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Evaluation of Minimum Bow Height and Freeboard Based on Probabilistic Deck-Wetness Considerations

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Abstract

The IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety is carrying out a major revision of the technical regulations of the 1966 International Convention on Load Lines. One of the main issues is to consider the minimum required bow height and freeboard, which are of importance from a safety and the economic perspective.

A procedure has been developed to evaluate minimum bow height and freeboard for conventional vessels with unrestricted service. Systematic seakeeping computations have resulted in long-term exceedance probabilities as regards deck wetness (based on relative motion analysis) for a variety of hull forms under varying operating conditions including severe weather. The objective is to establish a minimum acceptable probability level that should be satisfied by all ships. Strip theory has been applied to evaluate the relative wave elevation along the ship length from bow to stern. The mathematical model has been validated by means of extensive model tests.

The computations covered the following conditions. Systematic hull form variations have been used for Type A ships (tankers) and Type B ships (general cargo ships, including bulk carriers) and the ship size varies from small to large ($50 \text{ m} < L_{pp} < 400 \text{ m}$). Ships having lengths between 24 m and 50 m will be the subject of work in the near future. The wave conditions and the statistics are valid for the Winter North Atlantic. The computations have been carried out for 1008 ships for a range of wave directions and loading conditions (GM variations).

The following main conclusions are drawn from this work:

- The derived minimum required bow heights are governed by head sea conditions.
- Formulas have been derived to determine minimum bow height as a function of main ship parameters. Regardless of ship size and hull form the obtained minimum bow height results in the same long-term deck wetness probabilities.
- In terms of deck wetness the minimum required freeboard should not be based on head seas only; it is sensitive to wave direction (and to GM). The long-term probability for the required minimum freeboard is the same as for the minimum bow height. Reserve buoyancy aspects have not been considered in the study.

Introduction

Various countries have been involved with studies related to revision of the technical regulations of the 1966 International Convention on Load Lines (1966 ICLL). The revision process addresses a multitude of subjects: not only minimum bow height and freeboard requirements related to deck wetness are relevant, but also issues such as watertight integrity, size and location of openings, crew safety, interpretations of the regulations, harmonization with respect to other IMO instruments are important, among others. The work presented here concentrates on bow height and freeboard based on deck wetness considerations.

The flow of water on deck is highly nonlinear, as has been illustrated by Zhou, De Kat and Buchner (1999), for instance. Nevertheless, typically linear theory does well in predicting the probability of shipping water at the bow (at FPP) even in severe sea states, which is corroborated by the findings presented by Kapsenberg and De Kat (2000). In this study the linear strip theory ship motion program SEAWAY of the Delft University of Technology has been adapted and named SEAWAY-R. Journée (1997) has verified this program with extensive experimental data on vertical relative motions of a Dutch container vessel, published by Zhou, Zhou and Xie (1996).
This paper concentrates on the 1966 ICLL regulations and on results of probabilistic calculations of required minimum bow height and freeboard. Use has been made of a standard Type-B hull form design and of 13 other hull forms made available by the China Classification Society. Linear scaling of length, breadth and draught of these 14 parent hull forms resulted in 1008 different ships. These ships and the environmental conditions will be described and a short review of two different probabilistic approaches on probabilistic bow height will be given. Bow height formulas proposed recently by China, based on a probabilistic method, will be discussed. The structure of these formulas will be used to derive alternative bow height polynomials based on a general long-term probabilistic method. The values for the 1966 ICLL minimum bow height and those obtained from the newly derived polynomials will be compared.

The paper concludes with the derivation of minimum freeboard requirements based on probabilistic deck wetness considerations. The long-term probability derived for bow height definitions has been used to determine minimum freeboard values for different hull forms.

Selected Ships

Use has been made of the offsets of 13 Type A and B hull forms (made available by China) and those of a standard 1966 ICLL Type-B hull form, referred to as the "Vermeer ship" – with a block coefficient of 0.68 at a draught equal to 85 % of the depth.

The body plans of these 14 parent hull forms, with 21 equidistant stations, are given in Figure 1.

Based on an evaluation of systematically varied hull form series, in earlier IMO submissions China has defined a slenderness or UV-form parameter, n, of ships as follows:

$$n = 85.7 \cdot C_{wf} - 75.6 \cdot C_{bf} - 9.0 \qquad \text{with} : n \geq 0$$

where C_{wf} is the water plane coefficient of the fore body and C_{bf} is the block coefficient of the fore body, while the fore body of the ship is defined from $\frac{1}{2}L_{pp}$ to forward.

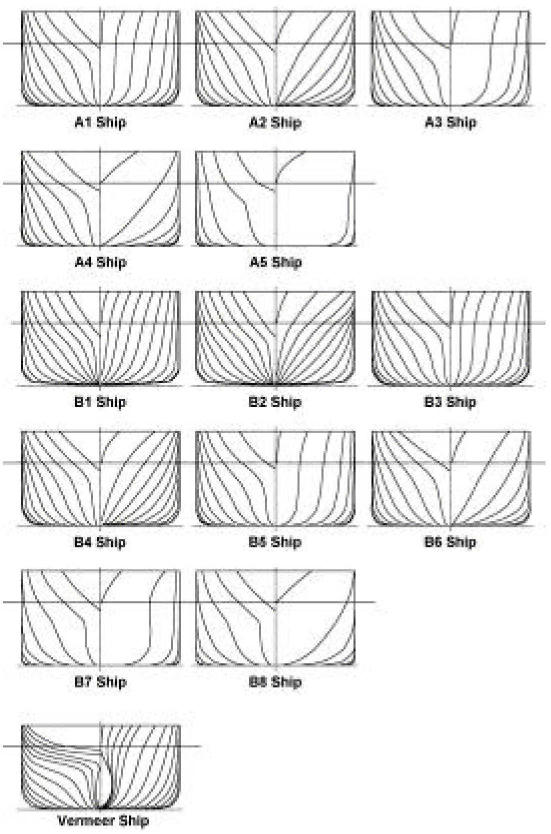


Figure 1 Body Plans of 14 Parent Hull Forms

These 14 ships cover a wide range of combinations of U and V shapes of the fore body and of block coefficients, C_b. The hull form coefficients and the UV-parameter, n, determined here from the offsets, are given in Table 1.

The UV-parameter, n, as found from the offsets of these hull form series, is given in Figure 2 as a function of the block coefficient, C_b. Also the practical boundaries of the U-forms and V-forms are given.

The radii of gyration for roll, pitch and yaw of each ship are fixed to 0.40B, 0.25L_{pp} and 0.25L_{pp}, respectively. All ships are assumed to be equipped with bilge keels extending over 30 % of the ship length with a height of 1.75 % of the ship breadth. Each of these 14 parent hull forms has been transformed linearly to principal dimensions following from all 72 combinations of the following dimensions:

- 6 ship lengths: L_{pp} = 50, 100, 150, 200, 300 and 400 m,
- 4 length over breadth ratios: L_{pp} / B = 6.0, 7.0 and 8.0 and
- 3 breadth over draught ratios: B / d = 2.50, 2.75, 3.25 and 4.00.

Ships	C_b	C_{wf}	C_{bf}	n
A1	0.70	0.754	0.711	1.9
A2	0.70	0.847	0.714	9.6
A3	0.80	0.887	0.857	2.2
A4	0.80	0.934	0.858	6.2
A5	0.90	0.962	0.952	1.5
B1	0.55	0.623	0.532	4.2
B2	0.55	0.736	0.531	13.9
B3	0.65	0.691	0.639	1.9
B4	0.65	0.797	0.639	11.0
B5	0.75	0.819	0.785	1.9
B6	0.75	0.881	0.785	7.2
B7	0.85	0.912	0.902	0.9
B8	0.85	0.954	0.903	4.5
Vermeer	0.66	0.730	0.634	5.6

Table 1 Main Hull Form Parameters

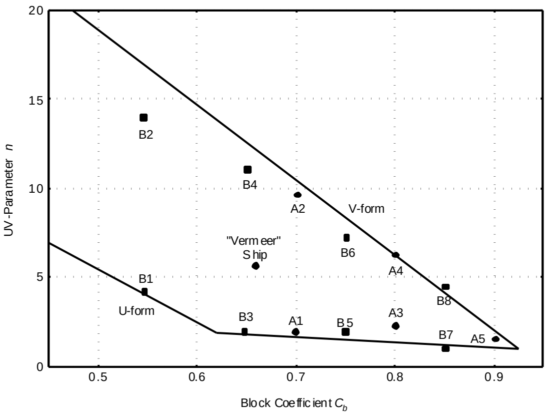


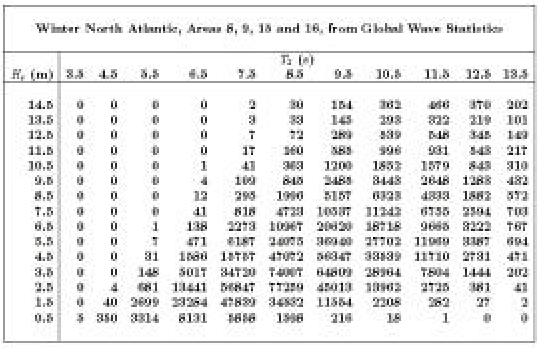
Figure 2 UV-Parameters n of 14 Parent Hull Forms

In this way a large number of 14 x 72 = 1008 different ships for studies on minimum bow height and freeboard have been created. For each of these 1008 ships, 21 equidistant stations have been considered. At each of these 21 stations the vertical relative motions have been calculated for 6 initial metacentric heights (GM = 0.025, 0.050, 0.075, 0.100, 0.150 and 0.200 times the breadth B of each ship), representing a practical variation of loading conditions.

This study has been carried out for ships with a length between 50 and 400 meters. A study for smaller vessels will be carried out in the near future.

Wave Environment

For the calculation of the vertical relative motions and the probability of deck wetness, it has been assumed that the ships are operating in weather conditions consisting of long-crested, irregular head waves, defined by Bretschneider wave spectra, in the Winter North Atlantic region. Table 2 presents the winter (months 11-1) wave scatter data of the North Atlantic (areas 8, 9, 15 and 16) provided by Global Wave Statistics [reference: BMT, 1986].



Winter North Atlantic, Areas 8, 9, 15 and 16, from Global Wave Statistics

	T_z (s)										
H_s (m)	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5
14.5	0	0	0	0	2	30	154	362	466	370	202
13.5	0	0	0	0	3	33	145	293	322	219	101
12.5	0	0	0	0	7	72	289	539	548	345	149
11.5	0	0	0	0	17	160	585	996	931	543	217
10.5	0	0	0	1	41	363	1200	1852	1579	843	310
9.5	0	0	0	4	109	845	2485	3443	2648	1283	432
8.5	0	0	0	12	295	1996	5157	6323	4833	1882	572
7.5	0	0	0	41	818	4723	10537	11242	6755	2594	703
6.5	0	0	1	138	2273	10967	20620	18718	9665	3222	767
5.5	0	0	7	471	6187	24075	36940	27702	11969	3387	694
4.5	0	0	31	1586	13787	47072	56347	33839	11710	2731	471
3.5	0	0	148	5017	34720	74007	64809	28964	7804	1444	202
2.5	0	4	681	13441	56847	77259	45013	13962	2725	381	41
1.5	0	40	2699	23264	47839	34832	11554	2208	282	27	2
0.5	5	350	3314	8131	3656	1396	216	18	1	0	0

Table 2 Winter North Atlantic Wave Scatter Diagram

13 wave directions have been considered in each of these 125 “non-zero” sea states: μ = 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165 and 180 degrees, where the direction is defined as follows: following waves is 0^{o}, from starboard incoming waves is 90^{o} and head waves is 180^{o}.

This implies that for the required minimum bow height and freeboard considerations, the vertical relative ship motions at $Fn = 0.10$ must be calculated for over 2 x 10^8 cases: 1008 ships x 21 points x 6 GM values x 125 sea states x 13 wave directions.

Previous studies by Journée, de Kat and Vermeer (2000a) have shown that the required minimum bow heights are governed by head sea conditions only. To investigate the influence of ship speed, the vertical relative motion calculations at the bow have been computed for head sea conditions with one initial metacentric height and two speeds ($Fn = 0.0$ and $Fn = 0.10$). This results in additional calculations: 1008 ships x 2 ship speeds x 125 sea states.

1966 ICLL Regulations

When using the 1966 ICLL regulations, it is assumed here that:

- the ships have no superstructure; they only have a forecastle with a length of $0.07L_{pp}$ with a standard height, see Figure 3,
- the ships have no sheer,
- the length L of the waterline at $0.85D$ is equal to $1.03L_{pp}$ and
- the freeboard is based on the summer draught.

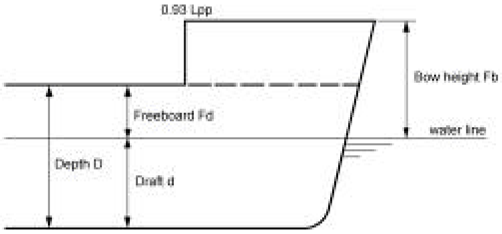


Figure 3 Definition of Bow Height and Freeboard

The tabular freeboards and standard bow heights of the 1966 ICLL are presented in Figure 4 for different ship types as a function of the ship length at 85 % of the depth, *D*.

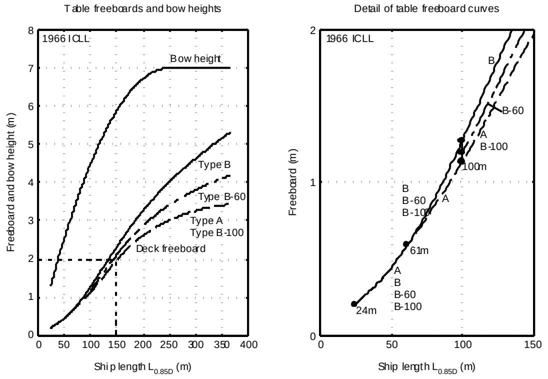


Figure 4 Table Freeboards and Standard Bow Heights

Depending on the characteristics of the ship, required corrections on these table data have to be accounted for.

Probabilistic Approaches

Linear strip theory has been used for the vertical relative motion computations. The 2-D potential coefficients have been determined by using the potential theory of Ursell and Tasai and a 10-parameter conformal mapping method. This theory has been described in the theory manual of the program SEAWAY; for more detailed information see also web site: http://dutw189.wbmt.tudelft.nl/~johan. For oblique waves, where roll motions are involved, the semi-empirical method of Ikeda, Himeno and Tanaka (1978) has been used for determining the (viscous) roll damping of the ship. The linearisation of the non-linear roll-damping coefficient has been carried out for mean regular wave amplitudes of 2.50 meters, which is equivalent to a sea state with a significant wave height $H_{1/3}$ of about 8 m.

General Long Term Probability Method

In a storm with a duration of 3 hours, a significant wave height $H_{1/3}$ and an average zero-upcrossing wave period T_2, the short-term probability on bow deck wetness P_S is given by:

$$P_S = P\{s_a > F_b\} = \exp\left(\frac{-F_b^{\ 2}}{2m_{0s}}\right)$$

where:

$P\{...\}$	probability
s_a	vertical relative motion amplitude at the bow
F_b	bow height (above still water level)
m_{0s}	zero-order moment of the vertical relative motion spectrum

This yields for the bow height F_b:

$$F_b = \sqrt{-2m_{0s} \cdot \ln(P_S)}$$

The long-term probability, P_{Lij}, follows from a multiplication of the short-term probability P_{Si} with the probability $P_{Wij} = P\{H_{1/3i}, T_{2j}\}$ on the occurrence of this sea state or storm, *ij*, in a wave scatter diagram of a certain sailing area:

$$P_{Lij} = P_{Sij} \cdot P_{Wij}$$

It is obvious that for a wave scatter diagram, with N_ixN_j sea states, the sum of the individual probabilities becomes 1.0:

$$\sum_{i=1}^{N_i} \sum_{j=1}^{N_j} P_{Wij} = 1.0$$

because all data in the wave scatter diagram have been divided by the total number of observations. The total long-term probability (LTP) on bow deck wetness P_L in this sailing area is determined by using the wave scatter diagram and summing up the N individual long term probabilities of deck wetness:

$$P_L = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} P_{Lij} = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} P_{Sij} \cdot P_{Wij}$$

In this approach the following conditions apply:

- ships with a length of 50 meters and above
- no static swell-up at the bow (bow wave)
- no “green water” on deck or a deck flooding height
- no dynamic swell-up
- head irregular long-crested waves
- the Winter North Atlantic wave scatter diagram.

The static and dynamic swell-up have been ignored; these effects are supposed to be included in P_L, the selected value of the long-term probability level. This probability can be determined now from the bow height according to the 1966 ICLL regulations for the summer season for some selected ships.

Long Term Probability Method of China

The China Classification Society has developed a methodology for the long-term prediction of the deck wetness of a ship, operating in a seaway while taking into account short-term deck wetness effects. Reference is made to the IMO documents SLF 37/8/1 and SLF 37/8/2, dated 28 September 1992. This method is based on a joint P_C-P_S probability criterion. In a sea state defined by ($H_{1/3}$,T_2), the short term probability on deck wetness P_S is defined by:

$$P_S = P\{s_a > F_b\} = \exp\left\{\frac{-(F_b - h_s)^2}{2m_{0s}}\right\}$$

or:

$$F_b = \sqrt{-2m_{0s} \cdot \ln(P_S)} + h_s$$

where F_b is the bow height and h_s is the bow wave height.

An empirical formula of Tasaki (1963), based on model experiments, is used for determining the static swell-up (or bow wave) at the forward perpendicular:

$$h_s = 0.75 \cdot B \cdot \frac{L}{L_e} \cdot Fn^2$$

with:

L	length of the ship
B	breadth of the ship
L_e	length of entrance of the water line
Fn	Froude number

Use is made of long-term ocean wave statistics, presented in a wave scatter diagram. Each number q_{ij} in this table represents the frequency of occurrence of a sea state with the parameter combination ($H_{1/3i}$,T_{2j}).

With the expression for F_b and a given constant short-term probability criterion for P_S, a minimum bow height F_{bij} can be obtained for each parameter combination ($H_{1/3i}$,T_{2j}) in plane q. When assuming a minimum bow height F_{ba}, the sum of all q_{ij}-values, satisfying the condition $F_{bij} > F_{ba}$, represents a long-term encounter probability P_C. Conversely, when a criterion for this encounter probability has been set, for instance $P_C = 0.015$, the required minimum bow height F_{ba} can be found numerically from the expression:

$$P_C = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} q_{ij} \{F_{bij} > F_{ba}\}$$

The short-term probability-criterion P_S and the encounter probability-criterion P_C for bow deck wetness have been taken as:

$$P_S = 40.0\,\% \quad \text{and} \quad P_C = 1.5\,\%$$

with the following conditions:

- forward ship speed equal to $Fn = 0.10$
- ships with a length of 24 meters and above
- a static swell-up at the bow (bow wave) according to Tasaki's formula
- no "green water" on deck or a deck flooding height
- no dynamic swell-up
- head irregular long-crested waves
- the Winter North Atlantic wave scatter diagram.

It is noted that the iteration procedure to be followed may not be a "smooth" process. An example of this iteration procedure with very small iteration steps (?F_{ba} ˜ 5 mm) is shown in Figure 5.

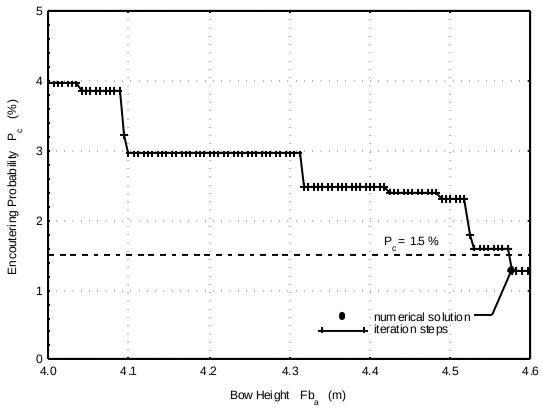


Figure 5 Iteration Behaviour for Determination of of the Probabilistic Method of China

The procedure involves assuming a given P_S-value. When calculating P_C with a given F_{ba}, a range of F_{ba}-values will give the same P_C-value. For instance, all F_{ba}'s in the range 4.10 m < F_{ba} < 4.31 m in Figure 5 will give the same P_C-value of 2.95 per cent. The condition $F_{bi,j} > F_{ba}$ is a yes/no or 1/0 condition and this results in a step function for P_C, on basis of F_{ba}, as shown in Figure 5. Problems may arise when calculating an F_{ba}-value with a given P_C-value. This problem is caused by the coarseness of the matrix of ($H_{1/3}$,T_2) in the wave scatter diagram, with relatively large increments of 1.0 m wave height and 1.0 s period. An artificially refined grid in each ($H_{1/3}$,T_2)-grid obtained by interpolation or a curve fitting routine solves this numerical problem.

Based on regression analyses of calculated bow heights obtained for these conditions, China proposed one of the next two formulas (options 1a and 1b) for required minimum bow height of ships with a length of 50 meter or more:

$$F_b = f(L)\cdot g\left(C_b, C_{bf}, C_{wf}, L/d\right)$$

$$\text{where:}$$

$$f(L) = +6.250\cdot(L/100) - 2.097\cdot(L/100)^2 + 0.242\cdot(L/100)^3$$

$$\text{and:}$$

$$g\left(C_b, C_{bf}, C_{wf}, L/d\right) = 2.133 - 0.899\cdot C_b + 1.467\cdot C_{bf} - 1.663\cdot C_{wf} - 0.115\cdot(L/d/10)$$

Equation 1, China Option 1a

or:

$$F_b = f(L)\cdot g_1(C_b)\cdot g_2\left(C_{bf}, C_{wf}\right)\cdot g_3(L/d)$$

$$\text{where:}$$

$$f(L) = +6.250\cdot(L/100) - 2.097\cdot(L/100)^2 + 0.242\cdot(L/100)^3$$

$$\text{and:}$$

$$g_1(C_b) = 1.560 - 0.820\cdot C_b$$

$$g_2\left(C_{bf}, C_{wf}\right) = 1.292 + 1.467\cdot C_{bf} - 1.663\cdot C_{wf}$$

$$g_3(L/d) = 1.230 - 0.115\cdot(L/d/10)$$

Equation 2, China Option 1b

The equations have a restriction for the maximum value of $f(L)$: if $f(L) > 6.412$ m then $f(L) = 6.412$ m. The length L in here is the ship length at 85 % of the depth. The above formulas are preliminary; with retention of the same format China has proposed recently updated formulas to IMO (see SLF 43/4/4) where the regression coefficients have been modified to some extent.

The bow heights obtained by these two formulas will be compared below with bow heights obtained by the 1966 ICLL regulations and by those of the general long-term probabilistic method.

Minimum Bow Height Calculations

A separate study indicated that the required minimum bow height is governed by head sea conditions; oblique seas result in lower probabilities of shipping water at the bow. The principal dimensions of the 14 parent hull forms (the standard Vermeer Ship, the 5 Chinese parent hull forms A1 through A5 and the 8 Chinese parent hull forms B1 through B8) have been varied as mentioned before, which resulted in 14 x 72 = 1008 different ships.

The long-term exceedance probabilities of water on deck at the FPP for all 1008 ships with the 1966 ICLL bow heights are presented in Figure 6-for zero forward ship speed ($Fn = 0.0$) as a function of the ship length, L_{pp}. The dashed line represents the mean values of these probabilities.

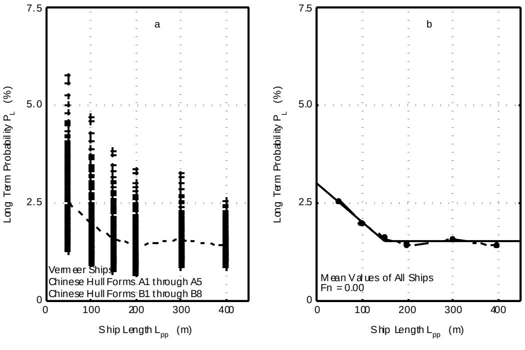


Figure 6 Long term Probabilities of 1008 Ships at Fn=0.0

Figure 6-b shows these mean values as a function of the ship length L_{pp}, which can be approximated by a simple relationship between the long-term probability P_L and the ship length L_{pp}:

$$P_L\{\text{Bow Deck Wetness}\} =$$

$$= 0.030 - 0.015 \cdot \frac{L_{pp}}{150} \quad \text{for:} \quad 50 \text{ m} \leq L_{pp} \leq 150 \text{ m}$$

$$= 0.015 \qquad \text{for:} \; 150 \text{ m} \leq L_{pp} \leq 450 \text{ m}$$

Equation 3, LTP, $Fn = 0.00$

The solid line in Figure 6-b shows this relationship. This deck wetness probability relationship could be used as the target (or reference) criterion to determine the minimum bow height for all hull forms, on the premise that *on the average* the 1966 ICLL has yielded ships with satisfactory seakeeping behaviour in terms of shipping water across the bow.

The above procedure has been repeated for a forward ship speed corresponding to $Fn = 0.10$. The (higher) long-term probabilities for all ships with minimum 1966 ICLL bow height are presented in Figure 7-a as a function of the ship length L_{pp}. The dashed line represents the mean values..

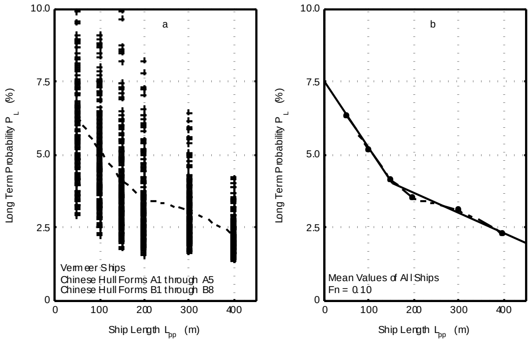


Figure 7 Long Term Probabilities of 1008 Ships at Fn=0.10

Figure 7-b shows these mean values as a function of the ship length L_{pp}, which can be approximated –as for $Fn = 0.0$ - by a simple relationship between the long-term probability P_L and the ship length L_{pp}:

$$
\begin{aligned}
P_L\{\text{Bow Deck Wetness}\} &= \\
&= 0.075 - 0.035 \cdot \frac{L_{pp}}{150} \quad \text{for:} \quad 50\ \text{m} \le L_{pp} \le 150\ \text{m} \\
&= 0.050 - 0.010 \cdot \frac{L_{pp}}{150} \quad \text{for:}\ 150\ \text{m} \le L_{pp} \le 450\ \text{m}
\end{aligned}
$$

Equation 4, LTP, *Fn* = 0.10

The solid line in Figure 7-b shows this relationship.

Subsequently, the minimum bow heights of all ships have been obtained by vertical relative bow motion calculations while satisfying the long-term probabilities P_L as given in Equation 3 and Equation 4. The computed minimum bow heights have been compared by Journée, de Kat and Vermeer (2000b) with the 1966 ICLL bow heights for all ships. The comparisons show on average a good agreement of LTP and 1966 ICLL bow heights, with a maximum deviation of a particular ship of about 1 m for *Fn* = 0.0 and about 2 m for *Fn* = 0.10. These deviations include the effect of hull form on the minimum bow height. A typical example is given here in Figure 8 for the Vermeer ships.

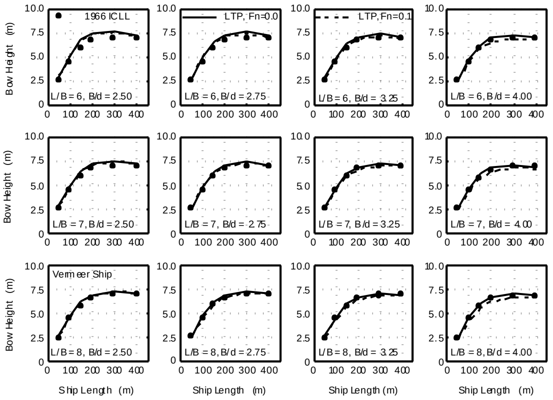


Figure 8 LTP Bow Heights at Fn=0.00 and Fn=0.10 for Vermeer ships

The structure of the options 1a and 1b of the formulas proposed by China have been used to derive bow height polynomials, while basing the coefficients on the bow heights obtained by the general long-term probabilistic (LTP) method. This has been done for the *Fn* = 0.0 case.

$$
\begin{aligned}
& F_b = f(L) \cdot g\left(C_b, C_{bf}, C_{wf}, L/d\right) \\
& \text{where:} \\
& f(L) = +6.325 \cdot (L/100) - 1.683 \cdot (L/100)^2 \\
& \qquad + 0.142 \cdot (L/100)^3 \\
& \text{and:} \\
& g\left(C_b, C_{bf}, C_{wf}, L/d\right) = 1.809 + 0.448 \cdot C_b \\
& \quad -0.008 \cdot C_{bf} - 1.378 \cdot C_{wf} - 0.052 \cdot (L/d/10)
\end{aligned}
$$

Equation 5, LTP Option 1a

or:

$$
\begin{aligned}
& F_b = f(L) \cdot g_1(C_b) \cdot g_2\left(C_{bf}, C_{wf}\right) \cdot g_3(L/d) \\
& \text{where:} \\
& f(L) = +6.338 \cdot (L/100) - 1.686 \cdot (L/100)^2 \\
& \qquad + 0.142 \cdot (L/100)^3 \\
& \text{and:} \\
& g_1(C_b) = 1.510 - 0.820 \cdot C_b \\
& g_2\left(C_{bf}, C_{wf}\right) = 1.455 + 1.062 \cdot C_{bf} - 1.528 \cdot C_{wf} \\
& g_3(L/d) = 1.097 - 0.057 \cdot (L/d/10)
\end{aligned}
$$

Equation 6, LTP Option 1b

The length *L* in here is the ship length at 85 % of the depth. In contradiction with the work done by China, no restrictions for the maximum value of *f(L)* are present here, due to numerical limits of the Least Squares Method used. It is remarkable that the influence of C_{bf} is very small in Option 1a, while it is significant in Option 1b.

A comparison between Equations 1 and 2 (1a and 1b of the typical long-term probability method of China), Equations 5 and 6 (1a and 1b, based on the general long-term probability method) and the 1966 ICLL bow heights are given in a report by Journée, de Kat and Vermeer (2000b). This report, which contains the graphs for all ships, can be found on the Internet. Figure 9 and Figure 10 show an example of these graphs for the Vermeer Ships.

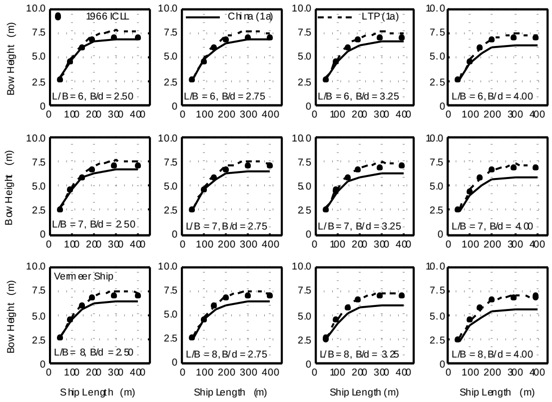


Figure 9 Comparison of 1966 ICLL and Option 1a Chinese and LTP Bow Heights of Vermeer Ships

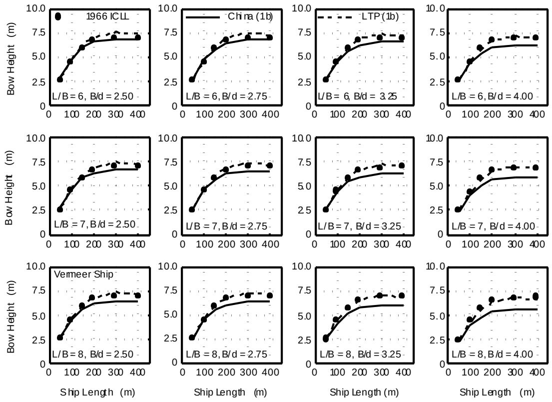


Figure 10 Comparison of 1966 ICLL and Option 1b Polynomial-based Bow Heights of Vermeer Ships

These graphs show that the LTP-based polynomials provide a slightly better fit of the 1966 ICLL bow heights. Options 1a and 1b give similar results. For the Vermeer ships the difference between the 1966 ICLL bow heights and computed bow heights is small; one would expect this, because it concerns the "standard" ICLL parent hull form. To illustrate the outcome for a full-bodied ship (such as a bulk carrier), Figure 11 shows the same type of curves for the B7 ship series.

Also for the full-bodied ships, bow heights determined according to the LTP-based formula are in rather close agreement with the 1966 ICLL values, except for vessels with combined L/B > 6 and B/d > 3.25.

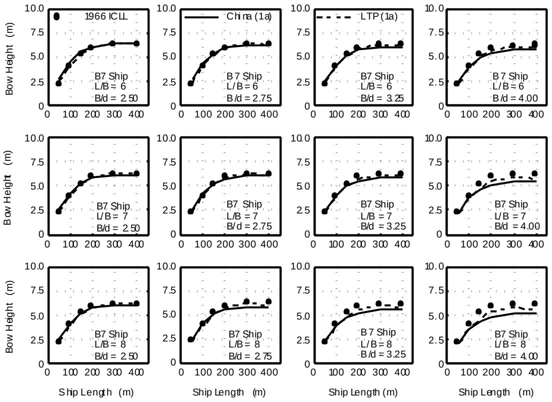


Figure 11 Comparison of 1966 ICLL and Option 1a Polynomial-based Bow Heights of B7 Ships

Option 1b gives very similar results. It is debatable whether or not to allow the bow height for L > 300 m to decrease slightly; one could require bow heights to remain constant (at the level for L = 300 m) for ships with L > 300 m.

Minimum Freeboard Calculations

The long-term probabilities for bow heights as given for *Fn* = 0.10 in Equation 4 have been used now to determine the required freeboards of the 1008 ships too. In total 21 locations on each ship have been considered, equally distributed along the ship length. At each of these points, the vertical relative motions at *Fn* = 0.10 have been calculated for the 78 combinations of:

- 13 wave directions: μ = 0, 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165 and 180 degrees from astern
- 6 initial metacentric heights: *GM* = 0.025, 0.050, 0.075, 0.100, 0.150 and 0.200 times the breadth *B* of each ship.

Together with the long-term probabilities and the Winter North Atlantic wave scatter diagram, 78 freeboard values have been calculated for each location on the ship.

For all ships, the extreme values in each point have been plotted along the ship length. These graphs are given in a report by Journée, de Kat and Vermeer (2000c), which can be found on the Internet.

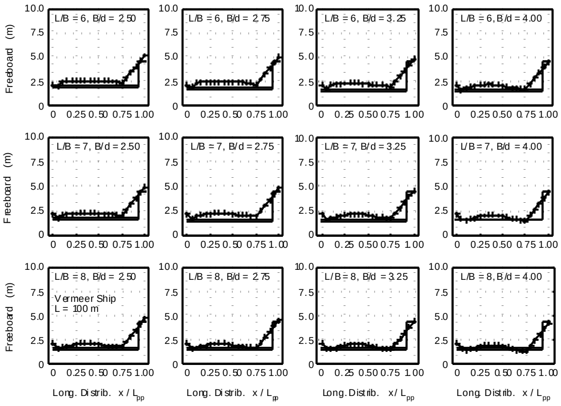


Figure 12 Freeboard Distribution of Vermeer Ships with L = 100 m

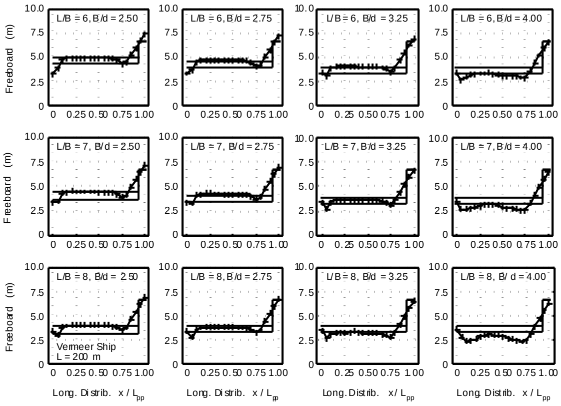


Figure 13 Freeboard Distribution of Vermeer Ships with L = 200 m

Figure 12 and Figure 13 show two examples of these graphs for the 100 and 200 meters length Vermeer Ships, with the following lines and curves:

- the 1966 ICLL bow height forward 0.93 L_{pp},
- the 1966 ICLL freeboard distribution for Type A ships (lower line) and for Type B ships (upper line) and
- the probabilistic freeboard distribution according to the highest vertical relative motion within the 78 μ-GM combinations in each cross section.

each for three L/B and four B/d ratios.

All curves of these 1008 ships have the same ship-length-depending long-term probability relation of exceeding the freeboard by the vertical relative motions in the Winter North Atlantic.

Generally, the probabilistic freeboard is higher than the 1966 ICLL freeboard for smaller ships and the opposite is the case for larger ships.

Conclusions

A study on required minimum bow heights and freeboards has been carried out for 1008 ships (14 parent hull forms, each with 72 different principal dimensions, and ship lengths between 50 m and 400 m) operating in seas defined by the Winter North Atlantic climate with and without forward ship speed.

The following conclusions can be drawn from this work for ships exceeding 50 m in length.

- ❑ Bow height:
  - The required minimum bow heights are governed by head sea conditions only.
  - For conventional ships with non-extreme hull forms, the 1966 ICLL minimum bow heights result in consistent long-term probabilities of exceeding this bow height in terms of vertical relative motions.
  - The bow heights obtained by both long-term probability methods (LTP and China) can be fit very well by the format used in the bow height formulas of China.
  - On the average, the LTP bow height polynomials are somewhat closer to the ICLL bow heights than the bow heights obtained by the formulas of China.
  - The proposed LTP polynomial formula provides a good fit of the LTP results.

  - For a large variety of conventional ships the LTP polynomial results for bow height are quite close to the 1966 ICLL minimum bow height values.
- Freeboard:
  - The long-term probabilities of the bow heights found for $Fn = 0.10$ in Equation 4 are suitable for determining the required minimum freeboard.
  - For smaller ships (50 m $< L_{pp} <$ 150 m), the probabilistic freeboards abaft about $0.80L_{pp}$ are generally equal to or somewhat higher than the 1966 ICLL freeboards.
  - For larger ships ($L_{pp} >$ 150 m), these probabilistic freeboards are generally equal to or somewhat smaller than the 1966 ICLL freeboards.
  - The probabilistic freeboards forward about $0.80L_{pp}$ are generally higher than the 1966 ICLL freeboards. They increase strongly from this location to forward.

An additional study on required minimum bow height and freeboard of small vessels (24 m $= L =$ 50 m) will be carried out in the near future.

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