fukuda has proposed a method of the short and long-term predictions on deck wetness, and shown the examples of its application to the various kinds of cargo ship forms. Takaishi et al. have confirmed the validity of the strip theory for relative motion by the model experiments. The 71 Regulation Research Committee of the Shipbuilding Research Association of Japan has been investigating the formula for the bow freeboard height based on the seakeeping theory in order to respond to the revision work of ICLL 66 at the SLF Sub-Committee.

This paper deals with the development and the application of this new regression equation for the bow freeboard which contains the various parameters indicating the effect of ship's principal particulars and the hull form features. The response characteristics are first obtained for the relative bow motion of 67 existing ships in regular waves based on the strip theory. Using the response characteristics, a regression equation is introduced to express the magnitude of the relative bow motion in irregular waves by the simple formula. Next the heights of the bow freeboard evaluated by the present method are compared to those of ICLL 66 and the Chinese formula. Finally we discuss the future works which are necessary for the revision work at SLF.

2. Short Term Prediction of Relative Bow Motion

2.1 Ships and Calculation Conditions

The 67 existing ships of different types with ship lengths from 24 to 313 m are used to estimate the effects of ship hull forms on the relative bow motions by the calculations.

When a ship is operating in long crested irregular head waves, the variance of vertical bow motions rela-
tive to a wave surface can be expressed as follows,
\[ [R_s(T_w)]^2 = \int_0^\infty S_r(\omega) [H(\omega)]^2 d\omega \]  
(1)
where, \( S_r(\omega) \) : Wave spectrum with mean wave period \( T_w \) and significant wave height \( H_{1/3} \),
\( R_s(T_w) \) : Standard deviation of relative bow motion,
\( H(\omega) \) : Response function of relative bow motion.

The significant wave height \( H_{1/3} \) and the mean wave period \( T_w \) can be evaluated by the following equation
\[ H_{1/3} = 4 \left( m_0 \right)^{1/3} \]
\[ T_w = 2\pi \left( \frac{m_0}{m_1} \right)^{1/3} \]  
(2)
where,
\[ m_0 = \int_0^\infty \omega^2 S_r(\omega) d\omega. \]  
(3)

We have performed the numerical calculations for 24 cases, which include six ITTC spectra with mean wave periods of 6, 8, 10, 12, 14, 16 sec. and four different ship speeds of \( F_s = 0.0, 0.15, 0.20, 0.25 \), and estimated the significant value of the relative bow motion of each ship. The response function \( H(\omega) \) has been estimated by applying the new strip method (N. S. M.).

2.2 Relative Bow Motions in Irregular Waves

Fig. 1 show the non-dimensional significant values of the relative bow motions for four kinds of Froude numbers of four ships with length of about 50, 100, 200, 300 m which are picked out arbitrarily from 67 ships. The abscissa is the mean wave period of irregular waves. It is shown from this figure that every relative bow motion has a maximum value at the mean wave period which corresponds to the wave with the same length to ship length irrespective of the ship speed. Namely it means that the relative bow motion becomes most dangerous to the deck wetness at this mean wave period on the assumption of a constant wave height. If we can determine the height of bow freeboard to be larger than the maximum relative bow motion in this situation, the ship may operate safely at any sea condi-

Fig. 1 Relative Bow Motion/\( H_{1/3} \) versus Mean Wave Period
2.3 Critical Wave Height of Deck Wetness

Assuming that the bow deck ships green water when the magnitude of relative bow motion \(Z_{\text{rel}}\) exceeds the bow freeboard \(f\), the expected probability \(P\) of deck wetness in the short-term irregular sea can be evaluated by the following equation\(^7\),

\[
P(Z_{\text{rel}} > f) = \exp\left(-\frac{f^2}{2R_{1/3}}\right) = \exp\left(-\frac{(f/H_{1/3})^2}{2(R_{1/3}H_{1/3})^2}\right),
\]

(4)

where, \(R_{1/3}\) : standard deviation of relative bow motion.

From equation (4), the height of bow freeboard \(f\) can be expressed as

\[
f = \sqrt{2 \log(1/P)} \left(\frac{R_{1/3}}{H_{1/3}}\right) H_{1/3}
\]

\[
= \left(4 \pi R_{1/3}\right)^{1/2} \left(\frac{\pi}{4} \sqrt{\log(1/P)}\right) H_{1/3}
\]

\[
= \left[\frac{2 \pi (Z_{\text{rel}})_{1/3}}{H_{1/3}}\right] \left(\frac{\pi}{4} \sqrt{\log(1/P)}\right) H_{1/3} = \bar{Y}_{1/3} \cdot H_{1/3}
\]

\[
= \bar{Y}_{1/3} \cdot H_{1/3} = \frac{5}{4} \sqrt{\log(1/P)} H_{1/3}
\]

(5)

where,

\[
\bar{Y}_{1/3} = \frac{4 \pi R_{1/3}}{H_{1/3}} = \frac{2 \pi (Z_{\text{rel}})_{1/3}}{H_{1/3}} : \text{Non-dimensional amplitude of relative bow motion},
\]

\[
H_{1/3} = \frac{5}{4} \sqrt{\log(1/P)} \cdot H_{1/3} : \text{Critical wave height with expected probability } P.
\]

The critical wave height \(H_{1/3}\) in (6) corresponds to the wave height when the bow deck ships green water with the expected probability \(P\). Thereby \(H_{1/3}\) can be expressed by using the significant wave height \(H_{1/3}\) as follows:

<table>
<thead>
<tr>
<th>Probability of Deck Wetness</th>
<th>Critical Wave Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P = 5%)</td>
<td>(H_{1/3} \cdot (1/20) = 1.221 \cdot H_{1/3})</td>
</tr>
<tr>
<td>(P = 10%)</td>
<td>(H_{1/3} \cdot (1/10) = 1.071 \cdot H_{1/3})</td>
</tr>
<tr>
<td>(P = 20%)</td>
<td>(H_{1/3} \cdot (1/5) = 0.894 \cdot H_{1/3})</td>
</tr>
<tr>
<td>(P = 30%)</td>
<td>(H_{1/3} \cdot (3/10) = 0.774 \cdot H_{1/3})</td>
</tr>
<tr>
<td>(P = 40%)</td>
<td>(H_{1/3} \cdot (2/5) = 0.674 \cdot H_{1/3})</td>
</tr>
<tr>
<td>(P = 50%)</td>
<td>(H_{1/3} \cdot (1/2) = 0.587 \cdot H_{1/3})</td>
</tr>
</tbody>
</table>

(7)

It is obvious from (5) that the height of bow freeboard \(f\) is proportional to the critical wave height \(H_{1/3}\) with expected probability \(P\). Therefore, if we only evaluate the non-dimensional amplitude of relative bow motion \(\bar{Y}_{1/3}\), we can easily estimate the height of bow freeboard \(f\) by multiplying the non-dimensional amplitude of relative bow motion \(\bar{Y}_{1/3}\) and the critical wave height \(H_{1/3}\) with the expected probability \(P\) of the sea region where the ship is going to operate.

3. Estimation of Bow Freeboard Height

3.1 Study of Regression Equation

One of the authors has ranked the seakeeping performance of container ships by applying the Bales' method\(^8\). Furthermore he has obtained the new regression equation with several principal coefficients of ship hull forms for each ship response, and finally made clear the method for deformations of ship hull form to reduce the responses of ship motions such as heaving, pitching, accelerations, relative motions, added wave resistance and so on\(^9\). According to that method\(^9\), the each response \(Y\) has been expressed by the following regression equation,

\[
Y = C_1 \cdot C_{\omega r} + C_2 \cdot C_{\omega a} + C_3 \cdot C_{\omega p} + C_4 \cdot C_{\omega d} + C_5 \cdot L/B + C_6 \cdot L/d + C_7,
\]

(8)

where,

\[
C_{\omega r}, C_{\omega a} : \text{Waterplane area coefficient of the fore and aft bodies},
\]

\[
C_{\omega p}, C_{\omega d} : \text{Vertical prismatic coefficient of the fore and aft bodies},
\]

\[
L : \text{Length of ship},
\]

\[
B : \text{Breadth of ship},
\]

\[
d : \text{Draught of ship}.
\]

The above expression seems to be very convenient method for improving the ship hull performance in an initial design stage, because the effect of ship hull forms on the seakeeping performances is represented quantitatively by using this expression which includes explicitly several parameters indicating the ship's principal particulars and the hull form features. In addition, the recent study\(^{10}\) by the tank tests has confirmed that the above method is useful for reducing the added wave resistance of middle-size bulk carriers.

The regression equation (8), however, does not include the effect of ship length on the responses, because the ship length \(L\) is normalized by the breadth \(B\) and the draught \(d\) of ship. We have, therefore, studied the regression expressions to contain explicitly the effect of the length \(L\), the breadth \(B\) and the draught \(d\). The height of bow freeboard \(f\) can be evaluated by multiplying the non-dimensional amplitude of relative bow motion \(\bar{Y}_{1/3}\) and the critical wave height \(H_{1/3}\) with the expected probability \(P\) as shown in (5). Accordingly we have tried to express the non-dimensional amplitude of relative bow motion \(\bar{Y}_{1/3}\) with the ship's principal particulars and the hull form features by changing the underlined part of equation (8) into four equations (9.A) - (9.D) as follows:

\[
\bar{Y}_{1/3} = C_1 \cdot C_{\omega r} + C_2 \cdot C_{\omega a} + C_3 \cdot C_{\omega p} + C_4 \cdot C_{\omega d} + C_5 \cdot L/B + C_6 \cdot L/d + C_7 \cdot L/d^2,
\]

(9.A)

\[
\bar{Y}_{1/3} = C_1 \cdot C_{\omega r} + C_2 \cdot C_{\omega a} + C_3 \cdot C_{\omega p} + C_4 \cdot C_{\omega d} + C_5 \cdot L/B + C_6 \cdot L/d + C_7 \cdot L/d^2,
\]

(9.B)

\[
\bar{Y}_{1/3} = C_1 \cdot C_{\omega r} + C_2 \cdot C_{\omega a} + C_3 \cdot C_{\omega p} + C_4 \cdot C_{\omega d} + C_5 \cdot L/B + C_6 \cdot L/d + C_7 \cdot L/d^2,
\]

(9.C)

\[
\bar{Y}_{1/3} = C_1 \cdot C_{\omega r} + C_2 \cdot C_{\omega a} + C_3 \cdot C_{\omega p} + C_4 \cdot C_{\omega d} + C_5 \cdot L/B + C_6 \cdot L/d + C_7 \cdot L/d^2,
\]

(9.D)

Fig. 2 shows the comparison of the direct calculated
results and the estimated results due to the above four equations concerning the relative bow motions of 22 full ships, which are chosen from a total 67 ships taken in this study, at the ship speed of \( F_n = 0.15 \) and the mean wave period of 14 sec. Furthermore Table-1 shows the values of standard deviations at the ship speed of \( F_n = 0.15, 0.20 \) and the mean wave periods of 6.0, 10.0, 14.0, 18.0 sec. which corresponds to the accuracies of the regression equations (9. A)–(9. D). It is obvious from the table that the estimated accuracy is improved from (9. A) to (9. D) in due order irrespective of ship speeds and mean wave periods. We will, therefore, use the equation (9. D) as the most accurate expression of the amplitude of relative bow motion \( Y_{1/3} \) hereafter. 

Substituting the non-dimensional amplitudes of relative bow motion of 67 ships to (9. D), we get the coefficients of the regression equation as shown in Table-2. The comparisons between the calculated values by N. S. M. and the estimated values by equation (9. D) at \( F_n = 0.0, 0.15, 0.20, 0.25 \) are shown in Fig. 3. It is recognized that almost all the non-dimensional amplitudes of relative bow motion can be estimated accurately by one regression equation for each ship speed. The forward speed affects little on the non-dimensional amplitudes of relative bow motion except for zero forward speed. The standard deviations of the regression equation for various ship speeds are shown in Table-3.
4. Assessment of ICLL 66

The calculated formula of the bow freeboard due to ICLL 66 are as follows:

\[
f = 56 \cdot L \left( 1 - \frac{L}{500} \right) \cdot \left( 1 + \frac{C}{0.68} \right) \cdot \frac{1.36}{C + 0.68},
\]

\[
f = 7000 \times \left( \frac{1.36}{C + 0.68} \right),
\]

(10)

where, \( C = C_s \) for \( C_s \geq 0.68 \), \( C = 0.68 \) for \( C_s < 0.68 \)

\( L \) : Length of ship (in m),

\( C_s \) : Block coefficient.

In order to study the correlation between the present method and the ICLL 66, we have estimated the bow freeboard height of the deck wetness probability of \( P = 5, 10, 20, 30, 40, 50\% \) under the significant wave height of \( H_{1/3} = 10, 7, 4 \) m which correspond to the wave condition proposed by IMO/SLF for comparative calculations as shown in Appendix A, but the Tasaki's formula is not applied for swell-up of bow wave in this study for simplicity.

Fig. 4 shows the effect of ship speeds on the bow freeboards of 44 ships as shown in Table-4. It is obvious from this figure that the effect of ship speeds on the bow freeboards is small for the range of \( F_n = 0.15 - 0.25 \), and the values with the zero forward speed \( F_n = 0 \) corresponds to about 70\% of values with the forward speed. The bow freeboard in the criterion that \( H_{1/3} = 4 \) m and \( F_n = 0.25 \) is smaller than these values. It is, therefore, enough for investigating the bow freeboard at the condition of zero forward speed.

Fig. 5 shows the comparison of the values due to ICLL 66 and the present method at the condition with \( F_n = 0 \),

\[
\begin{array}{c|c|c|c|c|c|c|c}
\hline
F_n & T_s & Standard Deviation (\sigma) & (9.A) & (9.B) & (9.C) & (9.D) \\
\hline
0.15 & 6.0 & 0.0288 & 0.0255 & 0.0224 & 0.0216 & 0.0189 \\
10.0 & 0.0729 & 0.0728 & 0.0702 & 0.0702 & 0.0186 \\
14.0 & 0.0258 & 0.0256 & 0.0195 & 0.0175 & 0.0189 \\
18.0 & 0.0242 & 0.0212 & 0.0235 & 0.0191 & 0.0189 \\
\hline
0.20 & 6.0 & 0.0235 & 0.0216 & 0.0177 & 0.0169 & 0.0189 \\
10.0 & 0.0743 & 0.0742 & 0.0736 & 0.0735 & 0.0191 \\
14.0 & 0.0287 & 0.0273 & 0.0242 & 0.0215 & 0.0189 \\
18.0 & 0.0256 & 0.0214 & 0.0250 & 0.0189 & 0.0189 \\
\hline
\end{array}
\]
Both values agree well for the large ships over 200 m in length, while the values of ICLL 66 are smaller than those of the present method for the small ships below 200 m in length. It means that the significant wave height of 10 m is unusual severe condition for the small ships below 100 m in length. It seems that ICLL 66 has been determined to correspond to the actual sea conditions which becomes smaller as the ship length decreases. We have, therefore, evaluated the significant wave heights for the ships below 200 m in length so that the values of present method correspond to those of ICLL 66. As the result, we have obtained the wave conditions as follows:

\[
H_{1/3} = \begin{cases} 
L/13 & \text{for } 24 \text{ m} \leq L \leq 100 \text{ m} \\
10 - 2.3 \times (200 - L)/100 & \text{for } 100 \text{ m} \leq L \leq 200 \text{ m} \\
10 & \text{for } 200 \text{ m} \leq L 
\end{cases}
\]

\[(11)\]
The circle is the values obtained by applying the results of \( F_n = 0, P = 30\% \) to the wave conditions of equation (11). The values with circles almost agree with the results of ICLL 66. According to the latest wave statistics\(^{12}\), the relationship between the wave height and the wave length of equation (11) corresponds to the upper bound of occurrences of wave height with the short wave length bellow 150 m as shown in Table-5. As the result of the above consideration, we can make clear the quantitative feature of ICLL 66 formula.

In addition to that, we have gotten the wave conditions of \( H_{13} = 7 \) and 4 m with forward speed which are proposed by IMO/SLF\(^{11}\) as follows:

\[
\begin{align*}
H_{13} &= f(V) \cdot L/13(m) \\
&= f(V) \cdot 10 - 2.3 \cdot (200/L)(m) \\
&= f(V) \cdot 10(m) \\
&= 200/m \leq L
\end{align*}
\]  

The heights of bow freeboard estimated under the wave conditions of \( H_{13} = 10 \) m are shown in Fig. 6 for the parameters of deck wetness probability.

5. Comparison of Chinese Formula

China has proposed the formula of minimum bow height at the 37th SLF Sub-Committee as shown in Appendix B\(^{4}\).

The results calculated by the Chinese formula for our 67 ships are shown with the solid circles in Fig. 6. The results of Chinese formula generally agree with those of ICLL 66 and our results in the range of ship length larger than 175 m, while they give larger values for smaller ship than 150 m in length. Thereby the Chinese formula seems to intend to give the higher bow freeboard for small ships.

6. Characteristic of Present and Future Work

6.1 Characteristic of Present Method

The response characteristics have been obtained for the relative bow motion in waves based on the strip theory, and the new regression equation has been introduced to evaluate the height of the relative bow motion in irregular waves. The expression contains explicitly various parameters indicating the ship's principal particulars and the hull form features. By using this expression, the relation between the bow freeboard height and the deck wetness probability can be evaluated by multiplying the non-dimensional amplitude of relative bow motion and the critical wave height or the significant wave height. Therefore this regression equa-

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**Table-5 Wave Climatology of the Winter Seasonal Zone of the North Pacific Ocean according to Hindcast Data**

<table>
<thead>
<tr>
<th>AREA</th>
<th>MEAN OF WAVE HEIGHT</th>
<th>MEAN OF WAVE PERIOD</th>
<th>MEAN OF MEAN WAVE PERIOD</th>
<th>TOTAL</th>
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</thead>
<tbody>
<tr>
<td>14. 75</td>
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<td></td>
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<tr>
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<td>0 0 0 0 0 0 0 0 1 19 197 222</td>
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</tr>
</tbody>
</table>

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\( f(V) = 1.0 : V = 0 \)
\( f(V) = 0.7 : V = 60\% \) of ship speed
\( f(V) = 0.4 : V = 90\% \) of ship speed

The heights of bow freeboard estimated under the wave conditions of \( H_{13} = 10 \) m are shown in Fig. 6 for the parameters of deck wetness probability.
tion can be easily apply to any sea area to estimate the necessary bow freeboard height as the function of the probability of deck wetness.

6.2 Future Work

The probability of the deck wetness and the increment of apparent slip ratio have been the important criteria with which the captain determines to reduce the ship speed and/or to change her course for safe navigation\(^{19}\). The height of bow freeboard is, therefore, important. We have estimated the height of bow freeboard of the deck wetness probability \(P=5, 10, 20, 30, 40, 50\%\) under the significant wave height \(H_{1/3}\) this time, but we have not considered which probability of shipping water is allowable.

According to the existing studies, the U.S.A. has indicated that the deck wetness in head seas \((H_{1/3}=10\ \text{m})\) to be about 100 green water deck loads of greater than 1 m at the bow per hour for range of ships between 100 and 180 m in length\(^{19}\). The other studies have recommended 10 deck wetness per hour\(^{14,15}\). Furthermore, the captain has used 6 deck wetnesses per hour as the criterion to decrease the ship speed in rough seas\(^{19}\). Assuming the mean period of the vertical bow motion is 10 sec., the probability of the deck wetness corresponds to \(P=27.8\%\) for the former case, \(P=2.8\%\) for the latter case and \(P=1.7\%\) for the captain. We have to keep the study to make clear which probability is the best situation both for the safe navigation and the safety of ship structure.

In the SLF Sub-Committee’s study, the significant wave height of \(H_{1/3}=10\ \text{m}\) is assumed for evaluating the height of bow freeboard\(^{11}\). However, this value corresponds to the sea state of Beaufort scale 10 which is a very severe condition as shown in Table-6\(^{16}\). According to the operating manual for a large vessel\(^{19}\), the captain pays his attention to navigate the ship around the sea state of Beaufort scale 7. It will be, therefore, necessary to understand the critical condition and define the wave steepness for bow freeboard determination in future. The wave statistics data of the main sea area worldwide should be studied in particular.

7. Conclusion

We have proposed the new regression equation for estimating the height of bow freeboard which contains explicitly the various parameters indicating the ship’s principal particulars and hull form features. Then we have assessed ICLL 66 and the Chinese formula by comparing with the result of the present method. The main conclusions obtained in this study can be summarized as follows:

Table-6 Beauford Scale and Significant Wave Height

<table>
<thead>
<tr>
<th>Beaufort scale</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind velocity (U_w) (mean value)</td>
<td>4.5 m/s</td>
<td>6.8 m/s</td>
<td>9.4 m/s</td>
<td>12.4 m/s</td>
<td>15.6 m/s</td>
<td>19.0 m/s</td>
<td>22.7 m/s</td>
<td>26.5 m/s</td>
</tr>
<tr>
<td>Wave height (H_{1/3})</td>
<td>0.6 m</td>
<td>1 m</td>
<td>2 m</td>
<td>3 m</td>
<td>4 m</td>
<td>5.5 m</td>
<td>7 m</td>
<td>9 m</td>
</tr>
<tr>
<td>Wave period (T_{m})</td>
<td>3.0 sec</td>
<td>3.9 sec</td>
<td>5.5 sec</td>
<td>6.7 sec</td>
<td>7.7 sec</td>
<td>9.1 sec</td>
<td>10.2 sec</td>
<td>11.6 sec</td>
</tr>
</tbody>
</table>

\* from WMO (World Meteorological Organization) code 1100

\*\* \(T_{m}=3.86 \sqrt{H_{1/3}}\) (by Pierson-Moskowitz)
The height of the bow freeboard has the largest value in the significant wave height of 10 m and \( F_n = 0 \) among the IMO/GLF Sub-committee’s condition for comparative calculation. Therefore, it is enough for evaluating the case of the zero ship speed.

The results of the Chinese formula and ICLL 66 generally agree in the range of larger ship length than 175 m, while the bow freeboard of the Chinese formula is larger than those of ICLL 66 for the smaller ships below 150 m in length.

The height of the bow freeboard due to ICLL 66 is nearly equal to the calculated values with the deck wetness probability of \( P = 30\% \), provided that the significant wave height of 10 m is adjusted by the ship length for smaller ships according to the wave climatology.

The effect of the ship speed on the relative bow motion is small in the range of \( F_n = 0.15 - 0.25 \). It has been shown that the relative bow motion with the zero forward speed is nearly equal to 70\% of those with the forward speed.

Acknowledgement

This study has been performed as the task of the 71 Regulation Research Committee of the Shipbuilding Research Association of Japan, and the result was submitted to the 36th SLF Sub-Committee as the Japanese paper. The authors would like to express their sincere gratitude to Prof. Fujino of University of Tokyo, Chairman of the 71 Regulation Research Committee and its members for their helpful discussions. They also thank the students in the Laboratory of Ocean Space Engineering at the Dept. of Engineering Systems in Hiroshima University.

References

2) DRAFTREPORT TO THE MARITIME SAFETY COMMITTEE, SLF 37/WP. 7 (1993).
Appendix A. Calculation Condition

Calculation Condition for Ship Motion Deck Wetness Study at SLF Sub-committee/IMO (Reference is made from SLF 32/21. 1987. 9 Basic principles for a future revision of the 1966 LL Convention. 9.3)

The Sub-Committee agreed that the deck wetness and the reserve buoyancy studies for monohull ships should be concurrently, using the following agreed criteria for the ship motion deck wetness studies:

- **Sea spectra:** ITTC (2 parameter)
- **Significant wave height:** $H_s = 10$ m, 7 m, 4 m
- **Direction of waves:** Head sea only

* The studies should initially be restricted to monohull ships of all sizes within the range of application of the Convention. The ships are to be considered at slow speed or hove to in the 10 m seaway. For $H_s = 10$ m-zero speed may be used. For 7 m and 4 m, 60% and 90% full speed respectively should be used. For height of bow wave, the Tasaki formula (Reference-R, Tasaki: Society of Naval Architects of Japan—60th Anniversary Series, Vol. 8, Chapter 6.4, 1963) should be used:

$$h_s = 3/4 \cdot B/L_e \cdot L \cdot F_s^2$$

**Geometric parameters to be varied are:**

- **Block coefficient:** 0.4-0.9
- **Bow flare:** U/V criteria as per page of SLF 32/9/3
- **Ship length:** 24 m upwards
- **Froude number:** 0.1-0.4

Appendix B. Chinese Formula

A proposal on revision of minimum bow height in Regulation 39 (1) of Annex I to 1996 ICLL (SLF 37/8/1, ANNEX 1, 1992)

(1) The bow height defined as the vertical distance at the forward perpendicular between the water line corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at side shall not less than: for ships of 50 meters and below in length:

$$
\left(0.97 + 5.78 \cdot \frac{L}{100}\right) \cdot K_{cb} \cdot K_n \quad (m)
$$

for ships over 50 meters in length:

$$
\left(2.28 + 3.46 \cdot \frac{L}{100} - 0.6 \left(\frac{L}{100}\right)^2\right) \cdot K_{cb} \cdot K_n \quad (m)
$$

where: $L$ is the length of the ship in meters which is to be taken as not greater than 230 m:

- $K_{cb}$ is the coefficient for the correction of block coefficient $C_b$ to be expressed as follows:

$$K_{cb} = 2.11 - 1.51 C_b$$

- $K_n$ is the coefficient for correction of U/V shape of the forebody to be expressed as follows:

$$K_n = 1.03 - 0.03 n$$

where: $n$ is the U/V shape criterion of the forebody, to be expressed as follows:

$$n = 85.7 C_{w_f} - 75.6 C_{o_f} - 9$$

which is to be taken as not greater than 12 nor less than zero.

**where:** $C_{w_f}$ and $C_{o_f}$ are respectively the waterplane coefficient and block coefficient of the forebody at the moulded of $d_i$. 