Joint Development of a Bow Height Formula by China and the Netherlands Based on Probabilistic Deck Wetness Analysis

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Report No. 1270-P, DUT July 2001

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Prepared for: IMO / SLF, Load Line Working Group, September 2001 Meeting, London, U.K.

Commissioned by: Directoraat-Generaal Goederenvervoer, P.O. Box 5817, 2280 HV Rijswijk. (Public Release)

Last revision: 06-07-2001

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Summary

On behalf of the "Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety" of the "International Maritime Organization" studies, related to a revision of the technical regulations of the 1966 International Convention on Load Lines, have been carried in several countries. This joint study of China and the Netherlands concentrates on bow heights.

Bow height calculations have been carried out in China for the "standard slender ship form" with C_b *(d)* = 0.65 and C_b *(d₁)* = 0.68, and the "standard full bodied ship form" with C_b *(d)* = 0.80 and other 336 different ship forms linear scaling of length, breadth and draught of 13 parent ship forms covering a wide range of slenderness parameters. In term of polynomial form:

$$F_b = F(L/100) \cdot G(C_b, C_{bf}, C_w, C_{wf}, L/d)$$

bow height formulas have been obtained from regression analyses for data calculated joint probability criteria on deck wetness at bow in the Winter North Atlantic of these ship forms.

Bow height calculations have been carried out in the Netherlands for the "standard" 1966 ICLL Vermeer parent ship ($C_b = 0.68$ at $d = 0.85 \cdot D$), 13 other parent ships (covering a wide range of slenderness parameters) and a parent rectangular pontoon. Linear scaling of length, breadth and draught of these 15 parent hull forms resulted in 1980 different ships. Bow height formulas have been obtained from calculated long-term probabilities on bow deck wetness in the Winter North Atlantic of these ships, using a similar polynomial form as proposed by China.

Finally, the results of both individual studies have been combined in a jointly proposed new formula for required minimum bow heights.

Contents

1 Introduction

On behalf of the "Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety' (SLF)" of the "International Maritime Organization (IMO)" studies, related to a revision of the technical regulations of the 1966 International Convention on Load Lines (1966 ICLL), are carried in several countries. The results of these studies were presented and discussed at Technical Progress Meetings, held at Wageningen in 1996, Shanghai in 1997, London in 1998, Gdansk in 1998, Washington in 2000, London in 2000 and Alameda in 2001.

The contributions of China to this study have been given in technical reports of China Classification Society (CCS) and China Ship Scientific Research Center (CSSRC) by Zhu Yonge, Chen Guoquan, Zhou Zhengquan, Lu Deming and Zhang Gaofeng (1996, 1997, 1998, 2000 and 2001).

The Dutch contributions to this study have been given in technical reports by Journée, de Kat and Vermeer (1997a, 1997b, 1998, 2000a, 2000b, 2000c and 2001), obtainable from web site http://shipmotions.nl or http://dutw189.wbmt.tudelft.nl/~johan.

This joint report of China and the Netherlands concentrates on bow height regulations and probabilistic calculations on required minimum bow heights.

In the contributions of China to this study, a new program named JPCM-FBS of CCS was developed for reviewing freeboards of 1966 ICLL based on the linear strip-theory ship motion computer program SHIPMOTION. The results of vertical relative motions of this program were compared with other Members' results of research in LL Working Group of SLF Sub-Committee of IMO and verified with data of seakeeping model test of Flokstra ship carried out at CSSRC by Zhou, Zhou and Xie in 1996.

In the Dutch contributions to this study, the linear strip-theory ship motions computer program SEAWAY of the Delft University of Technology was a basis for the creation of a new program, named SEAWAY-R. This program compares the results of research on load lines carried out in Japan, Germany, China and the Netherlands, respectively. Also, the rules of the 1966 International Convention on Load Lines (1966 ICLL) have been incorporated in this program. Journée (1997) has verified the program with experimental data on vertical relative motions of a Dutch container vessel, as determined by Zhou, Zhou and Xie (1996) in China.

Use has been made of the standard 1966 ICLL Vermeer ship, 13 parent ships made available by the Shanghai Rules and Research Institute in China and a rectangular pontoon. Linear scaling of length, breadth and draught of these 15 parent hull forms resulted in 1980 different ships, varying in length from 24 to 500 meters and sailing in head irregular seas defined by the Winter North Atlantic wave climate. Average length-depending long-term probabilities on deck wetness of the standard ICLL Vermeer ships ($C_b = 0.68$ at $d = 0.85 \cdot D$), fulfilling the 1966 ICLL bow height regulations, have been determined. These average long-term probabilities have been used for each individual other ship to calculate its bow height. Finally, a regression analysis has been used to obtain bow height formulas, taking some geometry parameters of the ship's hull form into account.

2 Parent Hull Forms and ICLL 1966 Regulations

Based on Vosser's study, it is clear that the influence of forebody section shape on the ship's behaviour in a seaway is great.
The following expression could be better to represent the U/V degree of section shape of the forebody for conventional ships:

$$n = 85.7\,C_{wf} - 75.6\,C_{bf} - 9.0$$

where C_{wf} and C_{bf} are the water plane coefficient and block coefficient of the forebody at the draught d. In absence of data for C_{wf} and C_{bf}, the following approximate formulas may be used:

$$C_{wf} = C_w + 2.1\,L_{CF} \quad \text{and} \quad C_{bf} = C_b + 2.1\,L_{CB}$$

Where C_w and C_b are the water plane area coefficient and block coefficient at the draught d, and L_{CF} and L_{CB} are the longitudinal centers of flotation and buoyancy forward of amidships at the draught d in ratio of the length L_{PP}, positive if forward of amidships and negative if abaft of amidships.

The Shanghai Rules and Research Institute have 13 parent ships been made available. Offsets of these Chinese parent hull forms, those of the standard 1966 ICLL Vermeer ship (with block coefficient 0.68 at a draught equal to 85 % of the depth) and a rectangular pontoon have been used here.

For making the systematic calculations of bow heights, 13 parent ships were designed as follows:

- Group A (5 ships):
  - Ship A1 and A2 — with $C_b = 0.7$, extreme U and extreme V
  - Ship A3 and A4 — with $C_b = 0.8$, extreme U and extreme V
  - Ship A5 — with $C_b = 0.9$, extreme U
- Group B (8 ships):
  - Ship B1 and B2 — with $C_b = 0.55$, extreme U and extreme V
  - Ship B3 and B4 — with $C_b = 0.65$, extreme U and extreme V
  - Ship B5 and B6 — with $C_b = 0.75$, extreme U and extreme V
  - Ship B7 and B8 — with $C_b = 0.85$, extreme U and extreme V

The body plans of these parent hull forms are given in Figure 1. These ships cover a wide range of combinations of U and V shapes of the fore body and of block coefficients, C_b, as given in Figure 2.

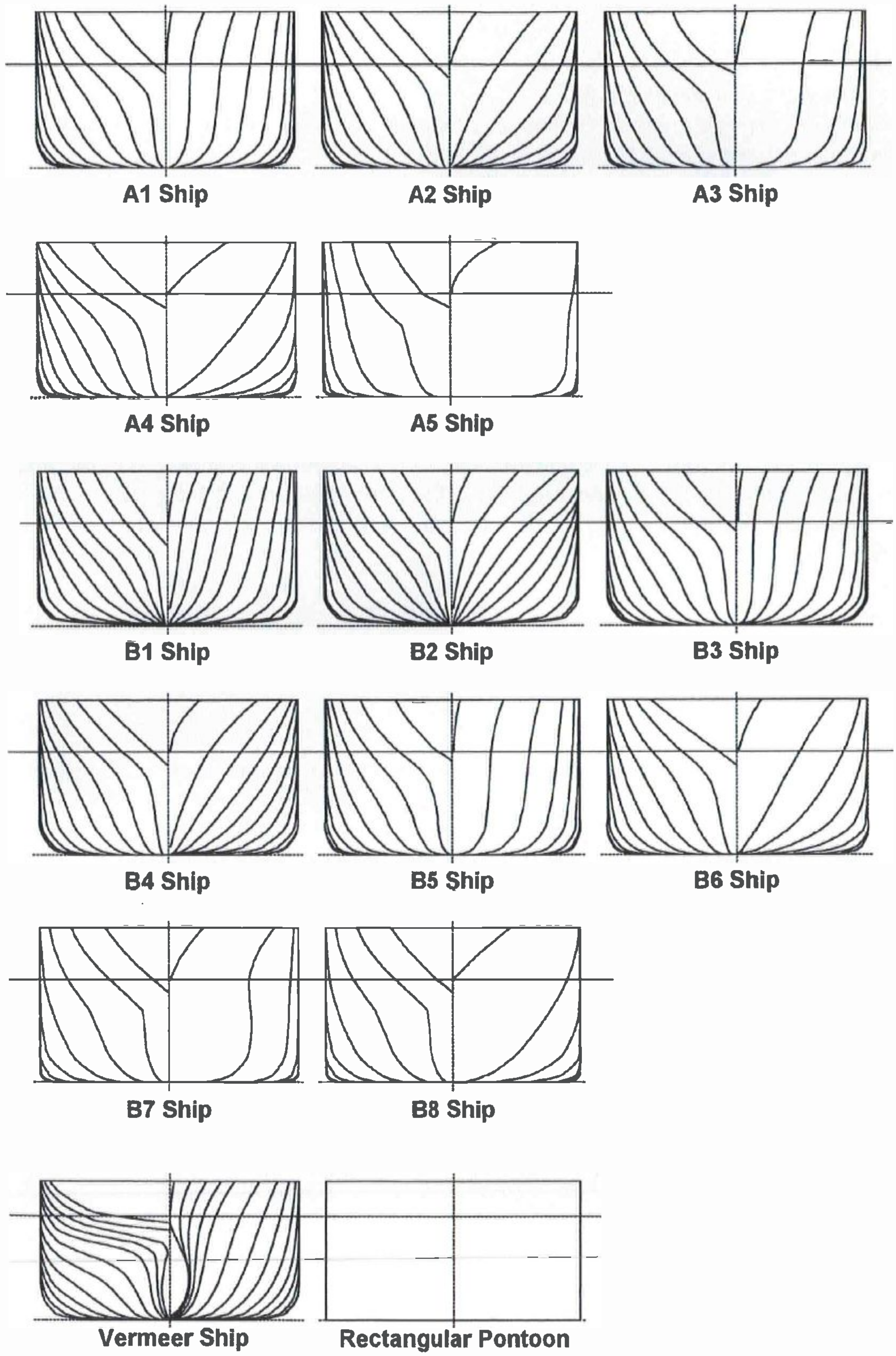

Figure 1 Body Plans of 15 Parent Hull Forms

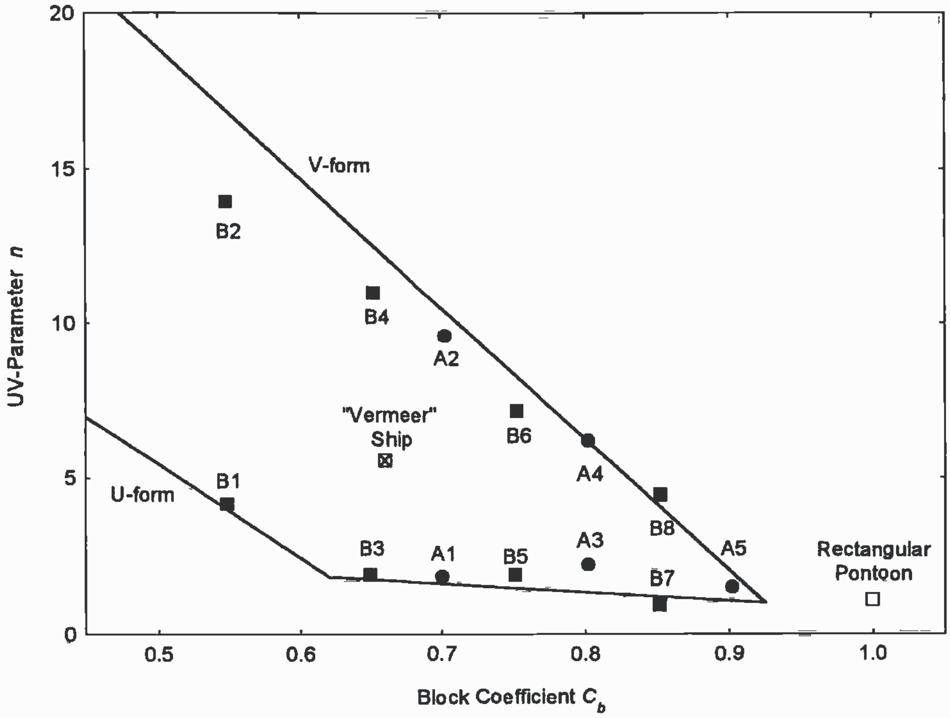

Figure 2 U-V Parameters of 15 Parent Hull Forms

The required minimum bow height is given in Paragraph (1) of Regulation 39 of the International Convention on Load Lines, 1966 as:

The minimum bow height, defined as the vertical distance at the forward perpendicular between the waterline corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at the side, shall not be less than:

- for ships below 250 meters in length:

$$H_b = 0.056 \cdot L \cdot \left(1 - \frac{L}{500}\right) \cdot \frac{1.36}{C_b + 0.68} \text{ meter}$$

- for ships of 250 meters and above in length:

$$H_b = 7.0 \cdot \frac{1.36}{C_b + 0.68} \text{ meter}$$

where: L is the length of the ship in meters,
C_b is the block coefficient, which is to be taken as not less than 0.68 and
H_b as defined in Figure 3.

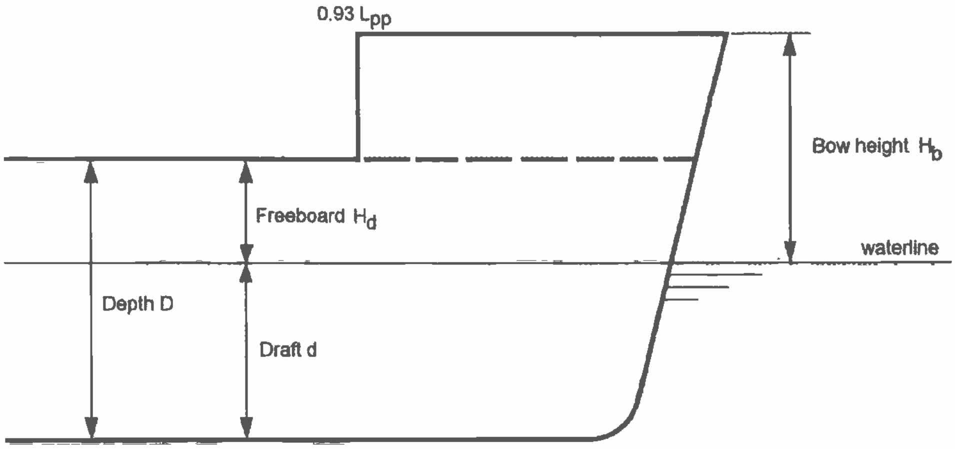

Figure 3 Definition of Bow Height

For a "standard" 1966-ICLL ship ($C_b = 0.68$), called here the Vermeer ship, the ship length dependency of the bow height is visualized in Figure 4.

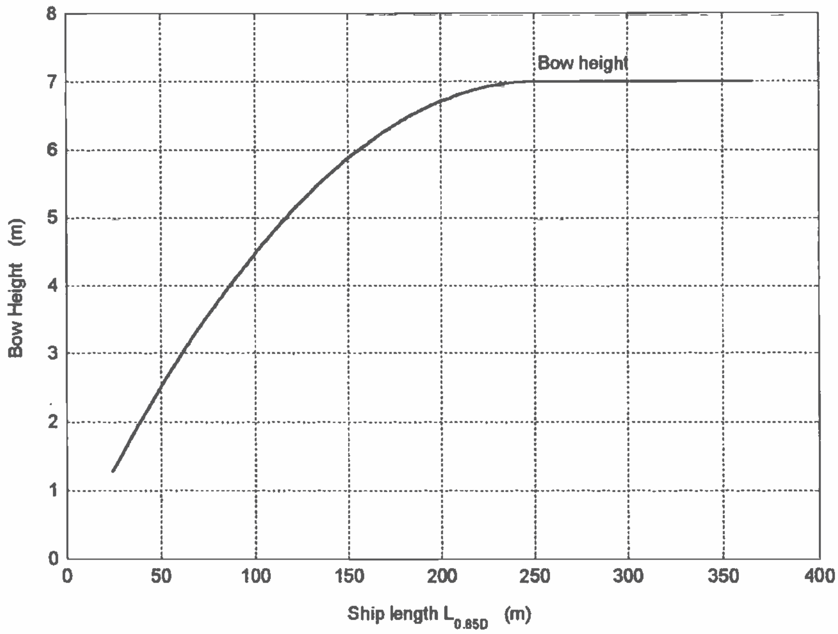

Figure 4 Length Dependency of Required Minimum Bow Height of Standard Ship

3 Probabilistic Method of China

This Chapter describes the probabilistic method, used by China, for determining the required minimum bow heights of ships exceeding 24 meters in length.

3.1 Ships and Environment

Each of 5 parent ships of Group A has been transformed linearly to 16 ships with parameters as follows:

$$L_{PP}/T = L_{PP}/B * B/T = 6\times2.50,\ 6\times2.75,\ 6\times3.25,\ 6\times4.00$$

and

$$L_{PP} = 80\text{ m},\ 150\text{ m},\ 250\text{ m},\ 350\text{ m}$$

Each of 8 parent ships of Group B has been transformed linearly to 32 ships with parameters as follows:

$$L_{PP}/T = L_{PP}/B * B/T = 7\times2.50,\ 7\times2.75,\ 7\times3.25,\ 7\times4.00$$

and

$$L_{PP} = 24\text{ m},\ 50\text{ m},\ 75\text{ m},\ 100\text{ m},\ 150\text{ m},\ 200\text{ m},\ 300\text{ m},\ 400\text{ m}$$

Using 13 parent ships 336 ship forms were resulted.

In addition, a "standard slender ship form" with L_{PP} = 150 m, C_b = 0.65, and n = 6.6 (middle V shape) and a "standard full bodied ship form" with L_{PP} = 200 m, C_b = 0.80, and n = 2.1 (U shape) were designed for check and regression of data of bow height of 336 ships above.

12 ships from the "standard slender ship form" were resulted:

$$L_{PP}/B = 5.5,\ 6.5,\ 7.5,\ 8.5$$

and

$$B/T = 2.50,\ 2.75,\ 3.00$$

12 ships from the "standard full bodied ship form" were resulted:

$$L_{PP}/B = 5.0,\ 5.5,\ 6.0,\ 6.5$$

and

$$B/T = 2.50,\ 3.00,\ 3.50$$

For making the systematic calculation of bow height, the details of process are given as follows:

INPUT	MEANS	OUTPUT
Wave Direction of Head Seas		
Speed Corresponding to Fn = 0.1	Linear Strip Theory for	
ITTC Wave Spectrum with Two Parameters	Calculation of Relative Motions	
North Atlantic Winter Wave Statistics (Zone of No. 8,9,15,16)	and	
Probability Criteria Pc=0.015, Ps=0.4	Ps-Pc Joint Probability Criteria	Bow Height
Hull Form	Method	
Height of Green Water above Deck: Hw = 0 m		
Static Swell-up of Tasaki Formula		
No dynamic swell-up		
Head irregular long-crested waves		

where the wave statistics of North Atlantic Winter were obtained from combination of wave data of zones of No. 8, 9, 15, and 16 (N. Hogben , 1986) as follows:

$H_{1/3}$(m)	Tz (s)											
	4.5	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**
12.5	0000	0000	0000	0000	0000	0025	0050	0075	0000	0000	0000	0000
11.5	0000	0000	0000	0000	0000	0050	0100	0100	0075	0000	0000	0000
10.5	0000	0000	0000	0000	0025	0125	0175	0175	0100	0025	0000	0000
9.5	0000	0000	0000	0000	0100	0250	0325	0275	0125	0045	0020	0010
8.5	0000	0000	0000	0000	0200	0525	0625	0425	0175	0070	0025	0005
7.5	0000	0000	0000	0100	0475	1050	1150	0700	0275	0090	0010	0000
6.5	0000	0000	0000	0250	1100	2050	1875	0975	0300	0080	0020	0000
5.5	0000	0000	0050	0650	2425	3725	2800	1225	0350	0080	0020	0000
4.5	0000	0000	0175	1600	4725	5625	3350	1175	0275	0075	0000	0000
3.5	0000	0000	0525	3475	7400	6450	2875	0800	0150	0000	0000	0000
2.5	0000	0075	1350	5700	7725	4500	1400	0275	0025	0000	0000	0000
1.5	0000	0275	2375	4775	3425	1125	0225	0025	0000	0000	0000	0000
0.5	0025	0325	0825	0600	0150	0000	0000	0000	0000	0000	0000	0000

SUM = 100000

3.2 Probabilistic Approach

The China Classification Society (CCS) has developed a typical methodology for the long-term prediction of the deck wetness of a ship, sailing in a seaway. Reference is given here 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:

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

or:

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

in which F_b is the bow height and h_s is the bow wave.

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 has been 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 an encountering probability P_C. Opposite, when a criterion for this encountering probability has been set, for instance P_C = 0.015, the required minimum bow height F_{ba} can be found numerically from the expression:

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

The short-term probability-criterion P_S and the encountering probability-criterion P_C for bow deck wetness has been determined by China as:

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

where the conditions as given in 3.1.

3.3 Probabilistic Calculations

For the Joint *Ps-Pc* Probability Criteria Method (JPCM) developed by CCS, the principal of determining probability criteria *Ps* and *Pc* is to make average level of bow height by JPCM for actual ships approximate those by the Regulation 39(1) of 1966 ICLL.

The encountering probability criterion *Pc* is taken as to equal the sum of probability of encountered heavy seas. And it is taken as 0.015 as an acceptable critical probability for normal operation of ships at seaway referring to the relevant seakeeping criteria suggested by ITTC Report.

The short-term probability *Ps* was determined based on variance analysis for data of bow height of actual ships by 1966 ICLL Regulation 39(1) and those by theory calculation with the conditions given in 3.1.

The Probability-Criterion *Ps* has been defined by the investigation of bow height of actual ships:

For 11 typical ships with:

L_{PP} = 34 m to 264 m and C_b = 0.59 to 0.83

The sum of variance $\Sigma\sigma^2$ for *Ps* = 0.2, 0.3, 0.4, and 0.5 are given as follows:

Ps	**0.2**	**0.3**	**0.4**	**0.5**
$\Sigma\sigma^2$	30.6118	9.1856	**1.1051**	2.3988

where: $\Sigma\sigma^2 = \Sigma(F_{b66i} - F_{bci})^2$

F_{b66} is the bow height of the ship by 1966 ICLL Regulation 39(1), and

F_{bc} is the bow height of the ship by theory calculation

From the above-mentioned table it is clear that the probability level of bow height by Regulation 39(1) of 1966 ICLL approximates to joint probability criteria of *Pc* = 0.015 and *Ps* = 0.4 at which a minimum $\Sigma\sigma^2$ is reached.

Therefore, the probabilistic method —*Ps-Pc* Joint Probability Criteria Method for making analysis of bow height by theory calculation for all conventional ships has been decided as follows:

Short-term Probability Criterion: *Ps* = 0.40

Encountering Probability Criterion: *Pc* = 0.015

3.4 Bow Height Polynomials

Reference to the formula in Regulation 39(1) of 1966 ICLL, the bow height has been decided to use a formula with a structure as follows:

$$F_b = F(L/100) \cdot G(C_b, C_{bf}, C_w, C_{wf}, L/d)$$

where:

$$F(L/100) = f_1 \cdot (L/100) + f_2 \cdot (L/100)^2 + f_3 \cdot (L/100)^3$$

and:

$$G(C_b, C_{bf}, C_w, C_{wf}, L/d) = g_1 + g_2 \cdot C_b + g_3 \cdot C_{bf} + g_4 \cdot C_w + g_5 \cdot C_{wf} + g_6 \cdot (L/d)$$

and where the following definitions have been used:

F_b	calculated bow height
L	$= L_{pp} =$ length between perpendiculars at Summer draught, d
B	moulded breadth
d	Summer Load Line draught at even keel condition
D	amidships depth
A_w	water plane area at draught d
∇	volume of displacement at draught d
C_b	block coefficient, determined by: $C_b = \nabla / (L_{pp} \cdot B \cdot d)$
C_{bf}	block coefficient forward of $L_{pp}/2$
C_w	water plane area coefficient, defined by: $C_w = A_w / (L_{pp} \cdot B)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$

The procedure of analysis is given as follows:

(1) Sensitive analyses of parameters including L_{PP}, C_b, n (combination of C_{bf} and C_{wf}) and L_{PP}/d based on the results of bow height of the systematic calculation.

(2) Primary regression analysis to establish the expression of bow height based on the sensitive parameters of L_{PP}, C_b, n and L_{PP}/d based on the results of systematic calculation.

(3) To define the basic expression $F(L_{PP})$ from the result of the primary regression analysis for standard ships under the condition:

$$G(C_b, C_{bf}, C_{wf}, L_{PP}/d) = 1$$

(4) Detail regression analyses to determine the coefficients in the expressions:

$$G\,(C_b, C_{bf}, C_{wf}, L_{PP}/d) = g_1 + g_2\,C_b + g_3\,C_{bf} + g_4\,C_{wf} + g_5\,L_{PP}/d$$

and

$$G\,(C_b, C_{wf}, L_{PP}/d) = g_1 + g_2\,C_b + g_4\,C_{wf} + g_5\,L_{PP}/d$$

where the standard technique was employed for the multi-parameters regression analysis.

3.4.1 Formula Based on Draught *d*

Based on regression analyses (based on draught d) of calculated bow heights, China has found the next formula for required minimum bow heights of ships with a length of 24 meter or more:

$$\boxed{F_b = F(L_{pp})\cdot G(C_b, C_{wf}, L_{pp}/d)}$$

with:

$$\boxed{F(L_{pp}) = 6.075\cdot(L_{pp}/100) - 1.875\cdot(L_{pp}/100)^2 + 0.200\cdot(L_{pp}/100)^3}$$

where in calculating $F(L_{pp})$, L_{pp} is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L_{pp}/d) = 1.876 + 0.935\cdot C_b - 1.663\cdot C_{wf} - 0.0115\cdot(L_{pp}/d)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
B	moulded breadth
d	Summer Load Line draught at even keel condition
∇	volume of displacement at Summer draught, d
A_{wf}	water plane area forward of $L_{pp}/2$ at draught d
C_b	block coefficient, defined by: $C_b = \nabla/(L_{pp}\cdot B\cdot d)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp}\cdot B/2)$

Expression $F(L_{PP})$ presents the bow height of the standard ships with V shape of forebody section and the following parameters:

$C_b = 0.68$, $C_{bf} = 0.68$, $C_{wf} = 0.7749$ and $L_{PP}/d = 19.4$

and

$G\,(C_b, C_{wf}, L_{PP}/d) = g_1 + g_2\,C_b + g_4\,C_{wf} + g_5\,L_{PP}/d$

$= 1.876 + 0.935 \times 0.68 - 1.663 \times 0.7749 - 0.0115 \times 19.4 = 1.0$

and

$n = 85.7\,C_{wf} - 75.6\,C_{bf} - 9 = 85.7 \times 0.7749 - 75.6 \times 0.68 - 9.0 = 6.0$ (see Figure 1)

3.4.2 Formula Based on Draught d_1

Based on regression analyses (based on draught d_1) of calculated bow heights, China has found the next formula for required minimum bow heights of ships with a length of 24 meter or more:

$$\boxed{F_b = F(L) \cdot G(C_b, C_{wf}, L/d_1)}$$

with:

$$\boxed{F(L) = 6.075 \cdot (L/100) - 1.875 \cdot (L/100)^2 + 0.200 \cdot (L/100)^3}$$

where in calculating $F(L)$, L is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L/d_1) = 1.954 + 1.085 \cdot C_b - 1{,}873 \cdot C_{wf} - 0{,}0146 \cdot (L/d_1)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
L	length at draught d_1 = 85 % of the depth D
B	moulded breadth
d	Summer Load Line draught at even keel condition
d_1	draught at 85 % of the depth D
D	amidships depth
∇	volume of displacement at draught d_1
A_{wf}	water plane area forward $L_{pp}/2$ at draught d_1
C_b	block coefficient, defined by: $C_b = \nabla/(L \cdot B \cdot d_1)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

Expression $F(L)$ presents the bow height of the standard ships with V shape of forebody section and the following parameters:

$$C_b = 0.68,\ C_{bf} = 0.68,\ C_{wf} = 0.7749,\ L/d_l = 16.5 \text{ and } G = 1.0$$

The comparison of bow height of standard ships of 1966 ICLL and the expression $F(L)$ is shown in Figure 5.

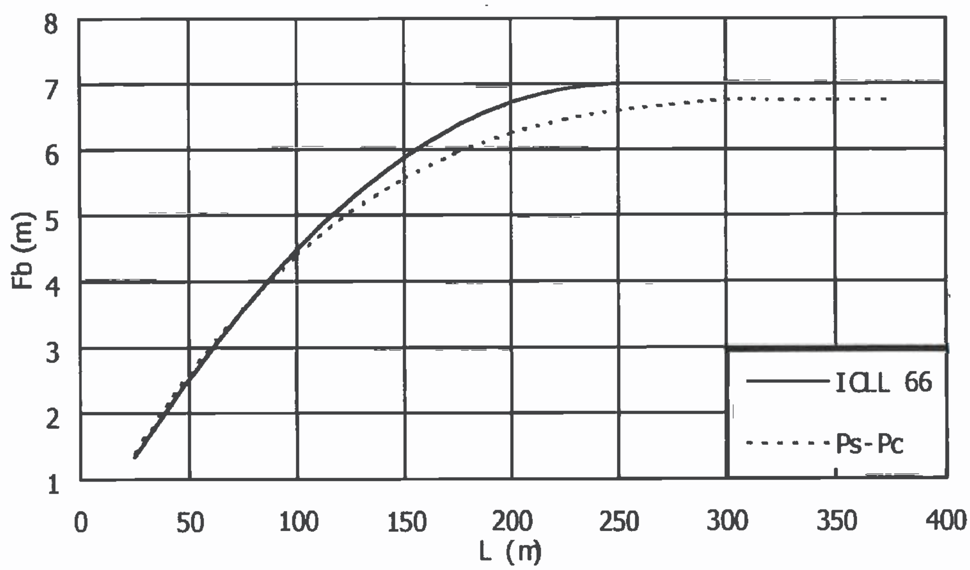

Figure 5 Length Dependency of Required Minimum Bow Height of Standard Ship

4 Probabilistic Method of the Netherlands

This Chapter describes the probabilistic method, used by the Netherlands, for determining the required minimum bow heights of ships exceeding 24 meters in length.

4.1 Ships and Environment

Each of these 15 parent hull forms has been transformed linearly to principal dimensions following from all 132 combinations of the dimensions given in Table 1 and Figure 6, which resulted in 1980 different ships.

L_{pp} (m)	24	38	50	75	100	150	200	250	300	400	500
L_{pp}/B (-)	low $3.50 < L_{pp}/B \leq 5.00$				medium $4.75 < L_{pp}/B \leq 6.25$			high $6.00 < L_{pp}/B \leq 7.50$			
B/d (-)	2.25			2.75			3.25			3.75	

Table 1 Range of Ship Dimensions

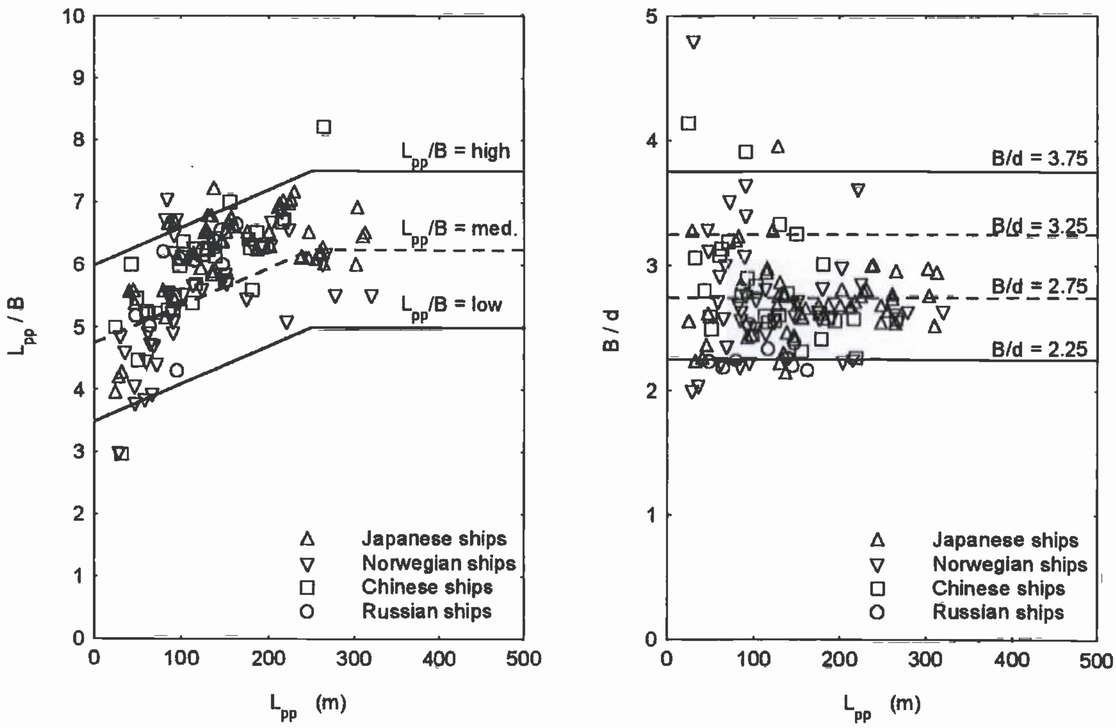

Figure 6 Length-Breadth and Breadth-Draught Ratios

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

- head waves play a significant role only,
- the ships have no superstructures; 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 $1.015L_{pp}$ (pontoon excepted) and
- the freeboard is based on the summer draught.

The radius of inertia for pitch of the solid mass of each ship is fixed to $0.25L_{pp}$.

The linear (modified) strip theory has been used for 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 detail in the theoretical manual of the strip theory program SEAWAY (see web site http://dutw189.wbmt.tudelft.nl/~johan or http://shipmotions.nl for a link to this site) which was basis for the calculations here. Bow deck wetness will be calculated from the vertical relative motions at the forward perpendicular, consisting of heave and pitch motions in undisturbed waves. It has been assumed that the ships are sailing in severe weather conditions with long-crested irregular head waves defined by ideal Bretschneider wave spectra and the Winter North Atlantic sailing area. A previous study by Journée, de Kat and Vermeer (2000a) has showed that the required minimum bow height is governed by head sea conditions.
Table 2 presents the winter (months 11-1) wave scatter data of the North Atlantic (areas 8, 9, 15 and 16) as Germanischer Lloyd has obtained it from Global Wave Statistics.

Winter North Atlantic, Areas 8, 9, 15 and 16 from Global Wave Statistics (GL)											
	T_2										
$H_{1/3}$	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	4333	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	15757	47072	56347	33539	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	23284	47839	34532	11554	2208	282	27	2
0.5	5	350	3314	8131	5858	1598	216	18	1	0	0

Table 2 Winter North Atlantic Wave Scatter Diagram

The long-term probability level, P_L, on bow deck wetness can be determined now from the short-term probability on deck wetness of the ship's bow at the forward perpendicular in head waves, a bow height according to the 1966 ICLL regulations and this wave scatter diagram. This determination will be described in the next Section.

4.2 Probabilistic Approach

In a storm defined by 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 deck wetness P_S is given by:

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

where:

$P\{...\}$	probability
s_a	vertical relative motion amplitude at the bow
m_{0s}	area of relative motion spectrum
H_b	bow height (above still water level)

This yields for the bow height: $H_b = \sqrt{-2m_{0s} \cdot \ln(P_S)}$

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

$$P_{Li} = P_{Si} \cdot P_{Wi}$$

It is obvious that for a wave scatter diagram with N sea states the sum of the N individual probabilities becomes $\sum_{i=1}^{N} P_{Wi} = 1.0$ because all data in the wave scatter diagram have been divided by its total number of observations.

The total long-term probability, LTP, on deck wetness P_L in this sailing area has been found here by using the wave scatter diagram and summing up these N individual long-term probabilities on deck wetness:

$$\boxed{P_L = \sum_{i=1}^{N} P_{Li} = \sum_{i=1}^{N} P_{Si} \cdot P_{Wi}}$$

under the following conditions:

- ships with a length between 24 and 500 meter,
- forward ship speeds corresponding to $Fn = 0.00$ and $Fn = 0.10$,
- no static swell-up at the bow (or bow wave),
- no dynamic swell-up,

- no "green water" on deck or a deck flooding height,
- head irregular long-crested waves and
- Winter North Atlantic wave scatter diagrams of Areas 8, 9, 15 and 16 of the North Atlantic Winter Season as Germanischer Lloyd has obtained it from Global Wave Statistics.

The static and dynamic swell-up have been ignored here; these effects are supposed to be included in P_L, the selected value of the long-term probability level. This probability level has been determined from bow deck wetness calculations in head waves for ships fulfilling the 1966 ICLL regulations for the summer season.

4.3 Probabilistic Calculations

All calculations have been carried here for $Fn = 0.00$ and $Fn = 0.10$ in head waves with the Winter North Atlantic wave scatter diagram.

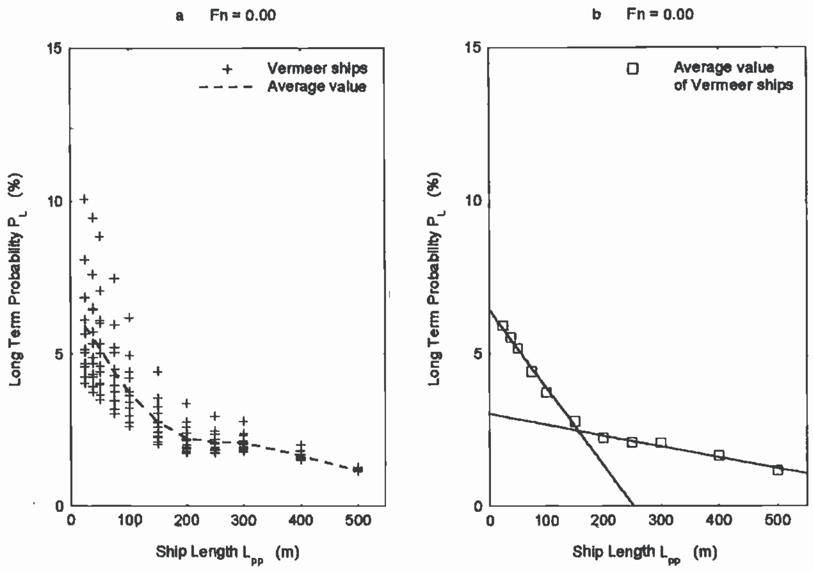

Figure 7 Long Term Probabilities of Vermeer Ships at Fn = 0.00

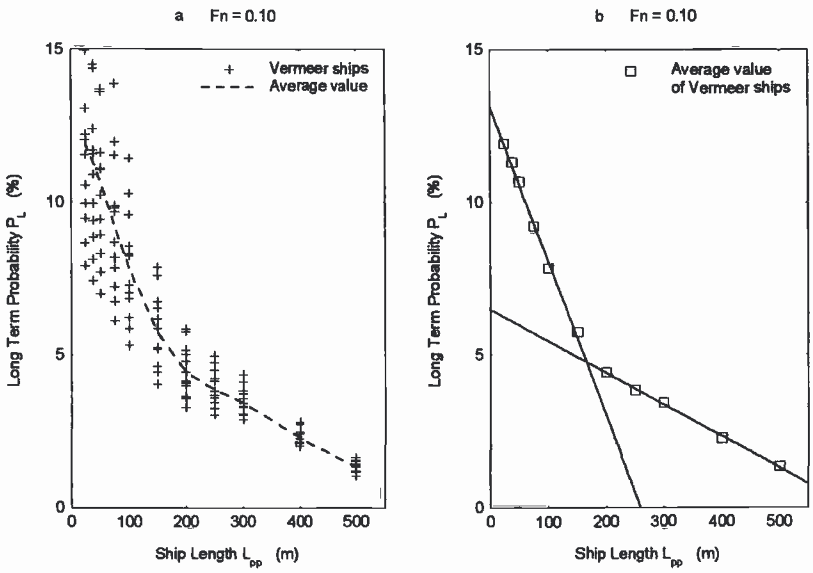

Figure 8 Long Term Probabilities of Vermeer Ships at Fn = 0.10

The long-term probabilities of exceeding the 1966 ICLL bow height by the vertical relative bow motions of all 132 Vermeer ships are presented in Figure 7-a and Figure 8-a for two Froude numbers as a function of the ship length L_{pp}. The mean value at each ship length is given in the figure too (dotted line).

Figure 7-b and Figure 8-b shows these mean values as a function of the ship length L_{pp}, separately. Based on these figures, it has been decided here to use for all ships a simple relation between the long-term probability P_L and the ship length L_{pp}:

$$Fn = 0.00: \quad P_L(\%) = \text{largest of} \begin{cases} 6.44 - 0.02540 \cdot L_{pp}(\text{m}) \\ 3.02 - 0.00356 \cdot L_{pp}(\text{m}) \end{cases}$$

$$Fn = 0.10: \quad P_L(\%) = \text{largest of} \begin{cases} 13.10 - 0.05040 \cdot L_{pp}(\text{m}) \\ 6.48 - 0.01030 \cdot L_{pp}(\text{m}) \end{cases}$$

These long-term probabilities have been used to calculate the required minimum bow heights of all ships at two forward ship speeds.

Figure 55 and Figure 56 show for all 1980 ships the bow heights obtained by this long-term probability (LTP) method (cross marks) compared with the 1966 ICLL bow heights (solid line).

Figure 57 through Figure 71 show these LTP bow heights (solid line for $Fn = 0.00$ and a dotted line for $Fn = 0.10$) compared with the 1966 ICLL bow heights (circular marks) in more detail.

4.4 Bow Height Polynomials

The average LTP bow height has been used to obtain a bow height formula with a structure as proposed by China:

$$F_b = F(L/100) \cdot G(C_b, C_{bf}, C_w, C_{wf}, L/d)$$

where:

$$F(L/100) = f_1 \cdot (L/100) + f_2 \cdot (L/100)^2 + f_3 \cdot (L/100)^3$$

and:

$$G(C_b, C_{bf}, C_w, C_{wf}, L/d) = g_1 + g_2 \cdot C_b + g_3 \cdot C_{bf} + g_4 \cdot C_w + g_5 \cdot C_{wf} + g_6 \cdot (L/d)$$

and where the following definitions have been used:

F_b	calculated bow height
L	$= L_{pp} =$ length between perpendiculars at Summer draught, d
B	moulded breadth
d	Summer Load Line draught at even keel condition
D	amidships depth
A_w	water plane area at draught d
∇	volume of displacement at draught d
C_b	block coefficient, determined by: $C_b = \nabla / (L_{pp} \cdot B \cdot d)$
C_{bf}	block coefficient forward of $L_{pp}/2$
C_w	water plane area coefficient, defined by: $C_w = A_w / (L_{pp} \cdot B)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$

The coefficients have to be determined by a dedicated least square method. The sum, S, of the squares of the deviations of the polynomial freeboards, F_{bi}, from the object freeboards, H_{bi}, has to be minimal:

$$S = \sum_{i=1}^{1848} \{[F_i(L/100) \cdot G_i(C_b, C_{bf}, C_w, C_{wf}, L/d)] - [H_{bi}]\}^2 = \text{minimal}$$

This yields that the derivatives of S to each of the coefficients f_1, f_2, f_3, g_1, g_2, g_3, g_4, g_5 and g_6 has to be zero.
The polynomial expression for the bow height has $3 + 6 = 9$ coefficients (f_1, f_2, f_3, g_1, g_2, g_3, g_4, g_5 and g_6), but a straight-forward least square method will solve $3 * 6 = 18$ coefficient-combinations (f_1g_1, f_1g_2, f_1g_3, f_1g_4, f_1g_5, f_1g_6, f_2g_1, f_2g_2, f_2g_3, f_2g_4, f_2g_5, f_2g_6, f_3g_1, f_3g_2, f_3g_3, f_3g_4, f_3g_5 and f_3g_6).

The procedure used here is as follows.

Set as starting values:

$$G_i\left(C_{bi}, C_{bfi}, C_{wi}, C_{wfi}, L_i / d_i\right) = 1.0$$

Then the sum of the squares of the deviations is:

$$S = \sum_{i=1}^{1848} \left\{ \left[f_1 \cdot (L_i / 100) + f_2 \cdot (L_i / 100)^2 + f_3 \cdot (L_i / 100)^3 \right] \cdot G_i - [H_{bi}] \right\}^2$$

$= \text{minimal}$

The derivative of this sum, S, to each of the coefficients f_1, f_2 and f_3 has to be zero:

$$\left.\begin{aligned}
\frac{\partial S}{\partial f_1} &= 2\sum_{i=1}^{1848} \left\{ \left[f_1 (L_i / 100) + f_2 (L_i / 100)^2 + f_3 (L_i / 100)^3 \right] \cdot G_i - [H_{bi}] \right\} \cdot (L_i / 100) = 0 \\
\frac{\partial S}{\partial f_1} &= 2\sum_{i=1}^{1848} \left\{ \left[f_1 (L_i / 100) + f_2 (L_i / 100)^2 + f_3 (L_i / 100)^3 \right] \cdot G_i - [H_{bi}] \right\} \cdot (L_i / 100)^2 = 0 \\
\frac{\partial S}{\partial f_1} &= 2\sum_{i=1}^{1848} \left\{ \left[f_1 (L_i / 100) + f_2 (L_i / 100)^2 + f_3 (L_i / 100)^3 \right] \cdot G_i - [H_{bi}] \right\} \cdot (L_i / 100)^3 = 0
\end{aligned}\right\}$$

The coefficients f_1, f_2 and f_3 can be solved from these 3 equations.

Now, the equations can be written as:

$$F_{bi} = F_i \cdot \left[g_1 + g_2 \cdot C_{bi} + g_3 \cdot C_{bfi} + g_4 \cdot C_{wi} + g_5 \cdot C_{wfi} + g_6 \cdot (L_i / d_i / 10) \right]$$

in which F_i is known.

Then the sum of the squares of the deviations is:

$$S = \sum_{i=1}^{1848} \left\{ F_i \cdot \left[g_1 + g_2 \cdot C_{bi} + g_3 \cdot C_{bfi} + g_4 \cdot C_{wi} + g_5 \cdot C_{wfi} + g_6 \cdot (L_i / d_i) \right] - [H_{bi}] \right\}^2$$

$= \text{minimal}$

The derivative of this sum, S, to each of the coefficients g_1, g_2, g_3, g_4, g_5 and g_6 has to be zero:

$$\left.\begin{aligned}
\frac{\partial S}{\partial g_1} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot 1.0 = 0 \\
\frac{\partial S}{\partial g_2} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot C_{bi} = 0 \\
\frac{\partial S}{\partial g_3} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot C_{bfi} = 0 \\
\frac{\partial S}{\partial g_4} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot C_{wi} = 0 \\
\frac{\partial S}{\partial g_5} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot C_{wfi} = 0 \\
\frac{\partial S}{\partial g_6} &= 2\sum_{i=1}^{1848}\left\{F_i \cdot \left[g_1 + g_2 C_{bi} + g_3 C_{bfi} + g_4 C_{wi} + g_5 C_{wfi} + g_6 (L_i / d_i)\right] - \left[H_{bi}\right]\right\} \cdot (L_i / d_i) = 0
\end{aligned}\right\}$$

The coefficients g_1, g_2, g_3, g_4, g_5 and g_6 can be solved from these 6 equations.

Then, this procedure will be repeated by a new determination of the coefficients f_1, f_2 and f_3 with the value $G_i = g_1 + g_2 \cdot C_{bi} + g_3 \cdot C_{bfi} + g_4 \cdot C_{wi} + g_5 \cdot C_{wfi} + g_6 \cdot (L_i / d_i)$, etc. The coefficients become constant in a few steps.

Coefficients f_1, f_2 , f_3, g_1, g_5 and g_6 have a very significant contribution into the bow height function, the contribution of g_2 is doubtful and the contributions of g_3 and g_4 appeared to be insignificant.

4.4.1 Formula Based on Draught *d*

The LPT bow heights at the two forward ship speeds ($Fn = 0.00$ and $Fn = 0.10$), for required minimum bow heights of all ships with a length of 24 meter or more is found by regression analysis as:

$$\boxed{F_b = F(L_{pp}) \cdot G(C_b, C_{wf}, L_{pp} / d)}$$

with:

$$\boxed{F(L_{pp}) = 6.173 \cdot (L_{pp}/100) - 2.093 \cdot (L_{pp}/100)^2 + 0.253 \cdot (L_{pp}/100)^3}$$

where in calculating $F(L_{pp})$, L_{pp} is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L_{pp}/d) = 2.143 + 0.499 \cdot C_b - 1.613 \cdot C_{wf} - 0.0093 \cdot (L_{pp}/d)}$$

where the following definitions have been used:

F_b calculated bow height

L_{pp} length between perpendiculars at Summer draught, d

B moulded breadth

d Summer Load Line draught at even keel condition

∇ volume of displacement at Summer draught, d

A_{wf} water plane area forward of $L_{pp}/2$ at draught d

C_b block coefficient, defined by: $C_b = \nabla/(L_{pp} \cdot B \cdot d)$

C_{wf} water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

Figure 72 through Figure 86 show a comparison of this polynomial expression, based on draught d, with the LTP bow heights.

4.4.2 Formula Based on Draught d_1

The average LTP bow heights at the two forward ship speeds ($Fn = 0.00$ and $Fn = 0.10$) has been used to obtain a bow height formula based on the draught d_1 at 85 % of the depth too:

$$\boxed{F_b = F(L) \cdot G(C_b, C_{wf}, L/d_1)}$$

with:

$$\boxed{F(L) = 6.087 \cdot (L/100) - 2.041 \cdot (L/100)^2 + 0.245 \cdot (L/100)^3}$$

where in calculating $F(L)$, L is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L/d_1) = 2.206 + 0.132 \cdot C_b - 1.332 \cdot C_{wf} - 0.0111 \cdot (L/d_1)}$$

where the following definitions have been used:

F_b calculated bow height

L_{pp} length between perpendiculars at Summer draught, d

L length at draught d_1 = 85 % of the depth D

B moulded breadth

d Summer Load Line draught at even keel condition

d_1 draught at 85 % of the depth D

D amidships depth

∇	volume of displacement at draught d_1
A_{wf}	water plane area forward $L_{pp}/2$ at draught d_1
C_b	block coefficient, defined by: $C_b = \nabla/(L \cdot B \cdot d_1)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

5 Joint Formulas of China and the Netherlands

The previous new formulas of China and the Netherlands result in relatively small mutual differences in calculated required minimum bow heights. Therefore, it was decided at the IMO/SLF Correspondence Group Meeting in April 2001 in Alameda (California, USA) by the authors of this report to take the average of their individually derived formulas as a jointly proposed new formula on required minimum bow heights.

5.1 Joint Formula Based on Draught *d*

China and the Netherlands propose the next joint formula (based on draught d) for required minimum bow heights of ships with a length of 24 meter or more:

$$\boxed{F_b = F(L_{pp}) \cdot G(C_b, C_{wf}, L_{pp}/d)}$$

with:

$$\boxed{F(L_{pp}) = 6.124 \cdot (L_{pp}/100) - 1.984 \cdot (L_{pp}/100)^2 + 0.227 \cdot (L_{pp}/100)^3}$$

where in calculating $F(L_{pp})$, L_{pp} is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L_{pp}/d) = 2.010 + 0.717 \cdot C_b - 1.638 \cdot C_{wf} - 0.0104 \cdot (L_{pp}/d)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
B	moulded breadth
d	Summer Load Line draught at even keel condition
∇	volume of displacement at draught d
A_{wf}	water plane area forward of $L_{pp}/2$ at Summer draught, d
C_b	block coefficient, defined by: $C_b = \nabla/(L_{pp} \cdot B \cdot d)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

In Figure 87 through Figure 101, the bow heights obtained by the new formulas (based on the draught d) of China and the Netherlands have been compared mutually and with the bow heights as obtained by the 1966 ICLL.

5.2 Joint Formula Based on Draught d_1

China and the Netherlands propose the next joint formula (based on draught d_1) for required minimum bow heights of ships with a length of 24 meter or more:

$$\boxed{F_b = F(L) \cdot G(C_b, C_{wf}, L/d_1)}$$

with:

$$\boxed{F(L) = 6.081 \cdot (L/100) - 1.958 \cdot (L/100)^2 + 0.223 \cdot (L/100)^3}$$

where in calculating $F(L)$, L is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L/d_1) = 2.080 + 0.609 \cdot C_b - 1.603 \cdot C_{wf} - 0.0129 \cdot (L/d_1)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
L	length at draught d_1 = 85 % of the depth D
B	moulded breadth
d	Summer Load Line draught at even keel condition
d_1	draught at 85 % of the depth D
D	amidships depth
∇	volume of displacement at draught d_1
A_{wf}	water plane area forward $L_{pp}/2$ at draught d_1
C_b	block coefficient, defined by: $C_b = \nabla/(L \cdot B \cdot d_1)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

5.3 Comparison of Joint Formulas with 1966 ICLL Regulations

In Figure 9 through Figure 23, the bow heights obtained by the new formulas (based on d as well as on d_1) have been compared for the 1980 ships with the bow heights of the 1966 ICLL.

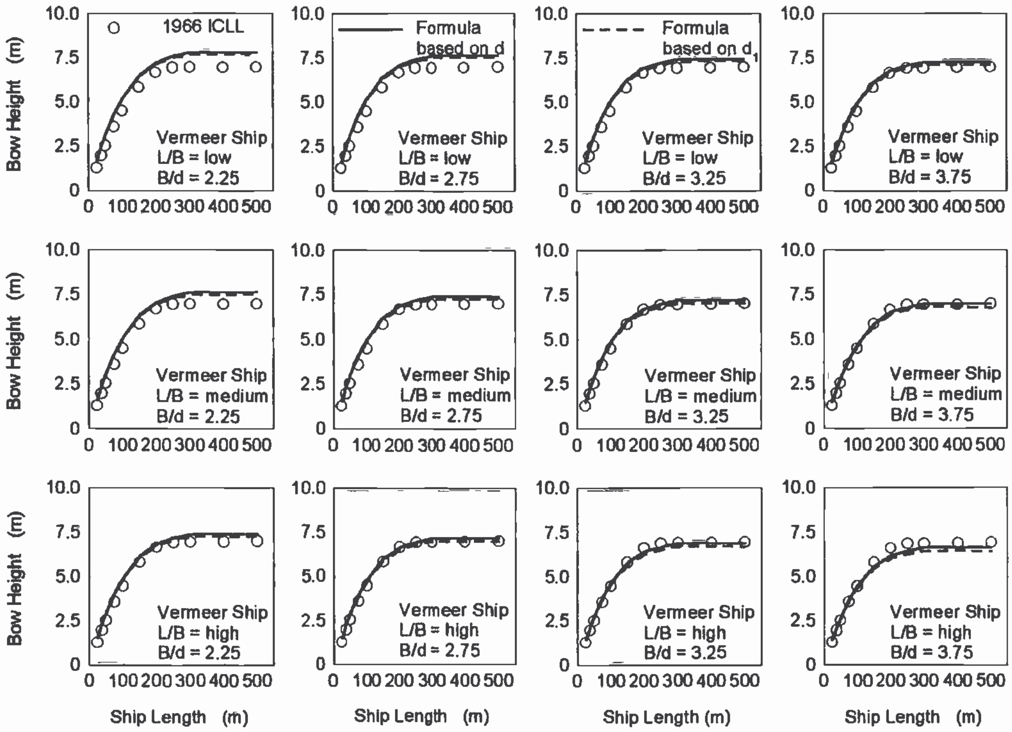

Figure 9 Final Bow Height Results of Vermeer Ships

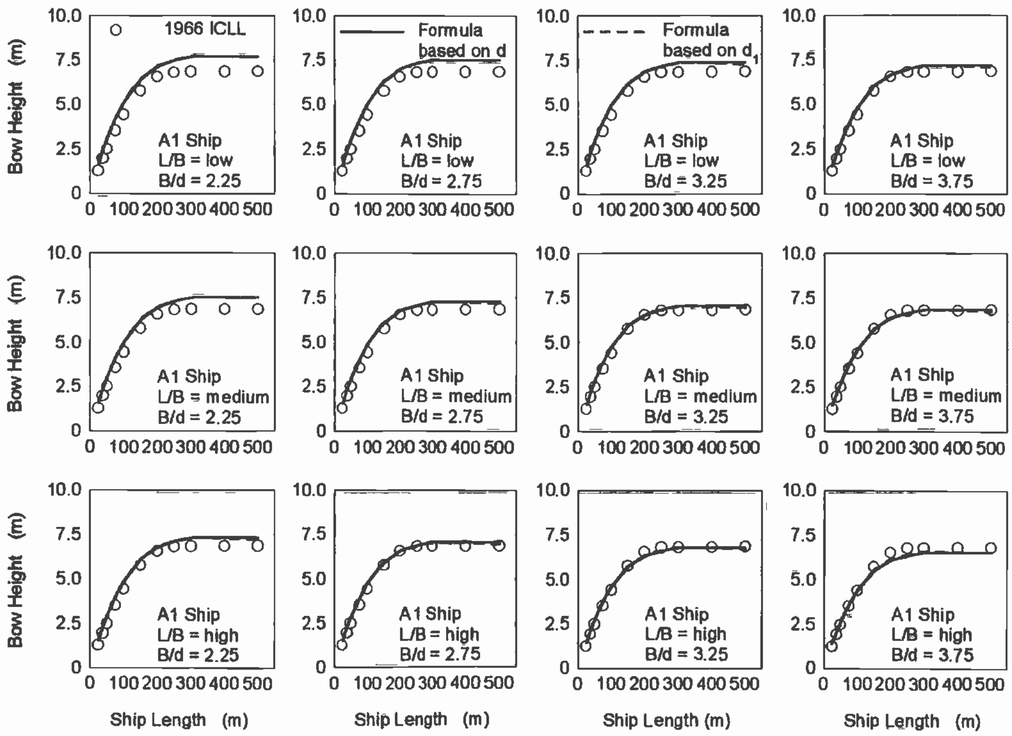

Figure 10 Final Bow Height Results of A1 Ships

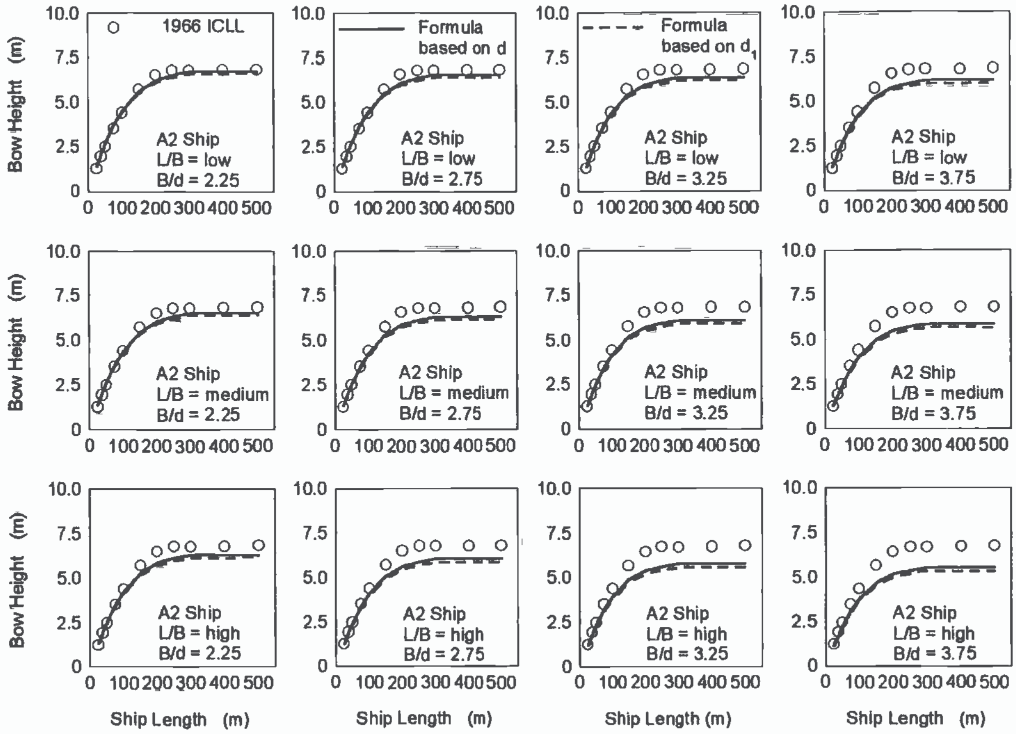

Figure 11 Final Bow Height Results of A2 Ships

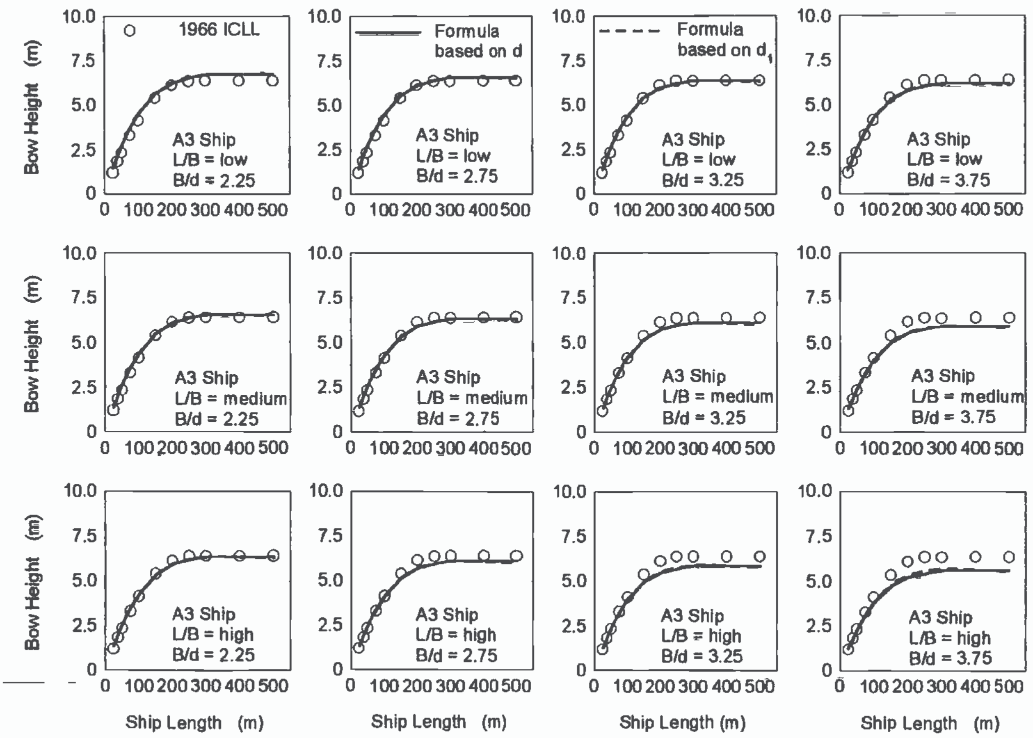

Figure 12 Final Bow Height Results of A3 Ships

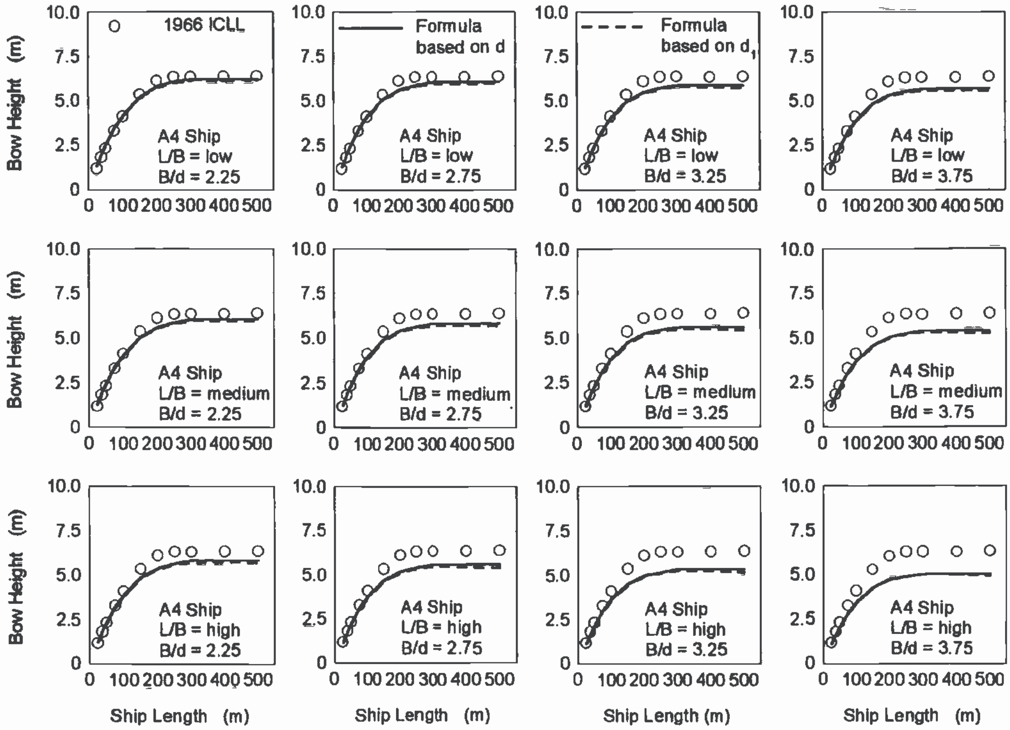

Figure 13 Final Bow Height Results of A4 Ships

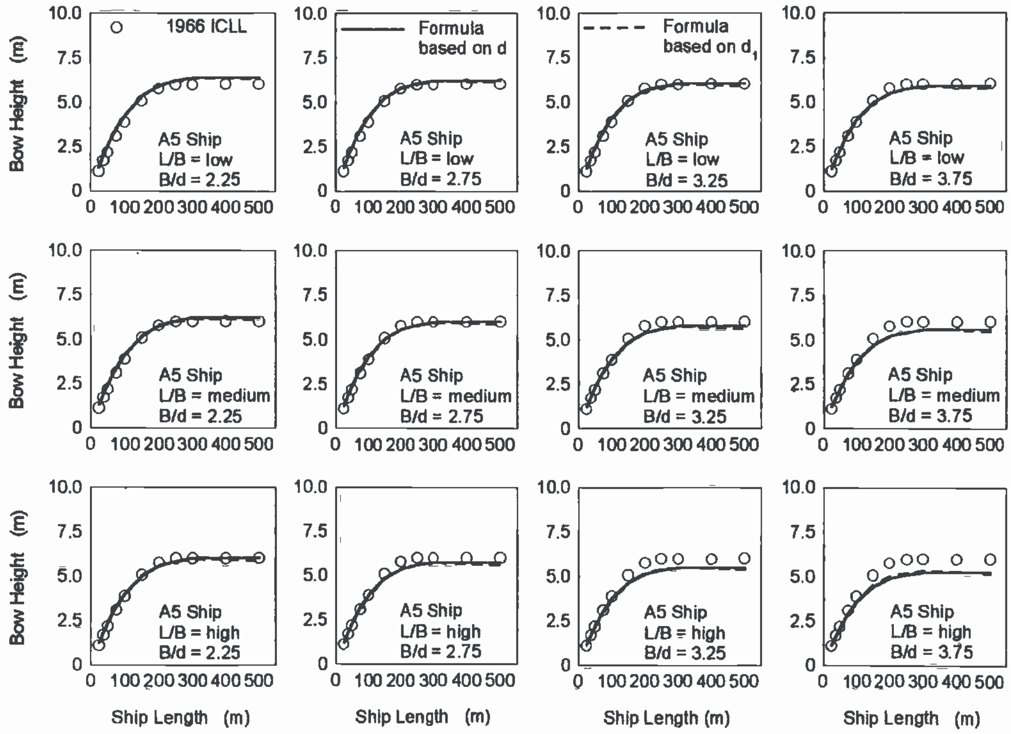

Figure 14 Final Bow Height Results of A5 Ships

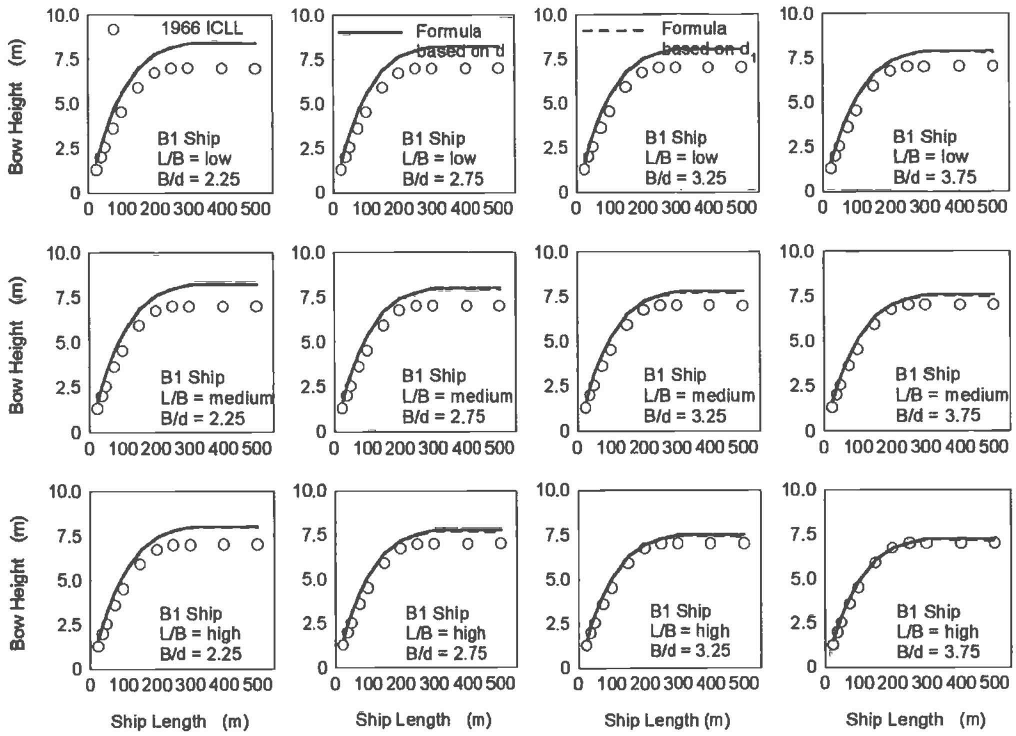

Figure 15 Final Bow Height Results of B1 Ships

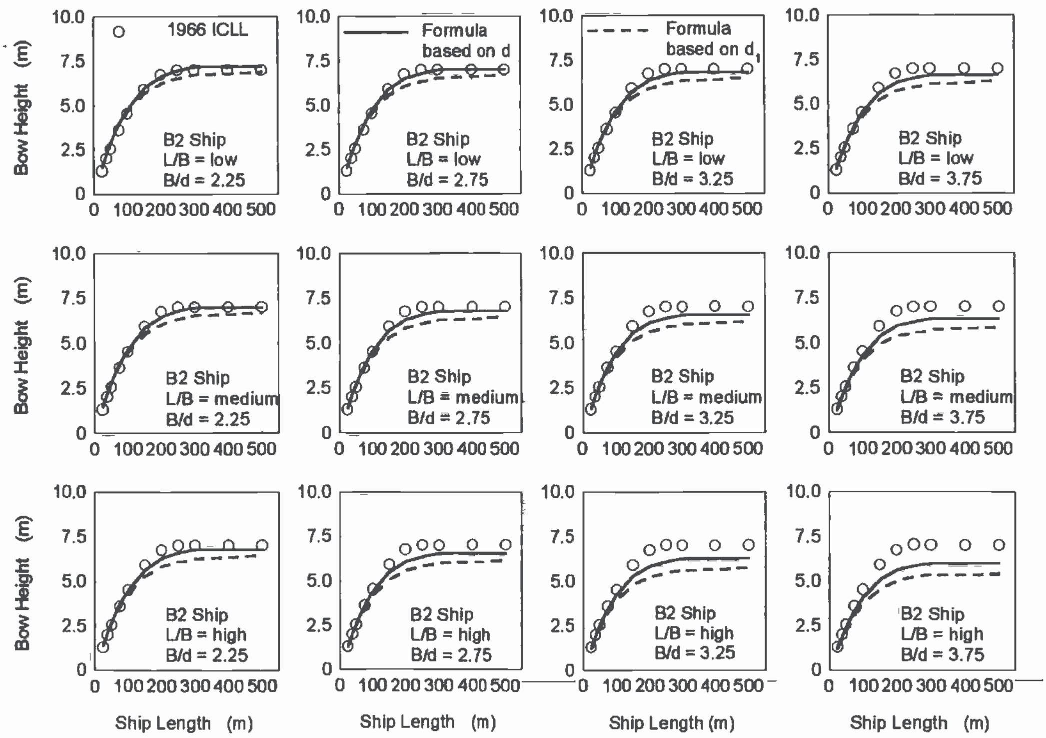

Figure 16 Final Bow Height Results of B2 Ships

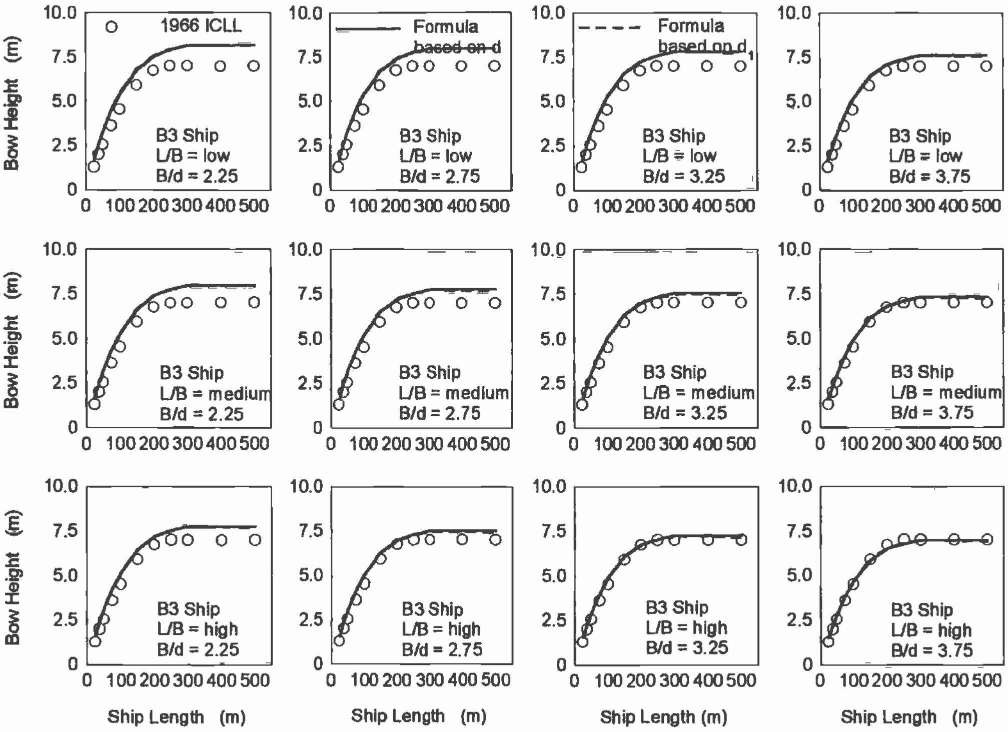

Figure 17 Final Bow Height Results of B3 Ships

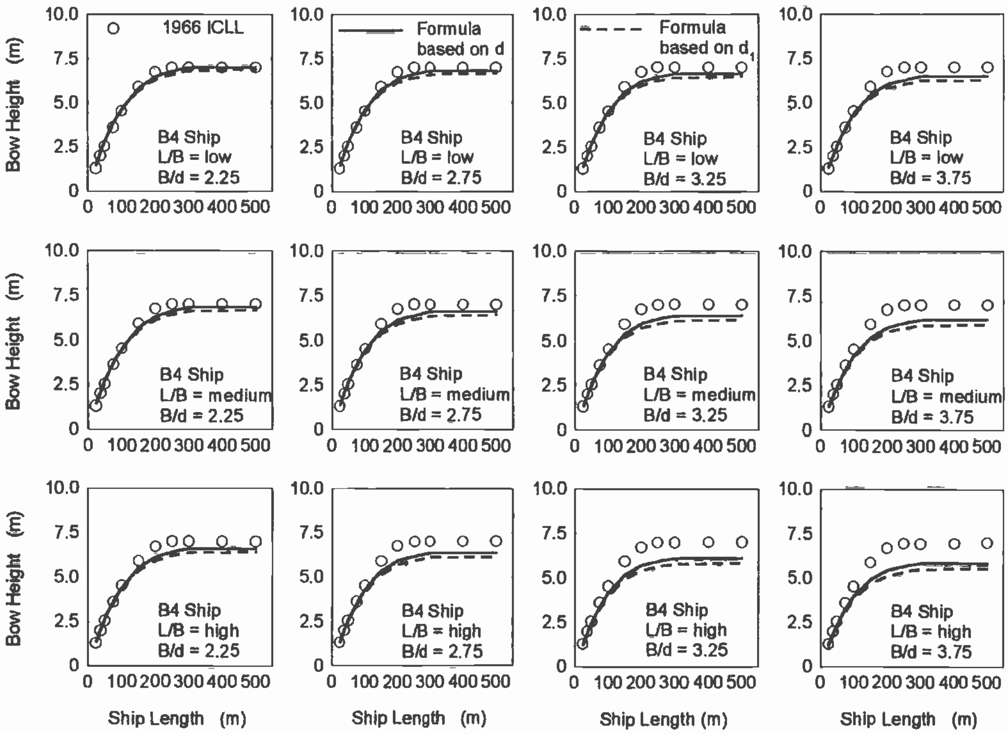

Figure 18 Final Bow Height Results of B4 Ships

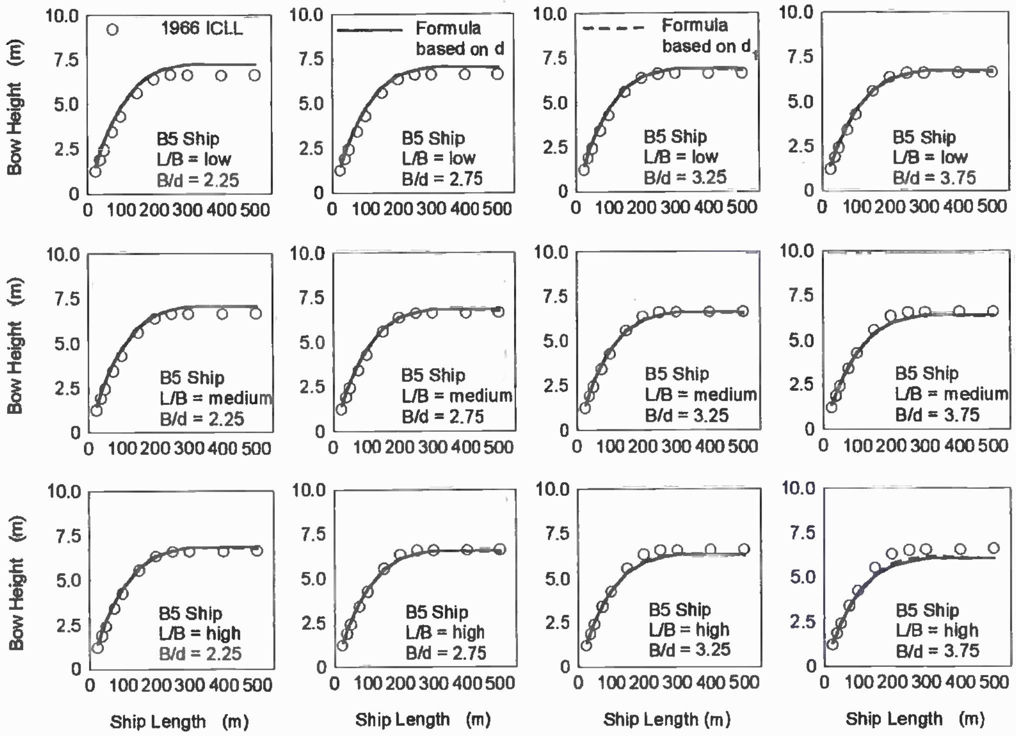

Figure 19 Final Bow Height Results of B5 Ships

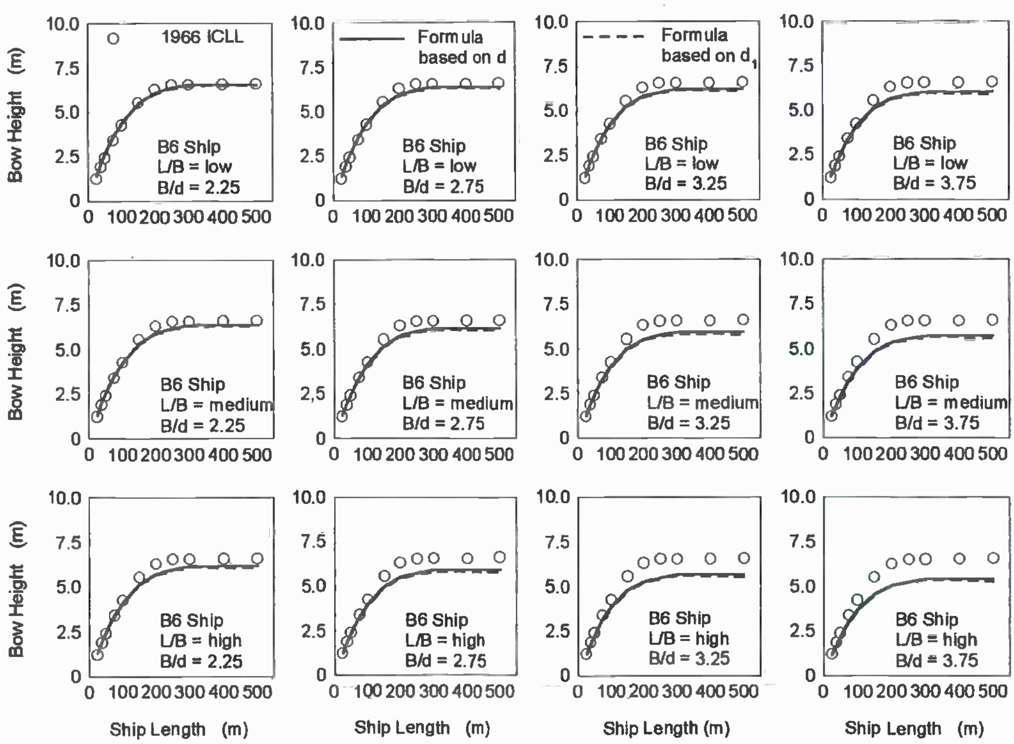

Figure 20 Final Bow Height Results of B6 Ships

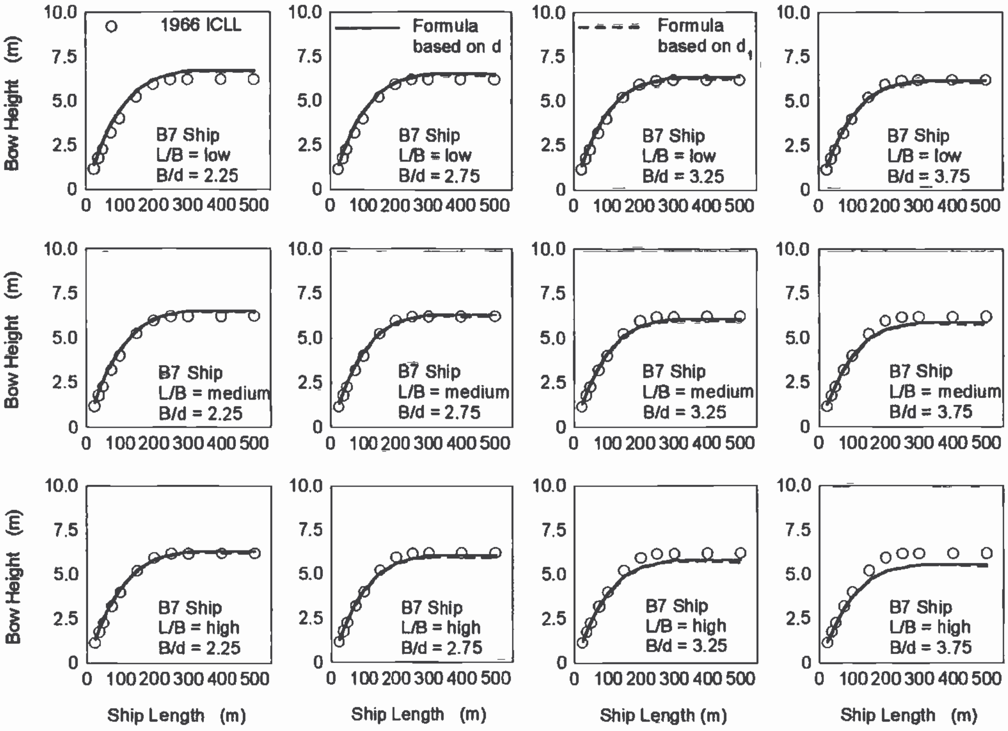

Figure 21 Final Bow Height Results of B7 Ships

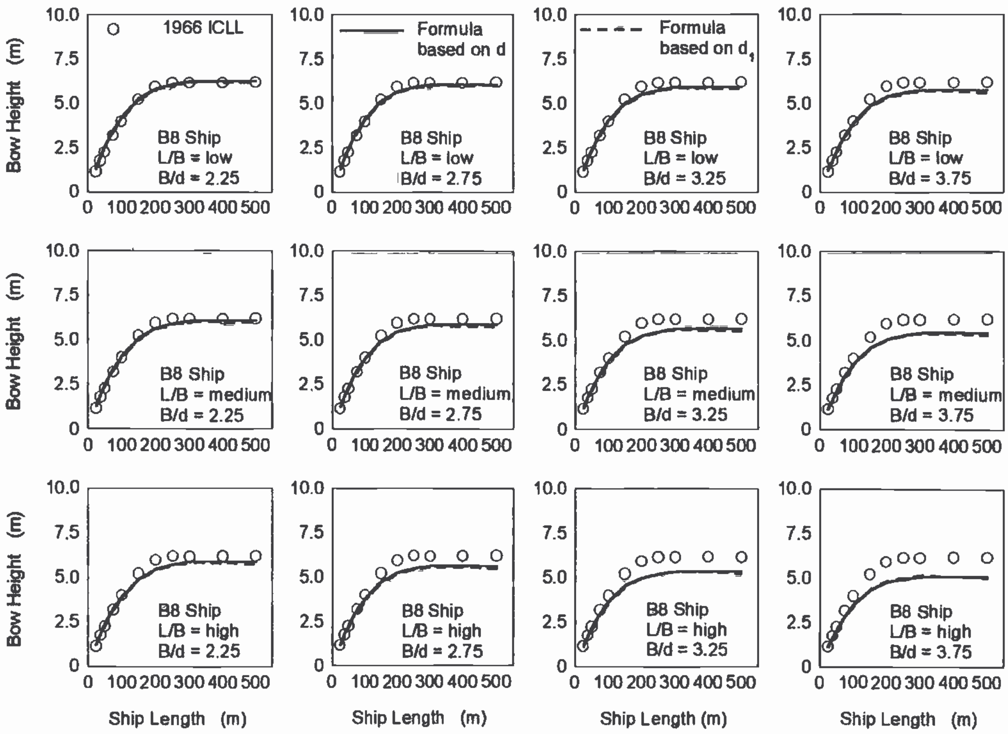

Figure 22 Final Bow Height Results of B8 Ships

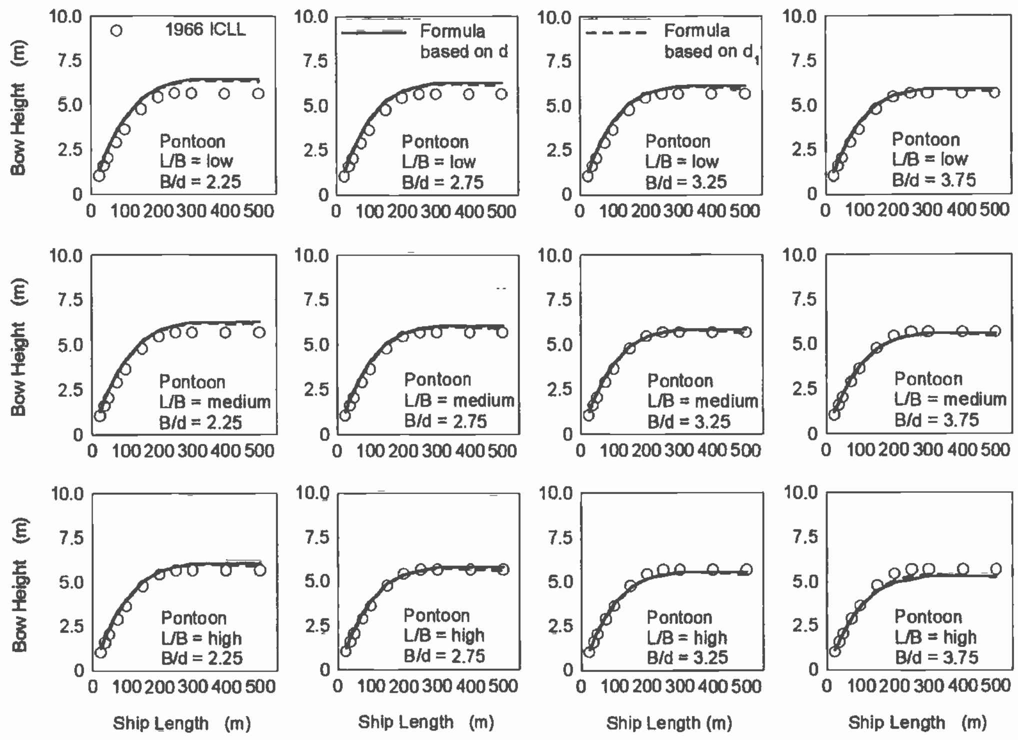

Figure 23 Final Bow Height Results of Rectangular Pontoons

5.4 Comparison of Joint Formulas with Bow Heights of Existing Ships

Figure 24, Figure 25 and Figure 26 give the final bow height results of 30 existing Chinese ships, 60 existing Japanese ships and 17 existing Norwegian ships.

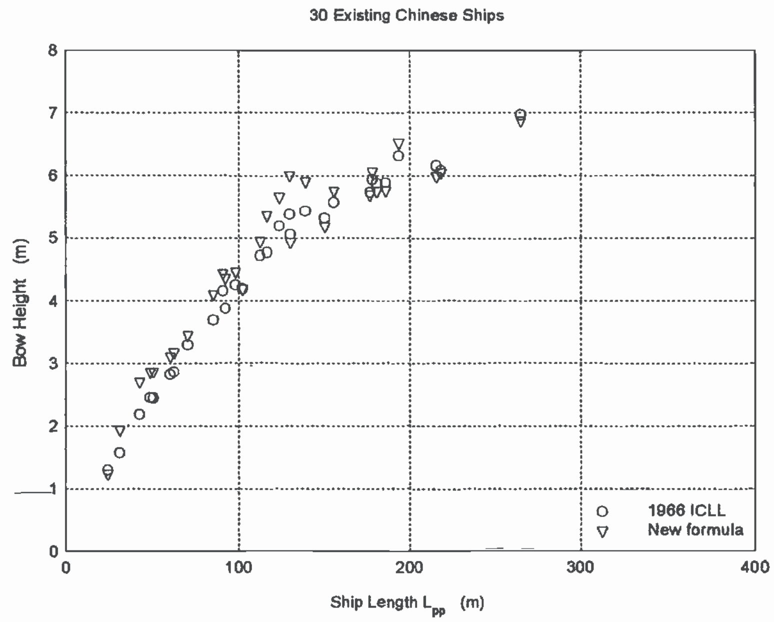

Figure 24 Final Bow Height Results of 30 Existing Chinese Ships

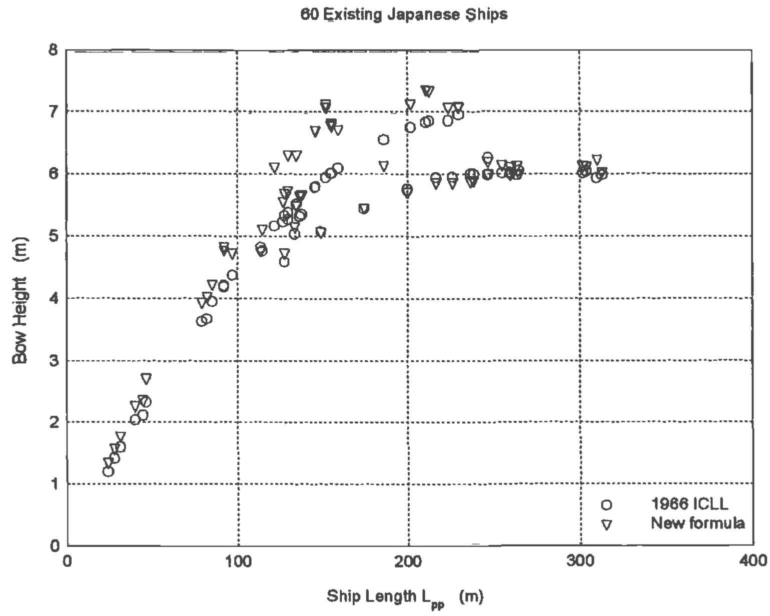

Figure 25 Final Bow Height Results of 60 Existing Japanese Ships

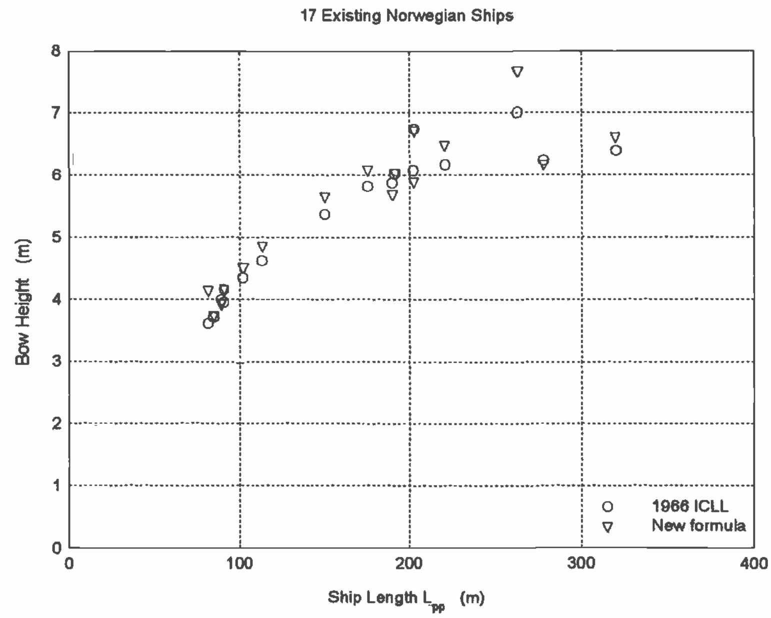

Figure 26 Final Bow Height Results of 17 Existing Norwegian Ships

6 Conclusions and Recommendations

Extensive studies on probabilistic deck wetness analysis has been carried out in China and in the Netherlands with respect to required minimum bow height of ships exceeding 24 m in length.

The following conclusions may be drawn from the results of these studies:

1. The present 1966 ICLL bow height formula accounts for ship length and block coefficient only. These parameters govern to a large extent the heave motions of the ship.

2. A revised bow height formula should in addition account for the water plane area coefficient of the fore ship and the ship's (Summer) draft. These parameters have an important influence on the pitch motions of the ship and hence govern the relative motions (as well as shipping water) at the bow.

3. From a scientific point of view China and the Netherlands propose the following formula, based on the (Summer) draught d, for the required minimum bow height of ships with a length of 24 meter or more:

$$\boxed{F_b = F(L_{pp}) \cdot G(C_b, C_{wf}, L_{pp}/d)}$$

with:

$$\boxed{F(L_{pp}) = 6.124 \cdot (L_{pp}/100) - 1.984 \cdot (L_{pp}/100)^2 + 0.227 \cdot (L_{pp}/100)^3}$$

where in calculating $F(L_{pp})$, L_{pp} is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L_{pp}/d) = 2.010 + 0.717 \cdot C_b - 1.638 \cdot C_{wf} - 0.0104 \cdot (L_{pp}/d)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
B	moulded breadth
d	Summer Load Line draught at even keel condition
∇	volume of displacement at draught d
A_{wf}	water plane area forward of $L_{pp}/2$ at Summer draught, d
C_b	block coefficient, determined by: $C_b = \nabla/(L_{pp} \cdot B \cdot d)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

4. A more or less equivalent but less scientifically based formula, based on moulded draught d_1, is given by:

$$\boxed{F_b = F(L) \cdot G(C_b, C_{wf}, L/d_1)}$$

with:

$$\boxed{F(L) = 6.081 \cdot (L/100) - 1.958 \cdot (L/100)^2 + 0.223 \cdot (L/100)^3}$$

where in calculating $F(L)$, L is to be taken as 300 m for ships of 300 m and above in length,
and:

$$\boxed{G(C_b, C_{wf}, L/d_1) = 2.080 + 0.609 \cdot C_b - 1.603 \cdot C_{wf} - 0.0129 \cdot (L/d_1)}$$

where the following definitions have been used:

F_b	calculated bow height
L_{pp}	length between perpendiculars at Summer draught, d
L	length at draught d_1 = 85 % of the depth D
B	moulded breadth
d	Summer Load Line draught at even keel condition
d_1	draught at 85 % of the depth D
D	amidships depth
∇	volume of displacement at draught d_1
A_{wf}	water plane area forward $L_{pp}/2$ at draught d_1
C_b	block coefficient, defined by: $C_b = \nabla/(L \cdot B \cdot d_1)$
C_{wf}	water plane area coefficient forward of $L_{pp}/2$: $C_{wf} = A_{wf}/(L_{pp} \cdot B/2)$

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8 Appendix A: Figures with Detailed Data of China

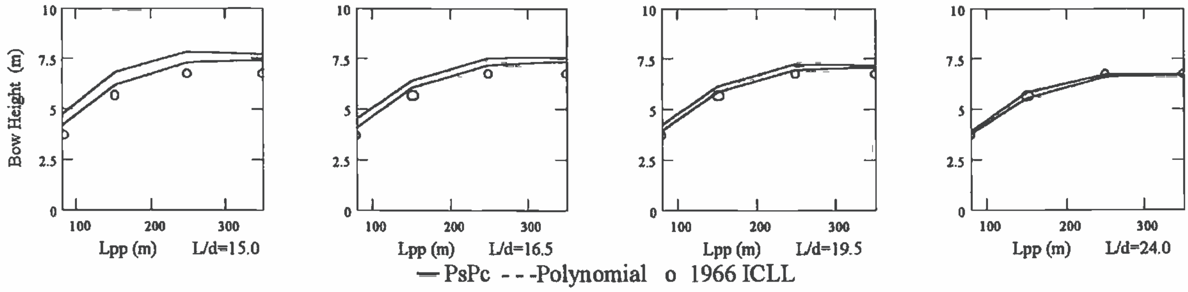


Figure 27 Bow Height Results of A1 Ships

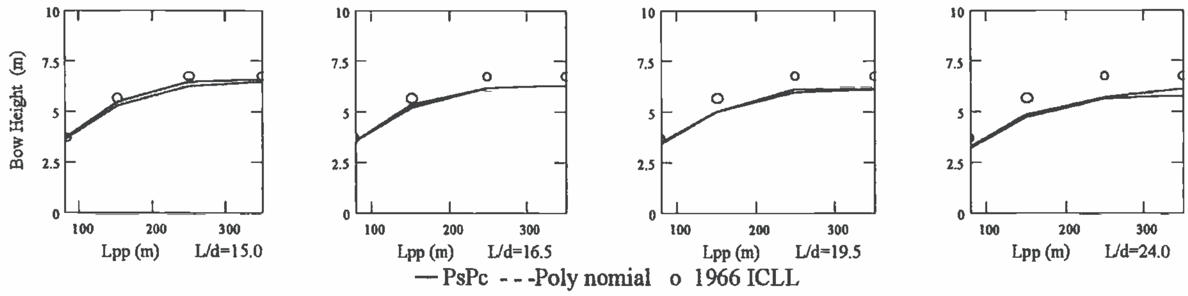


Figure 28 Bow Height Results of A2 Ships

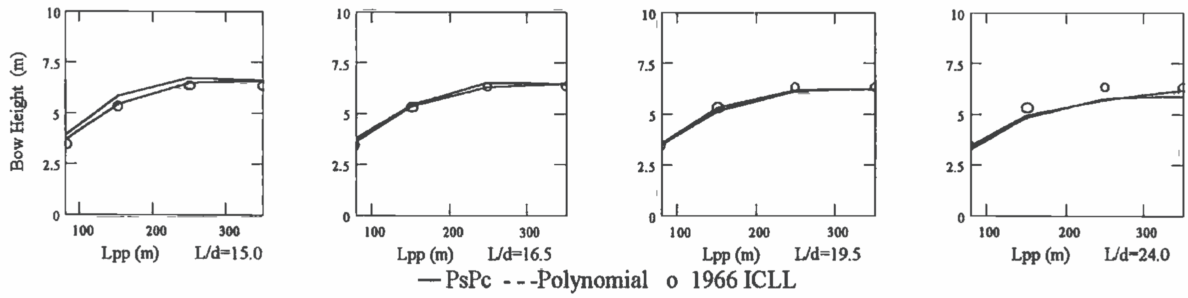


Figure 29 Bow Height Results of A3 Ships

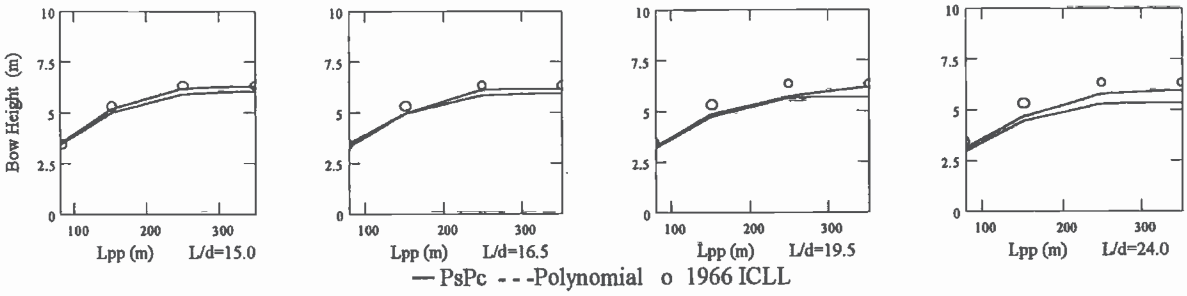


Figure 30 Bow Height Results of A4 Ships

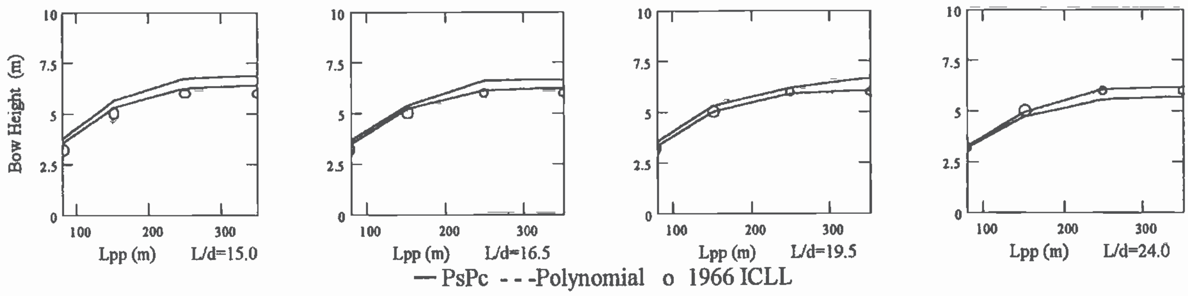


Figure 31 Bow Height Results of A5 Ships

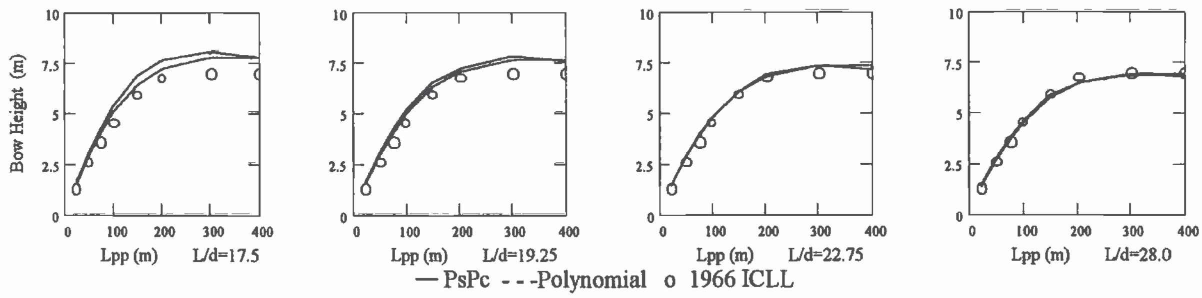


Figure 32 Bow Height Results of B1 Ships

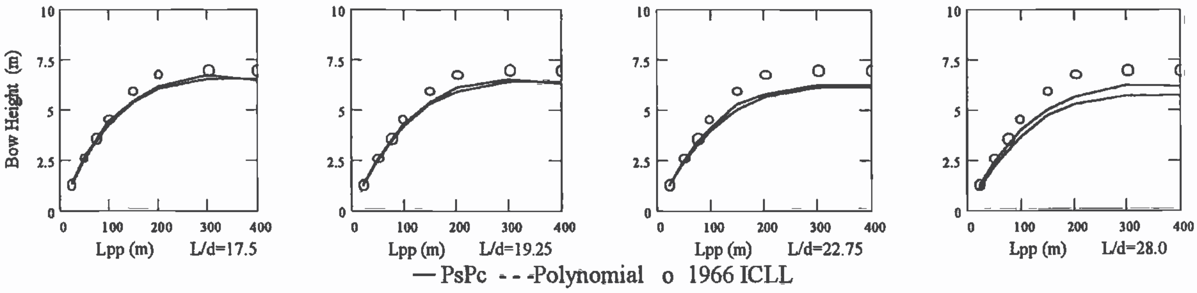


Figure 33 Bow Height Results of B2 Ships

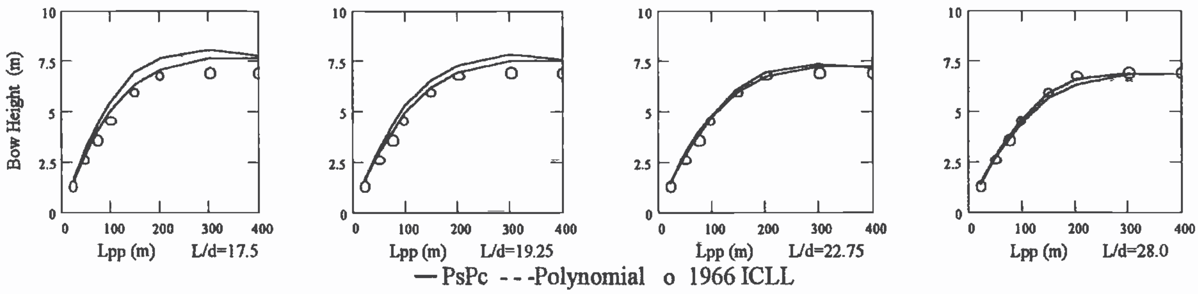


Figure 34 Bow Height Results of B3 Ships

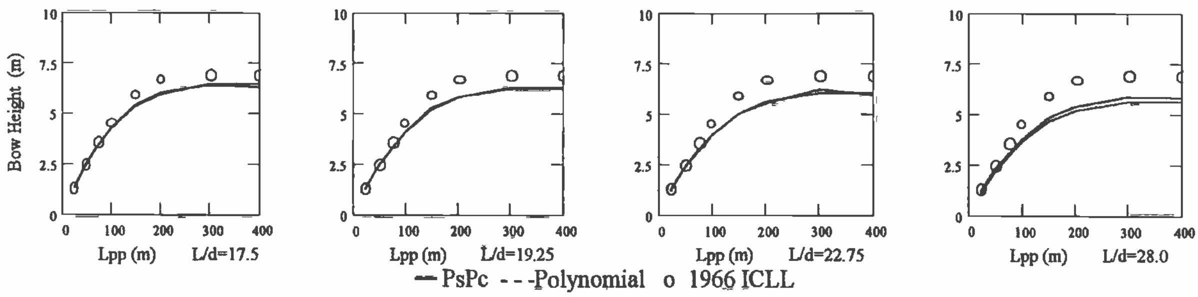


Figure 35 Bow Height Results of B4 Ships

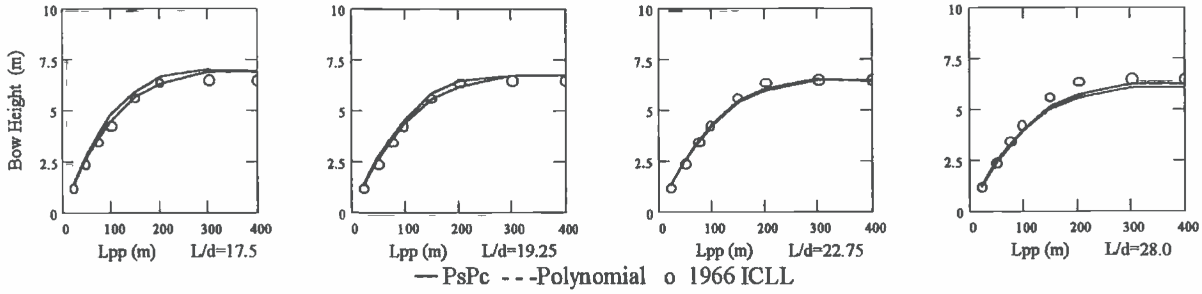


Figure 36 Bow Height Results of B5 Ships

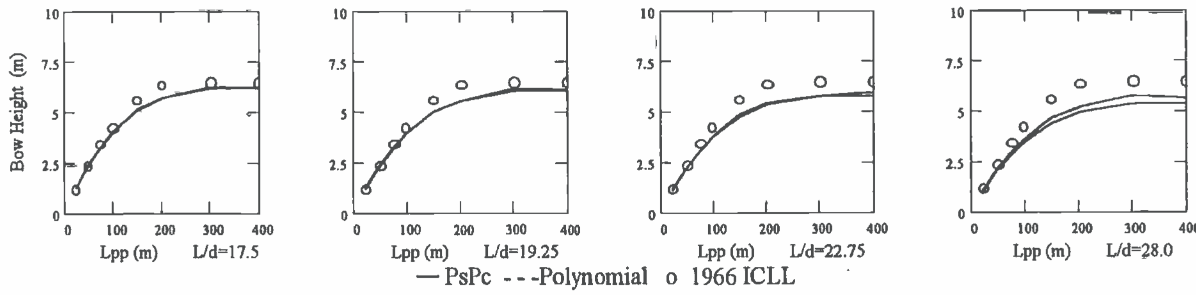


Figure 37 Bow Height Results of B6 Ships

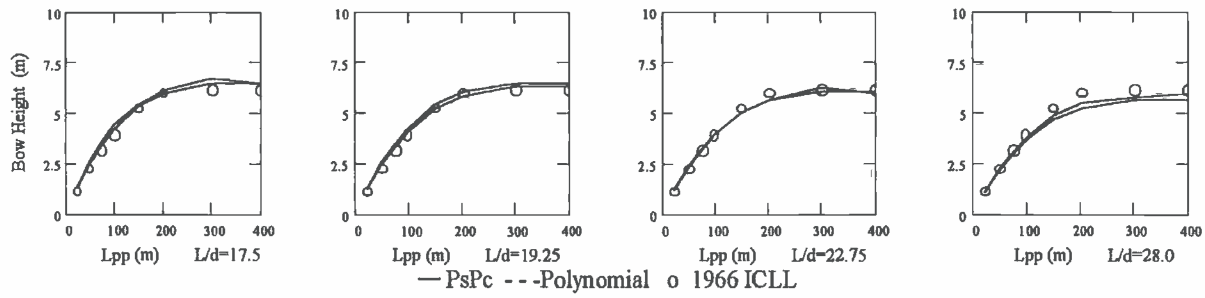


Figure 38 Bow Height Results of B7 Ships

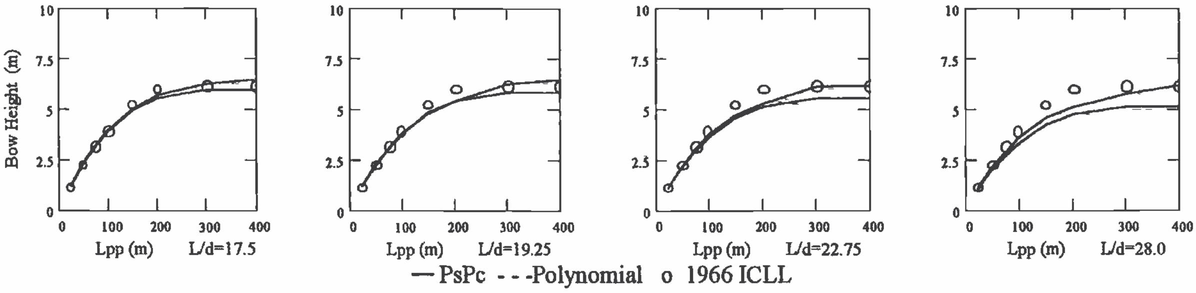


Figure 39 Bow Height Results of B8 Ships

8.2 Figures with Detailed Data for the Netherlands Series

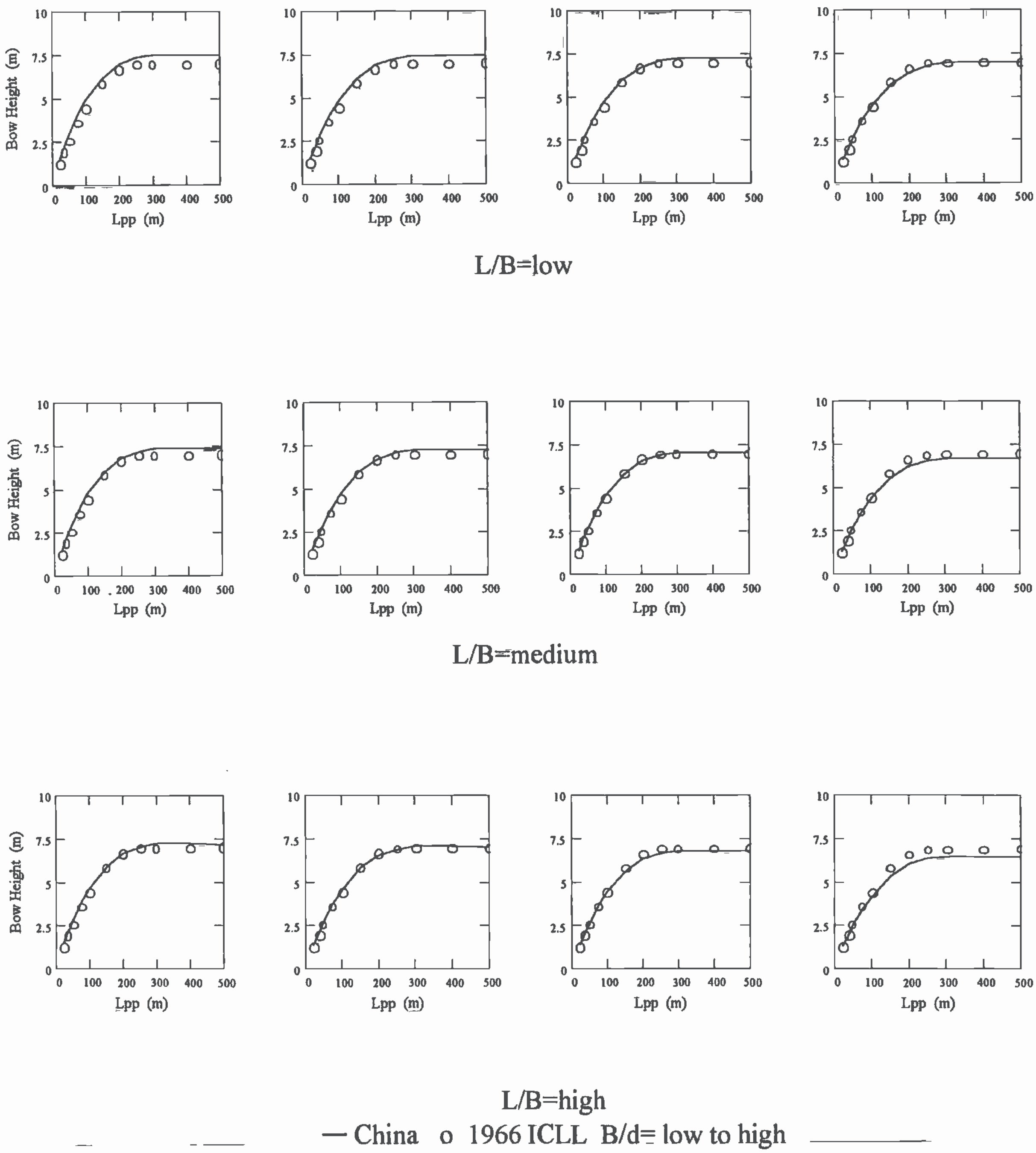
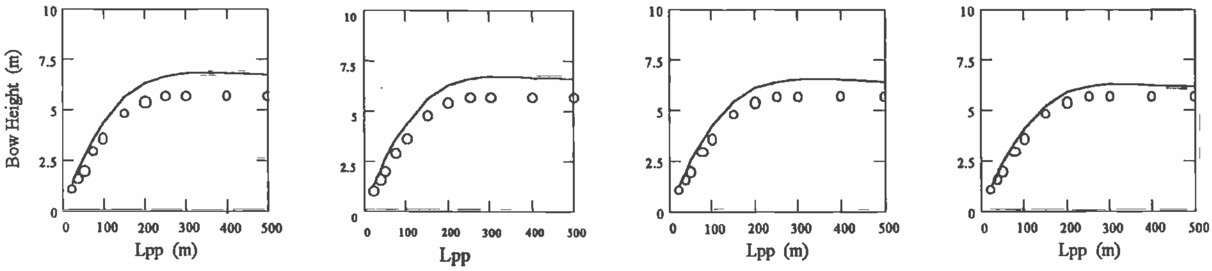


Figure 40 Bow Height Results of Vermeer Ships



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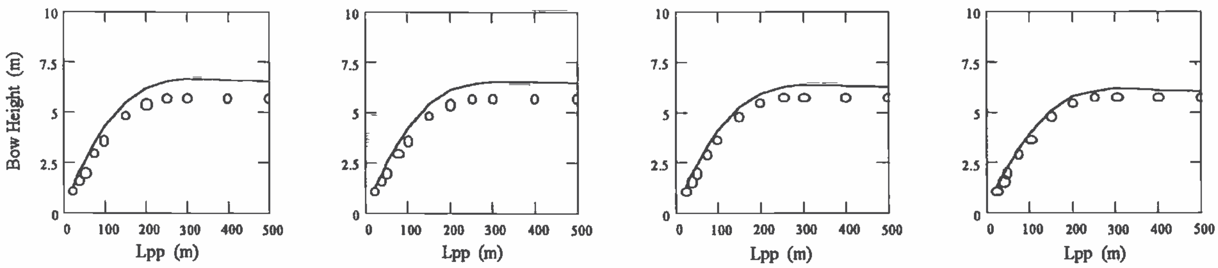

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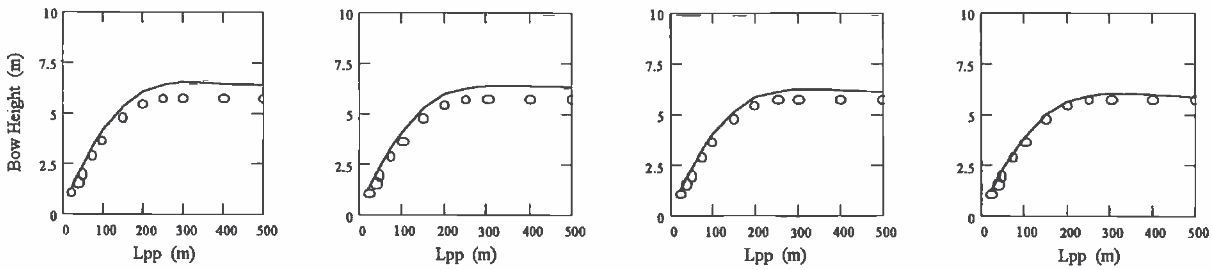
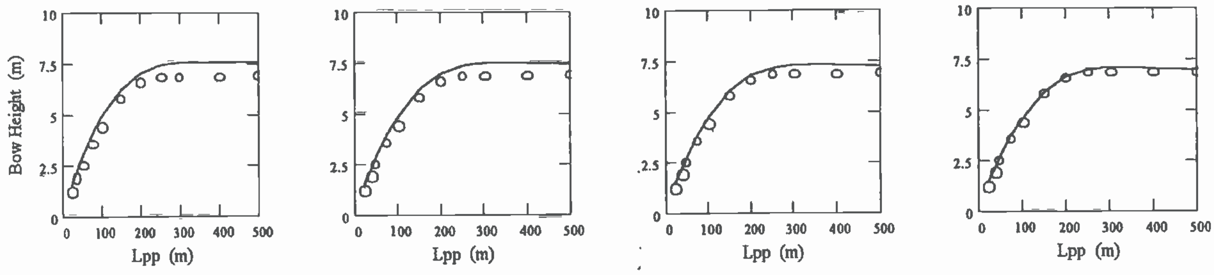


L/B=high

— China o 1966 ICLL B/d= low to high

Figure 41 Bow Height Results of A1 Ships



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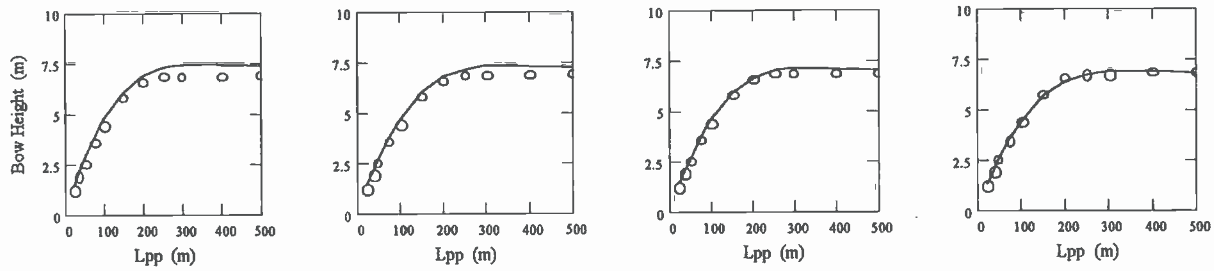

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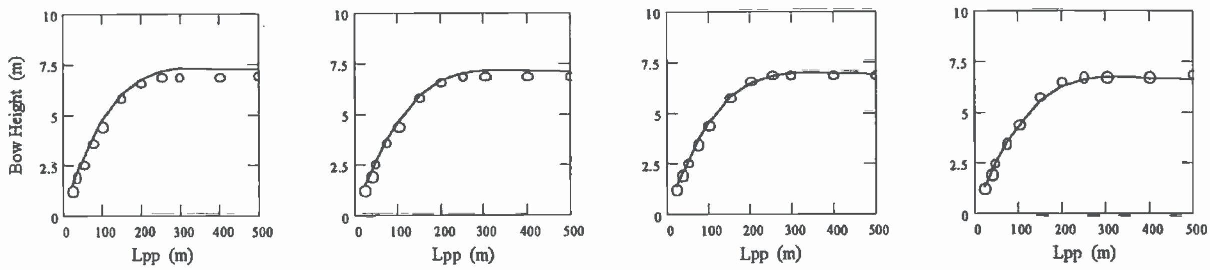

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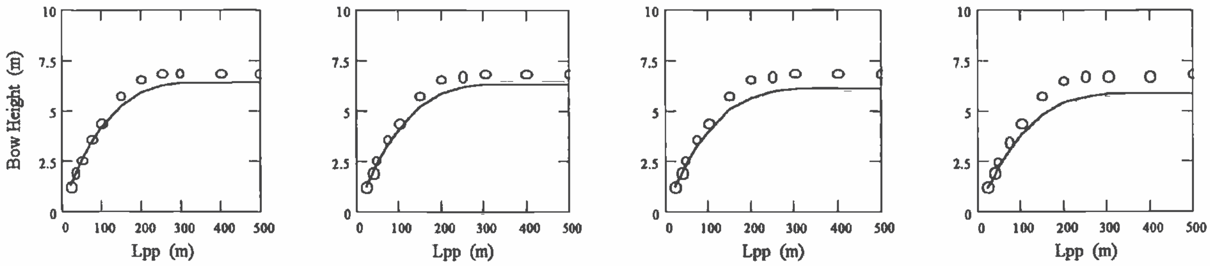
Figure 42 Bow Height Results of A2 Ships



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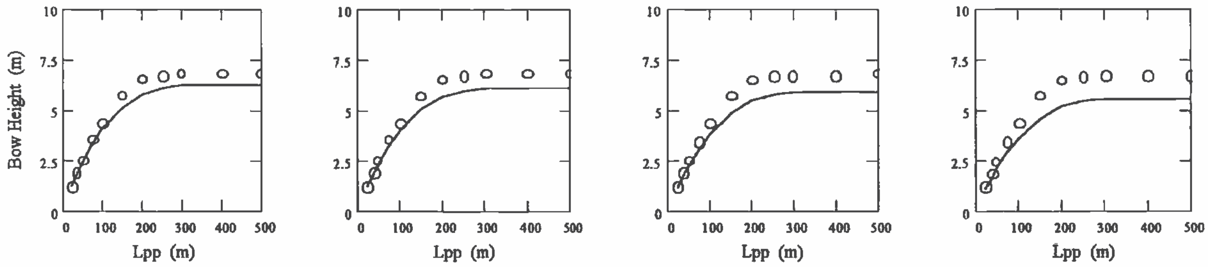

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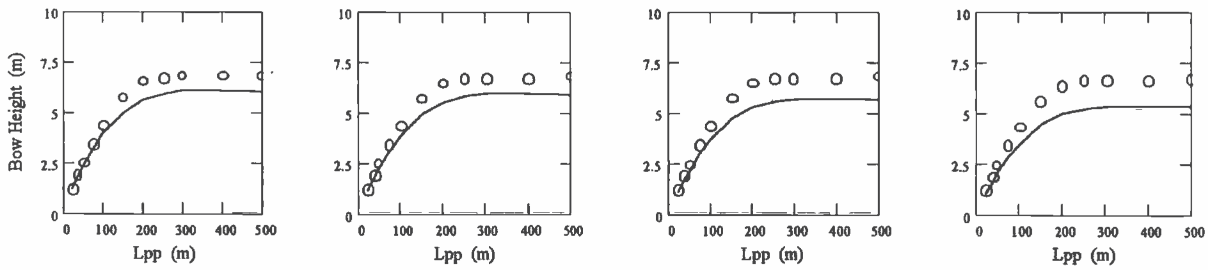

L/B=high

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Figure 43 Bow Height Results of A3 Ships

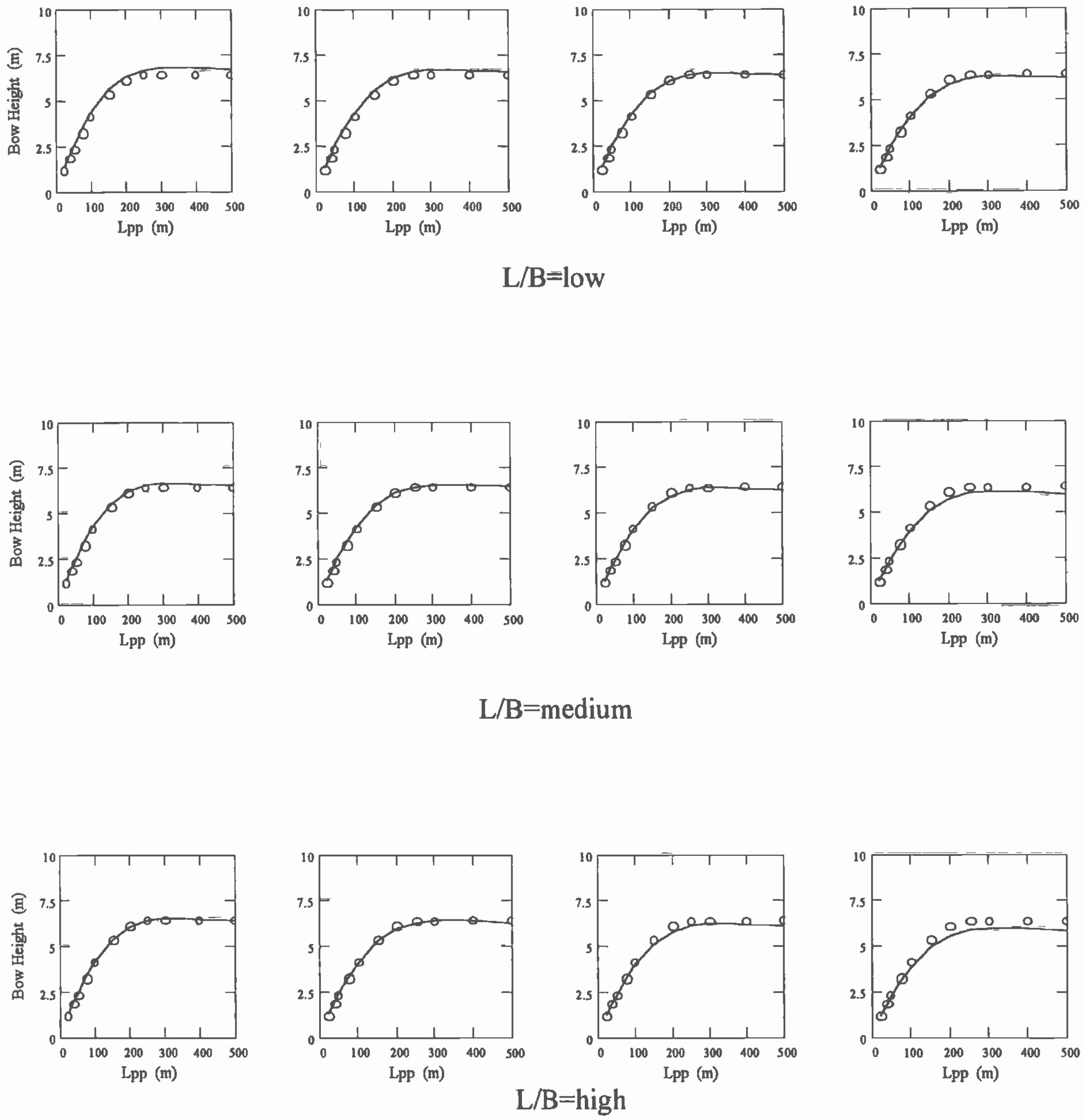

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Figure 44 Bow Height Results of A4 Ships

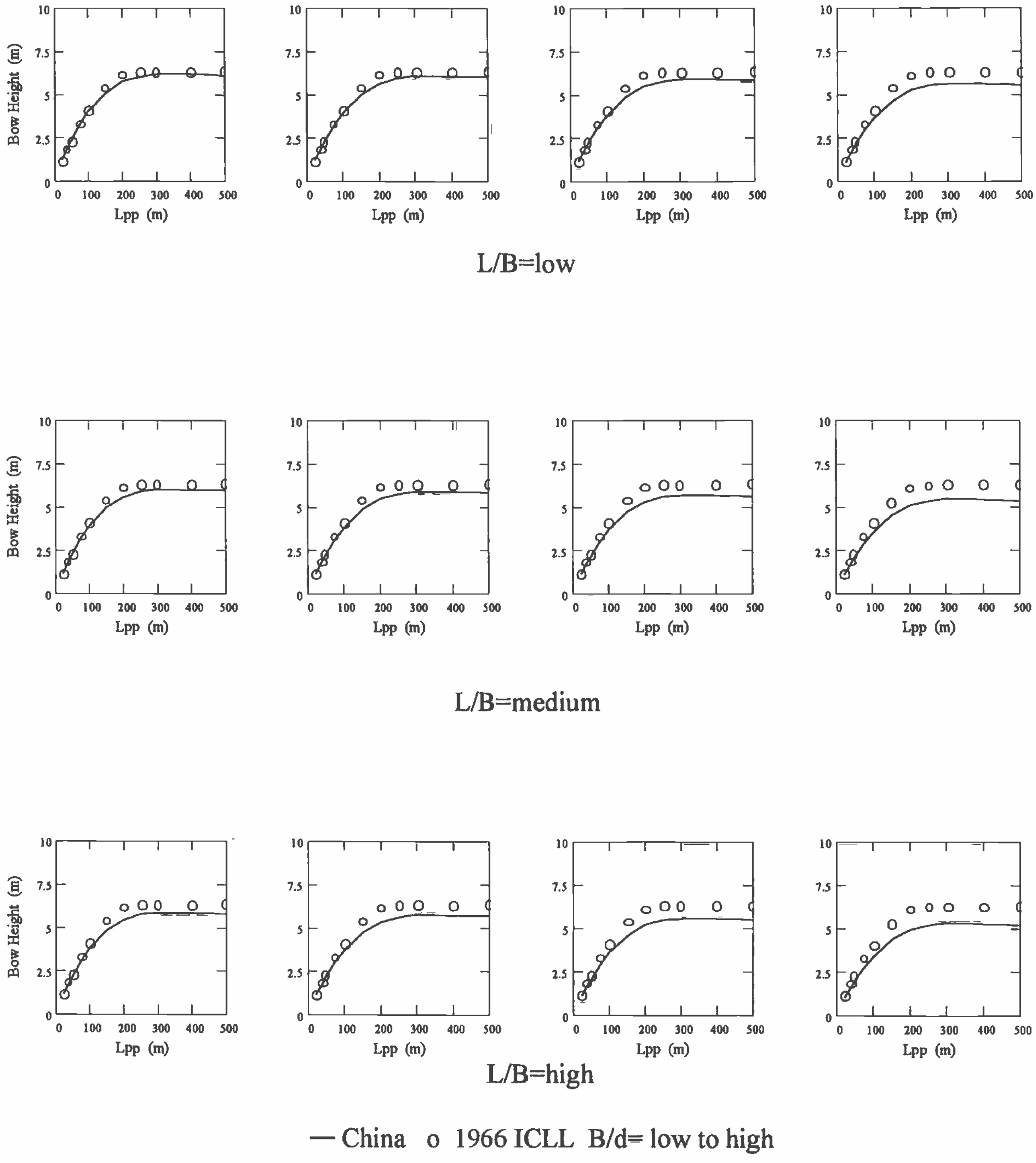

Figure 45 Bow Height Results of A5 Ships

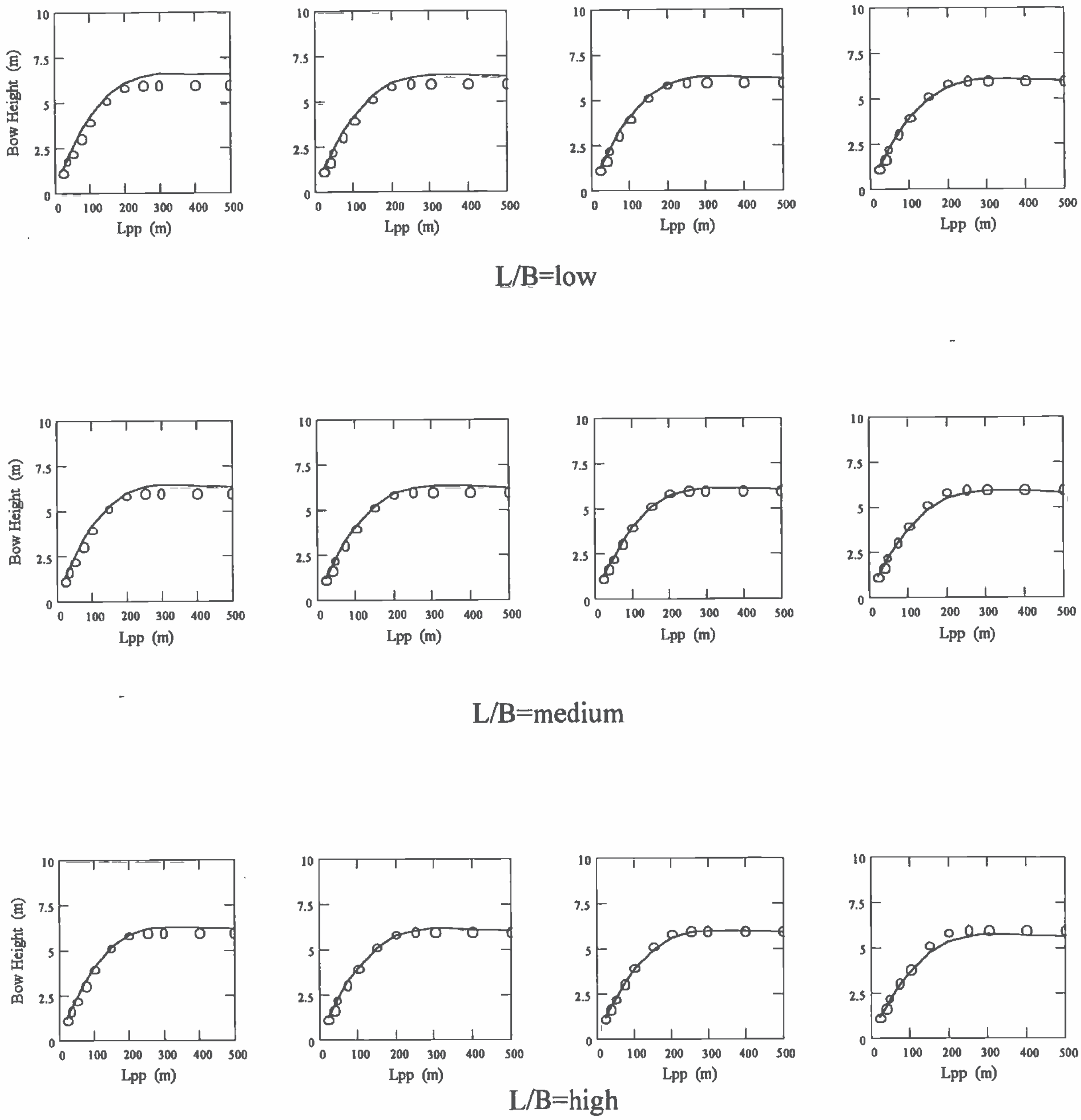

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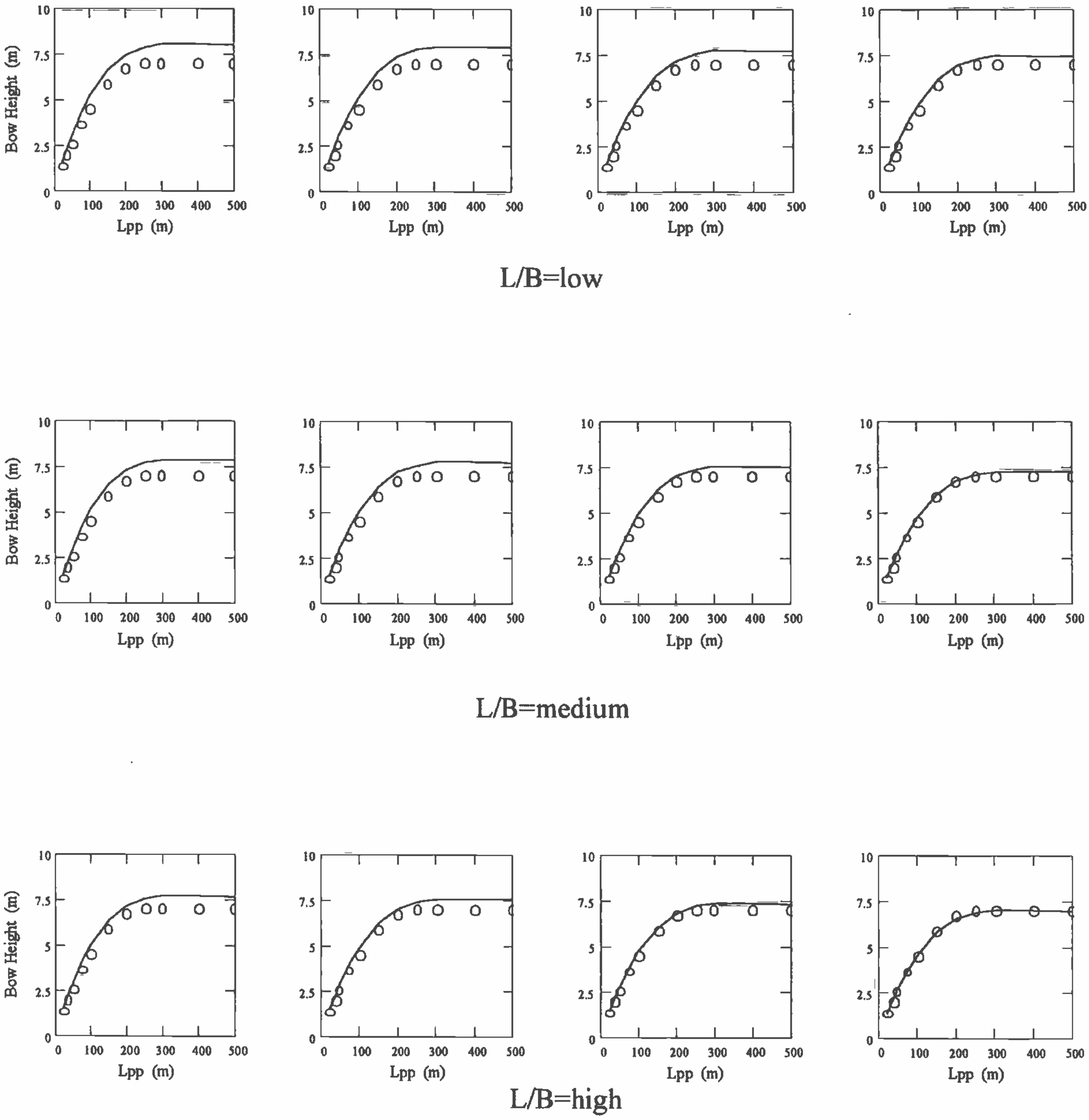
Figure 46 Bow Height Results of B1 Ships



— China o 1966 ICLL B/d= low to high

Figure 47 Bow Height Results of B2 Ships

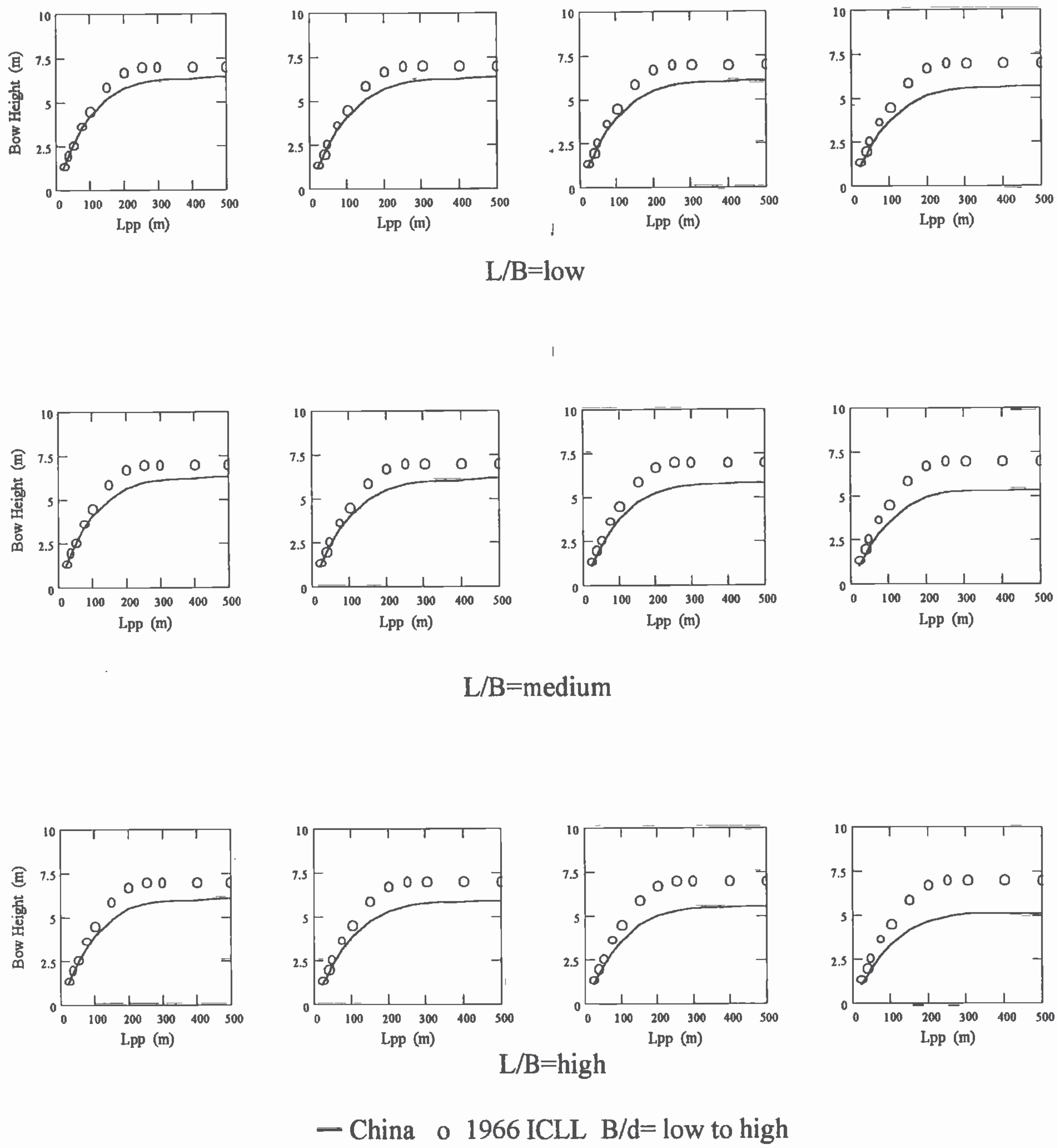
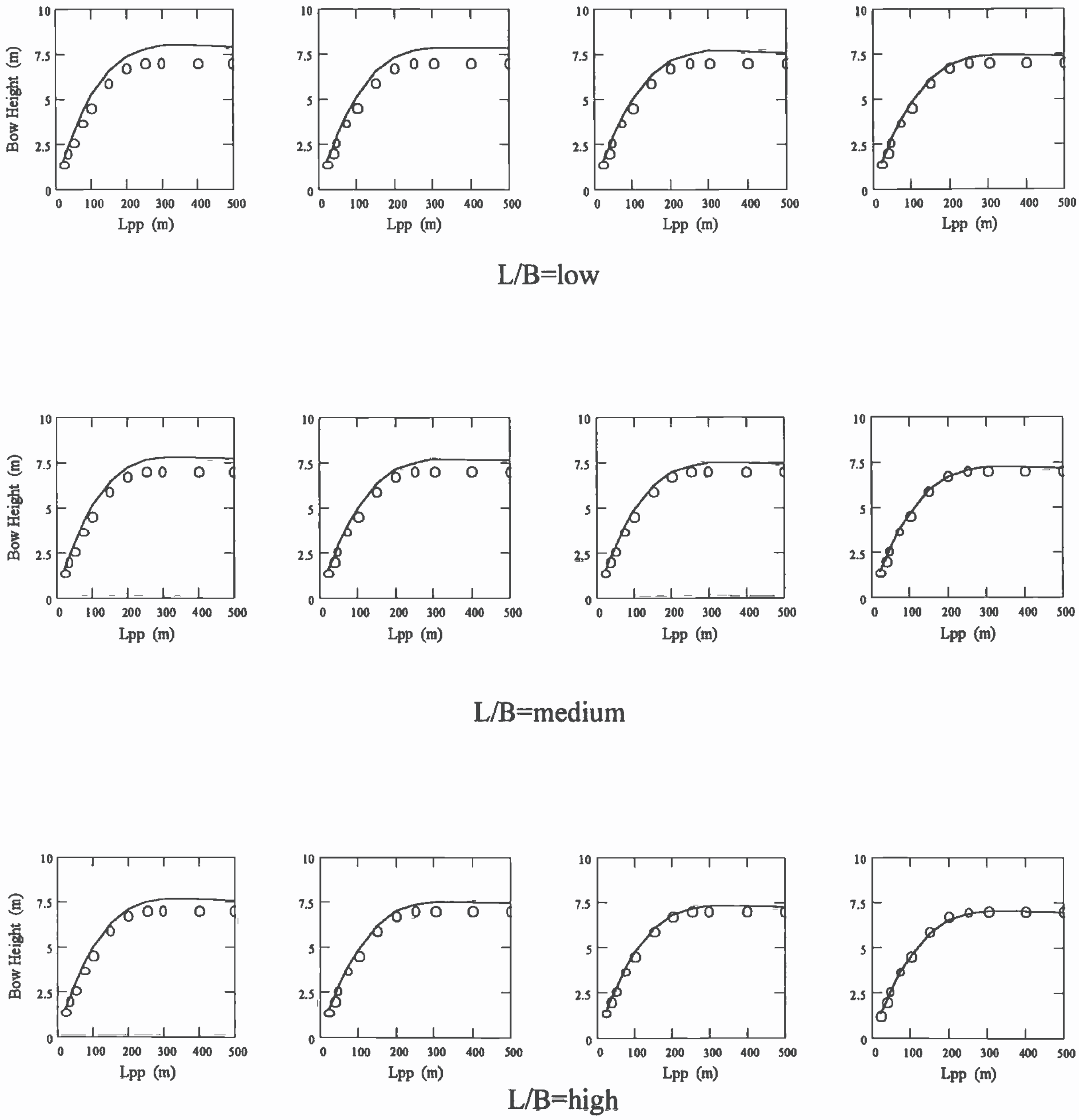


Figure 48 Bow Height Results of B3 Ships



— China o 1966 ICLL B/d= low to high

Figure 49 Bow Height Results of B4 Ships

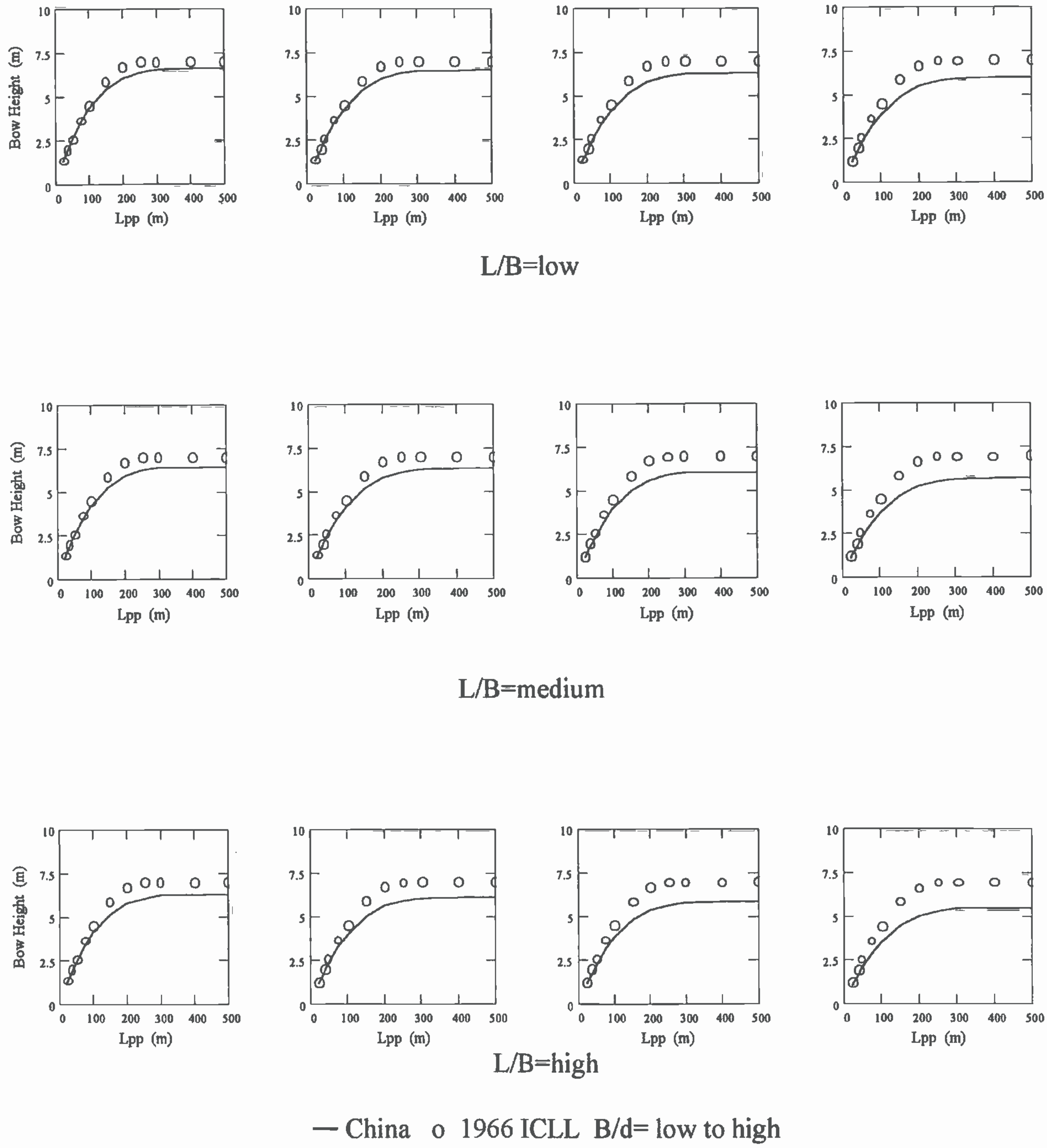
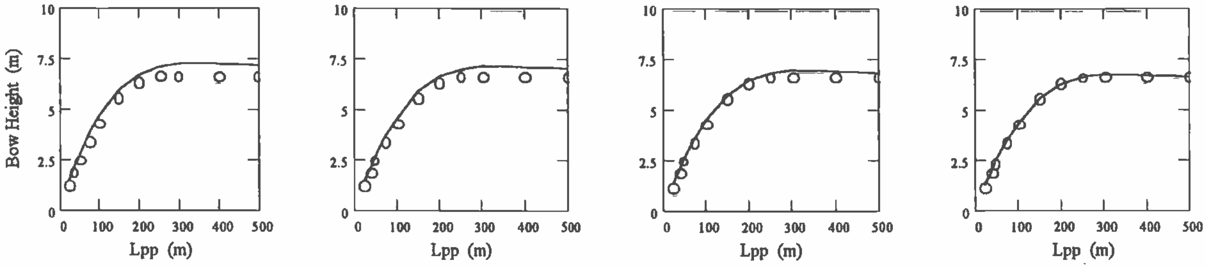


Figure 50 Bow Height Results of B5 Ships



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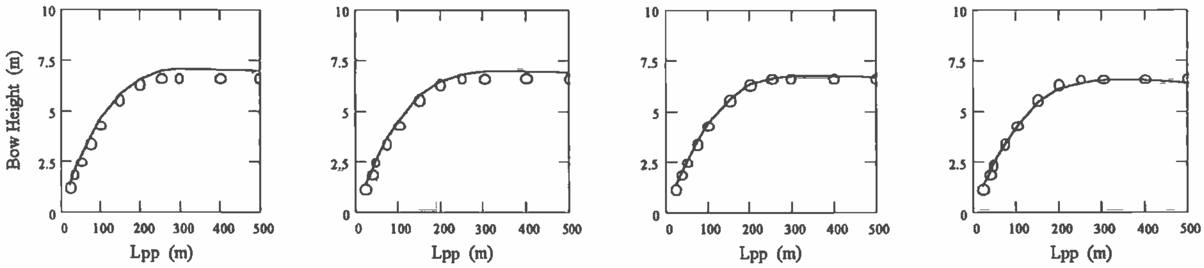

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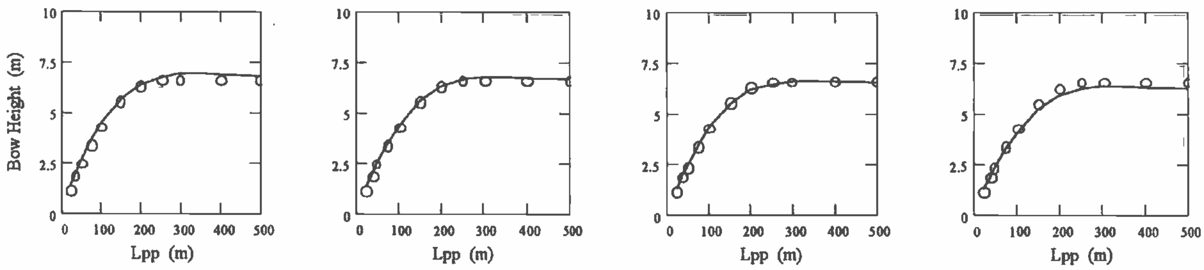

L/B=high

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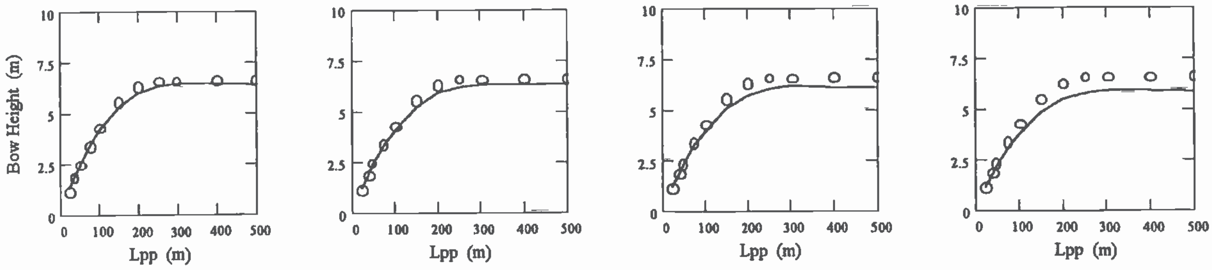
Figure 51 Bow Height Results of B6 Ships



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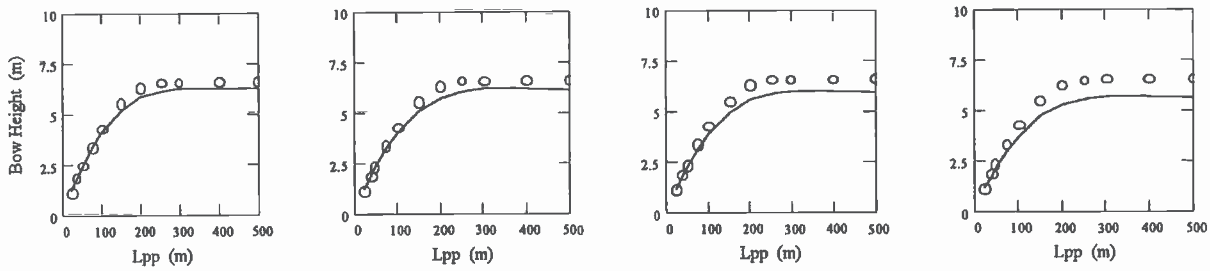

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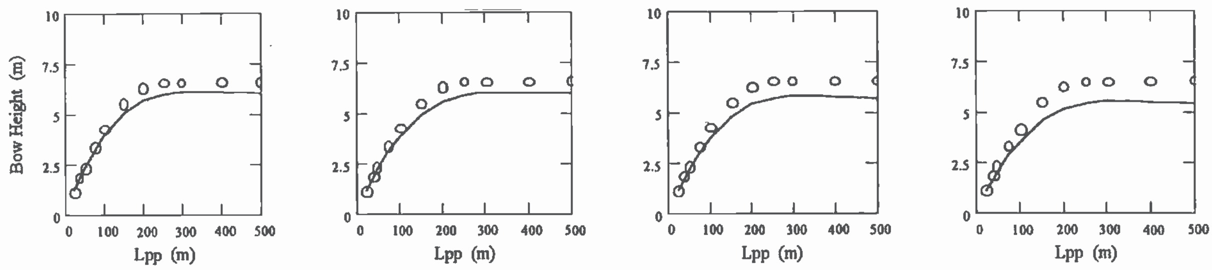
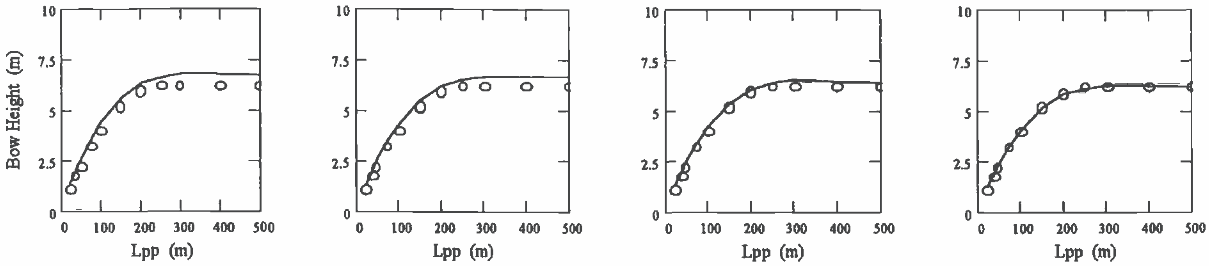


L/B=high

— China o 1966 ICLL B/d= low to high

Figure 52 Bow Height Results of B7 Ships



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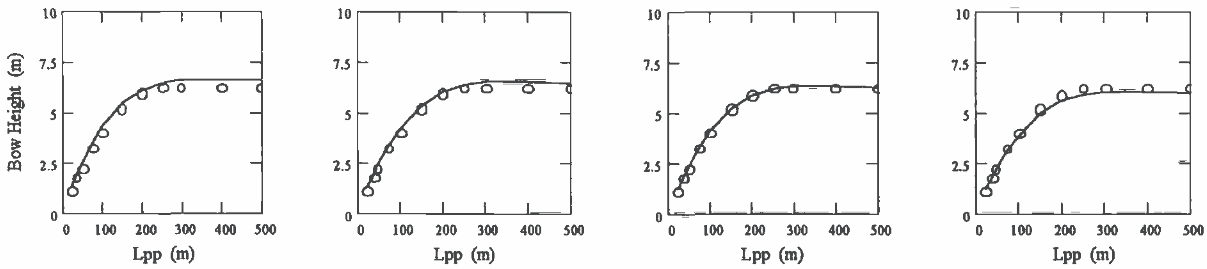

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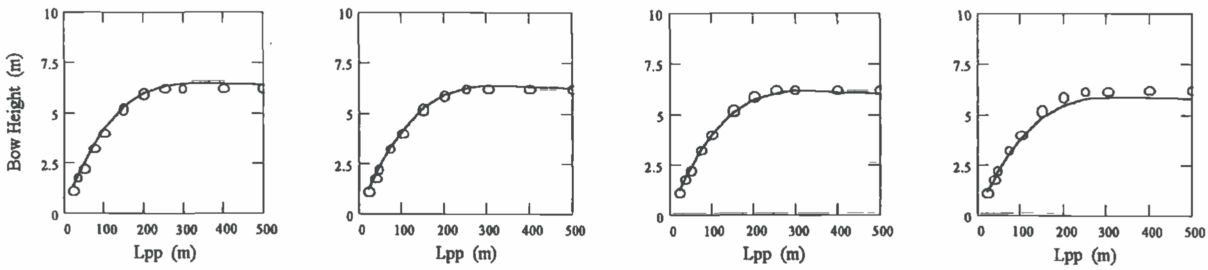

L/B=high

— China o 1966 ICLL B/d= low to high

Figure 53 Bow Height Results of B8 Ships

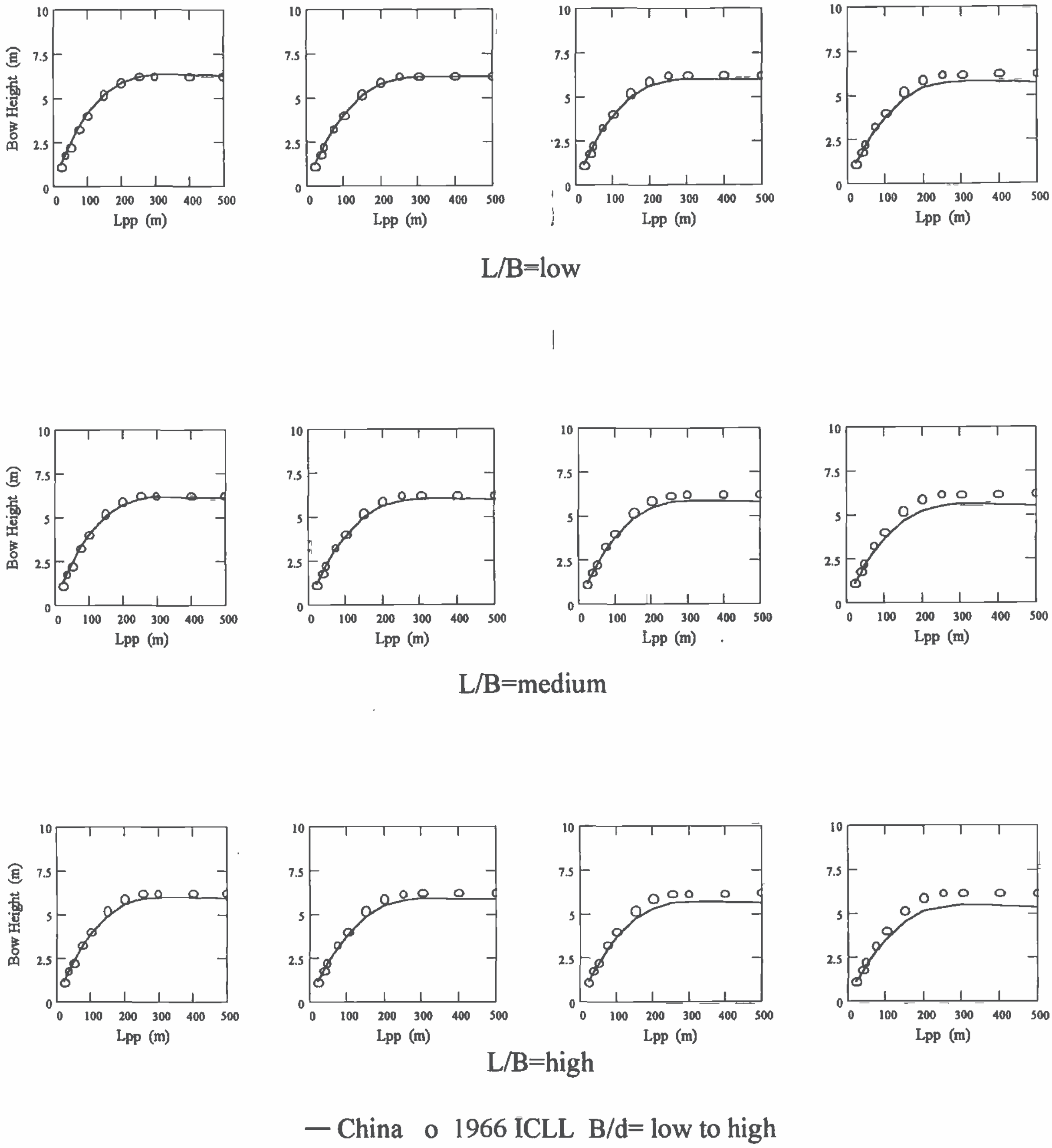

Figure 54 Bow Height Results of Rectangular Pontoons

9 Appendix B: Figures with Detailed Data of the Netherlands

Figure 55 and Figure 56 show for all 1980 ships the bow heights obtained by the long-term probability (LTP) method (cross marks) compared with the 1966 ICLL bow heights (solid line).

Figure 57 through Figure 71 show the LTP bow heights (solid line for $Fn = 0.00$ and a dotted line for $Fn = 0.10$) compared with the 1966 ICLL bow heights (circular marks) in more detail.

Figure 72 through Figure 86 show a comparison of the polynomial expression, based on draught d, with the LTP bow heights.

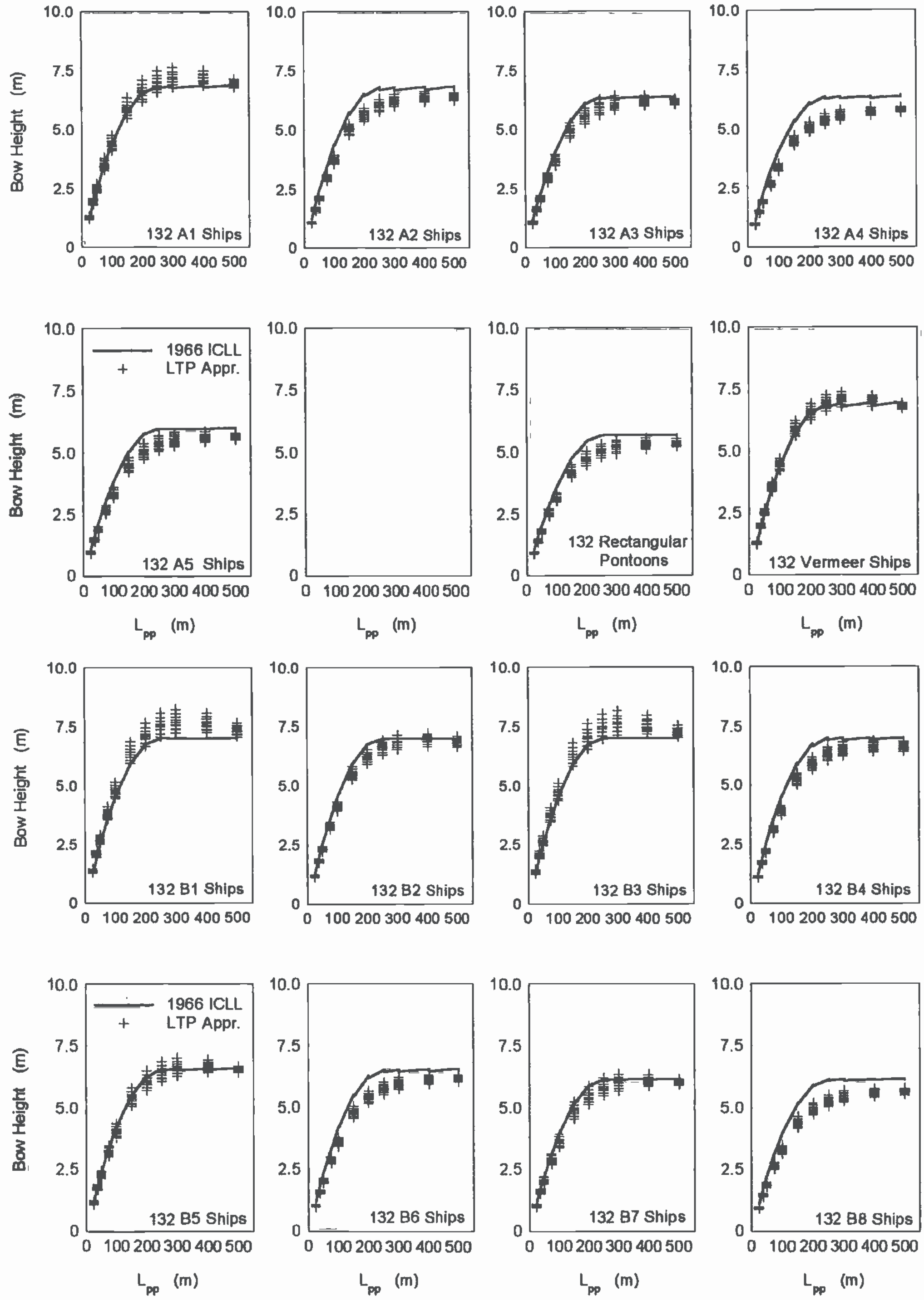

Figure 55 LTP Bow Heights of 1980 Ships for Fn = 0.00

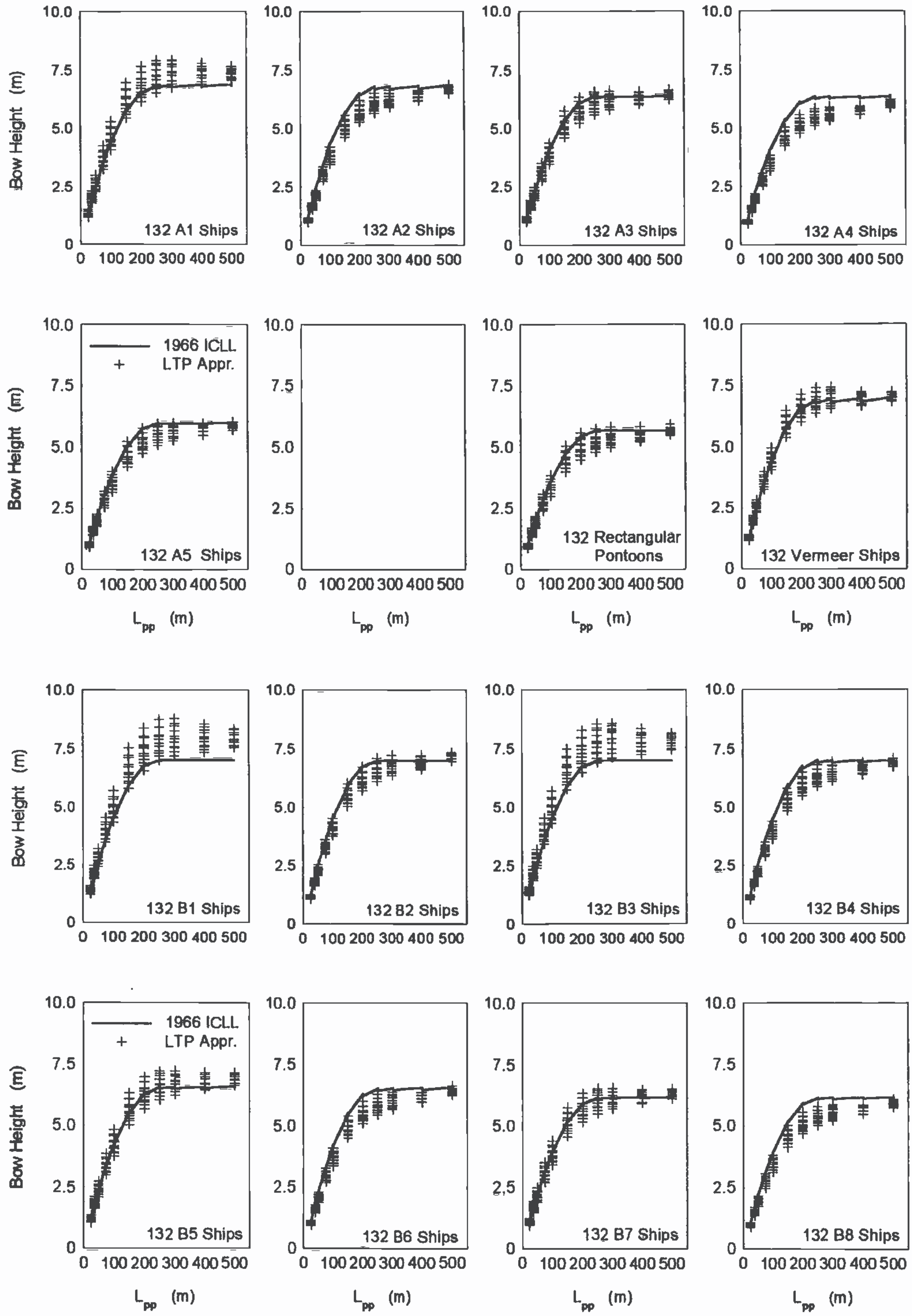

Figure 56 LTP Bow Heights of 1980 Ships for Fn = 0.10

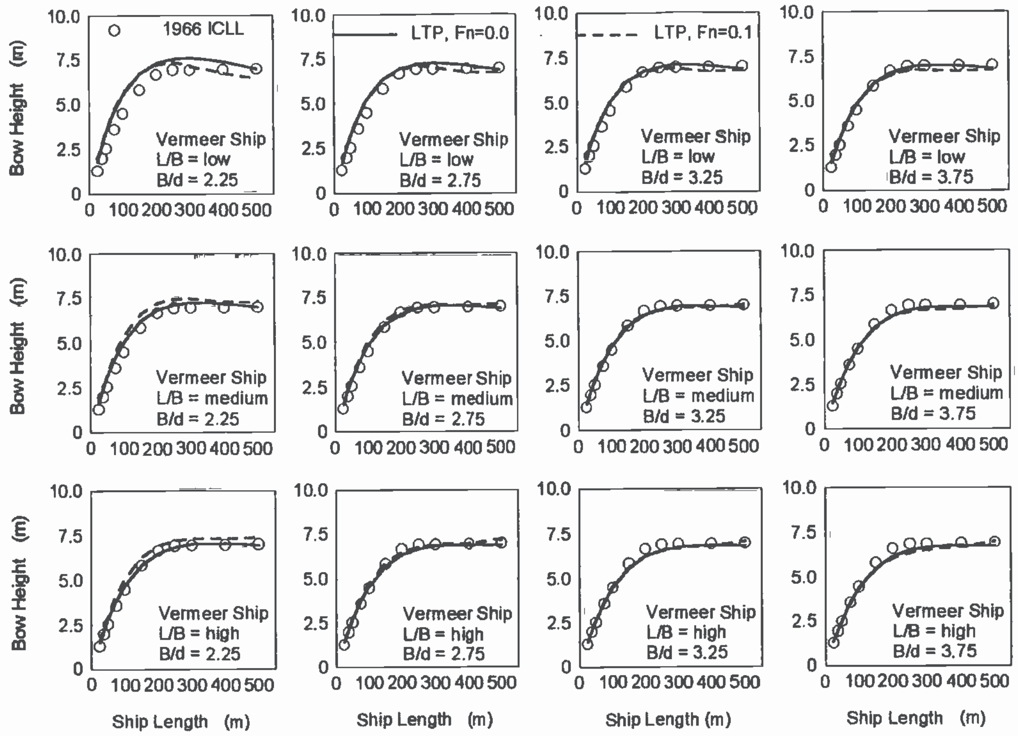

Figure 57 Bow Heights of Vermeer Ships for Averaged LTP's

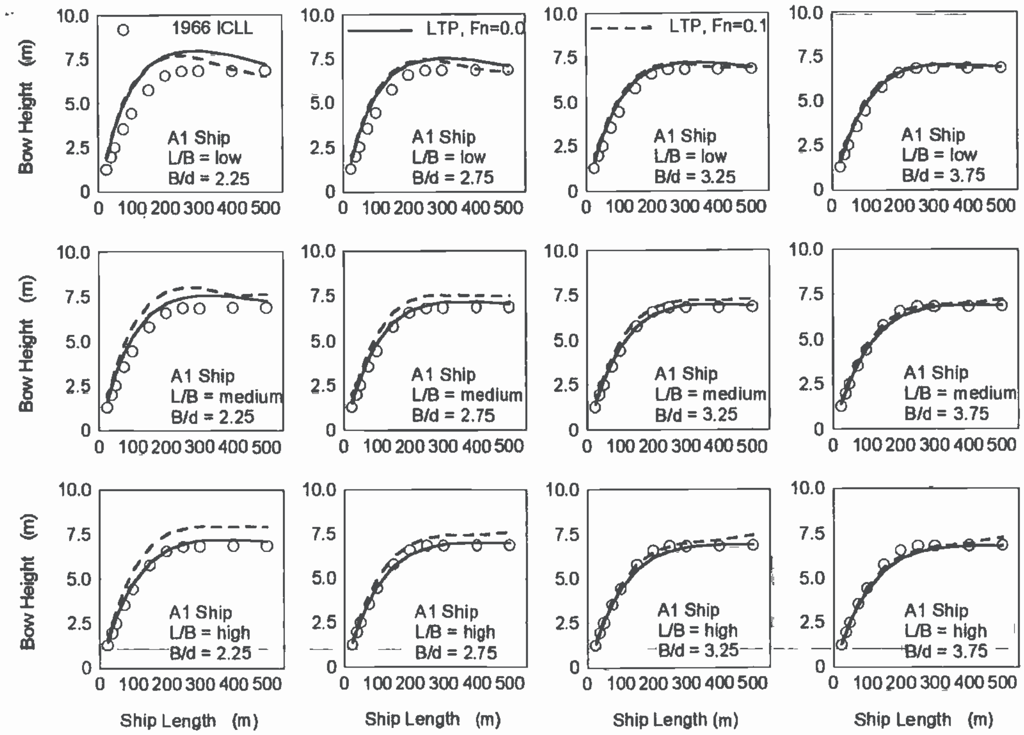

Figure 58 Bow Heights of A1 Ships for Averaged LTP's

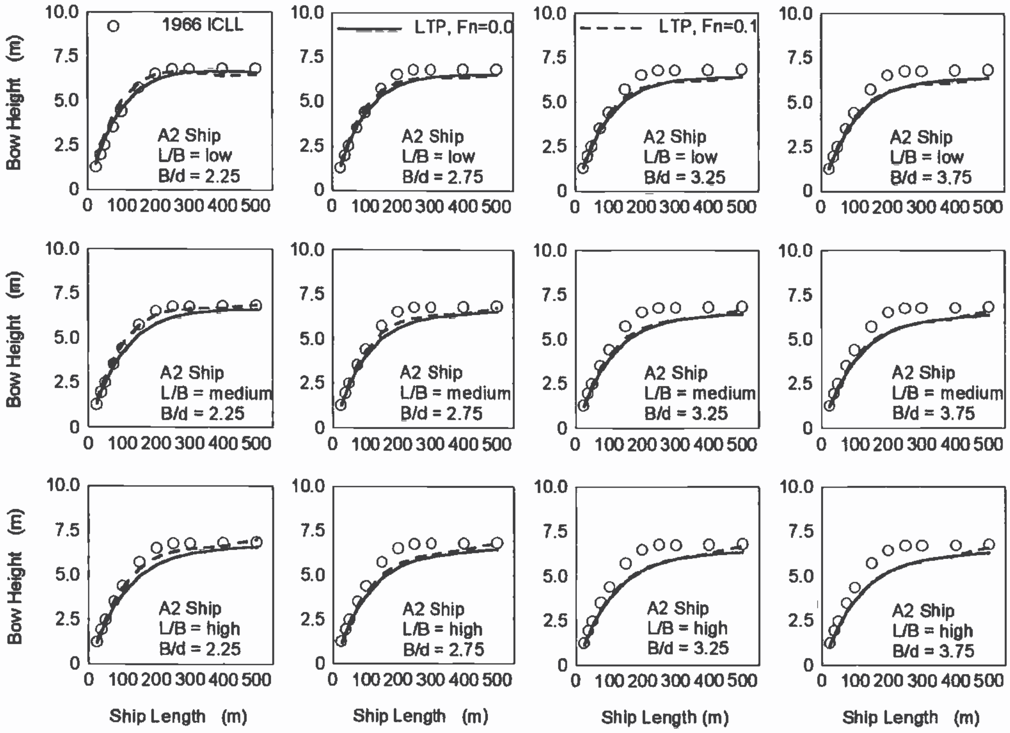

Figure 59 Bow Heights of A2 Ships for Averaged LTP's

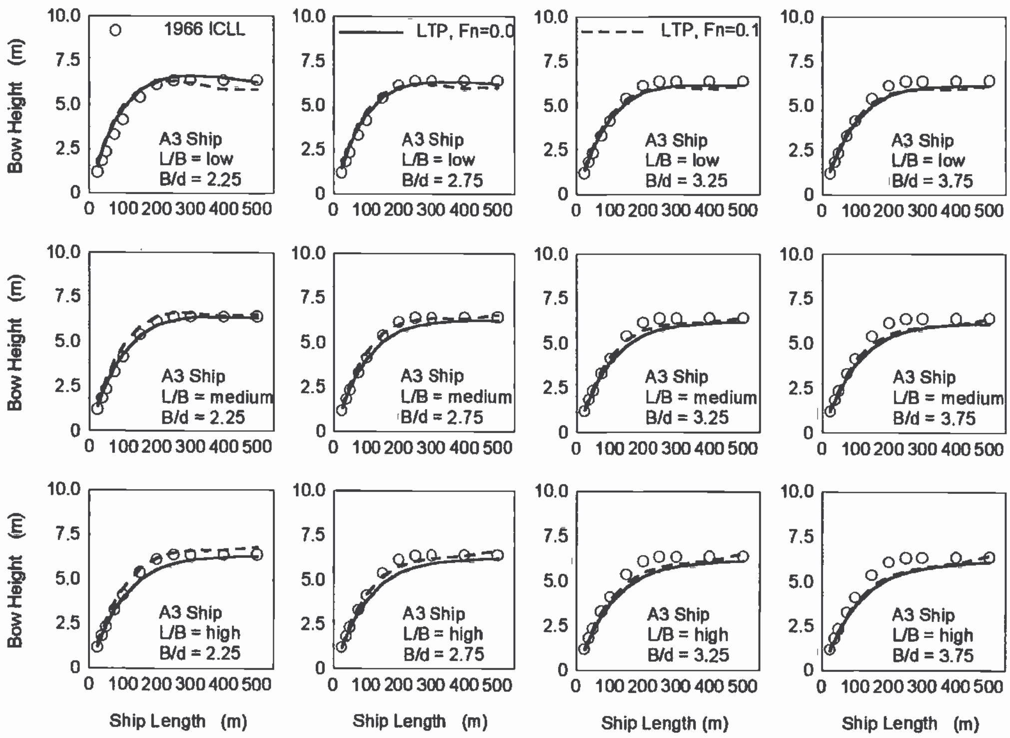

Figure 60 Bow Heights of A3 Ships for Averaged LTP's

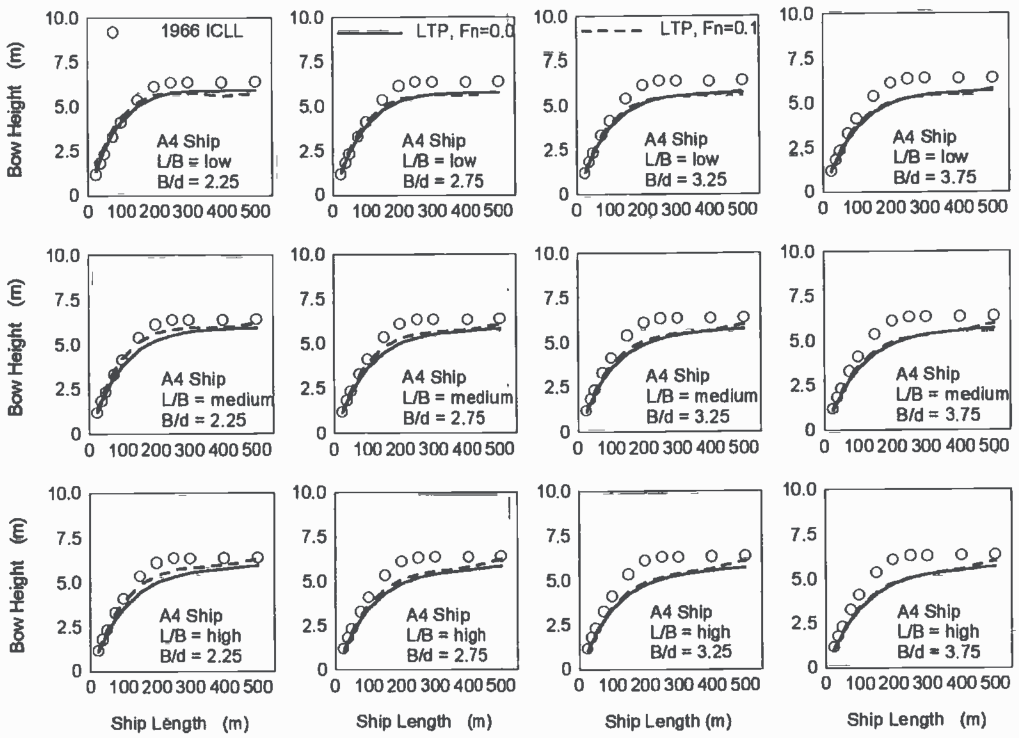

Figure 61 Bow Heights of A4 Ships for Averaged LTP's

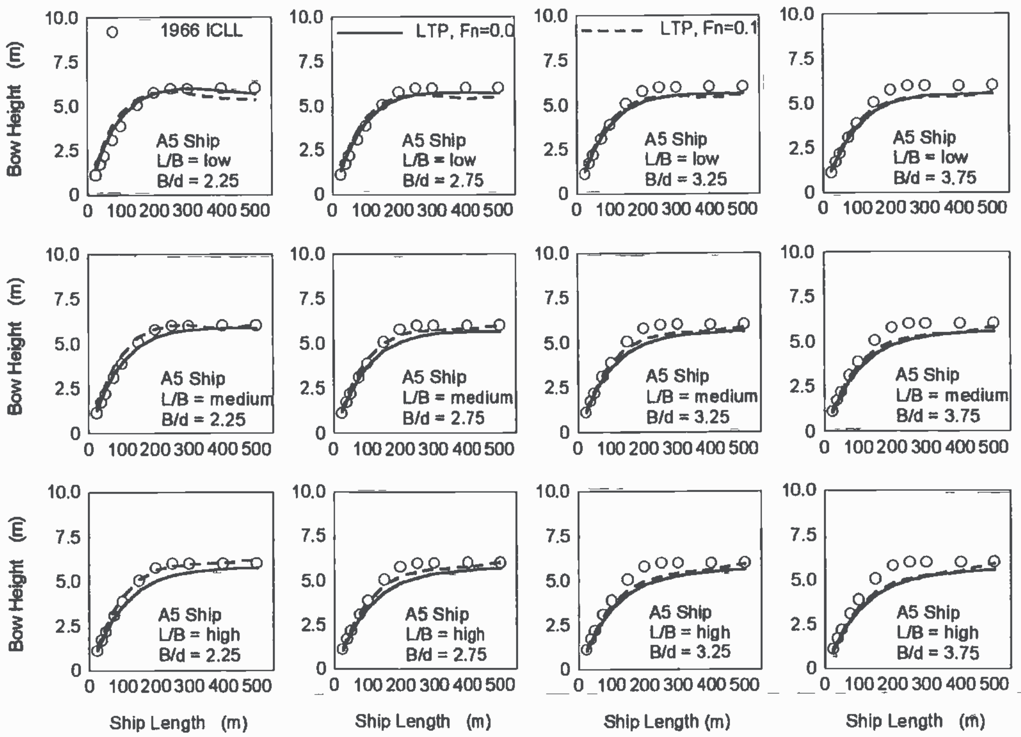

Figure 62 Bow Heights of A5 Ships for Averaged LTP's

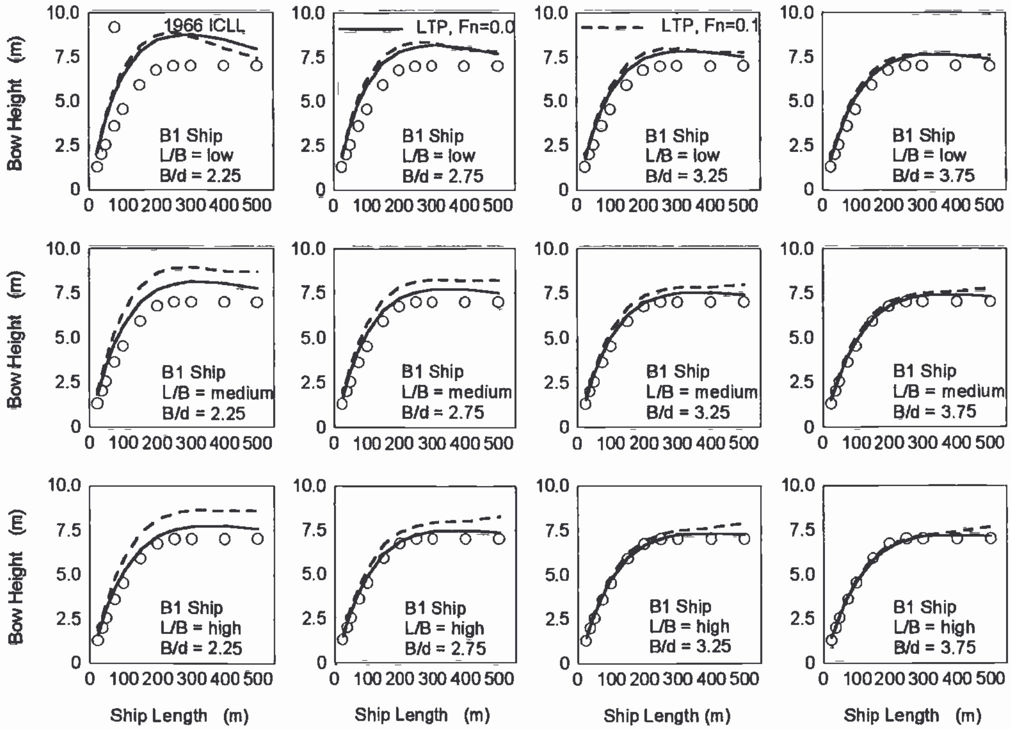

Figure 63 Bow Heights of B1 Ships for Averaged LTP's

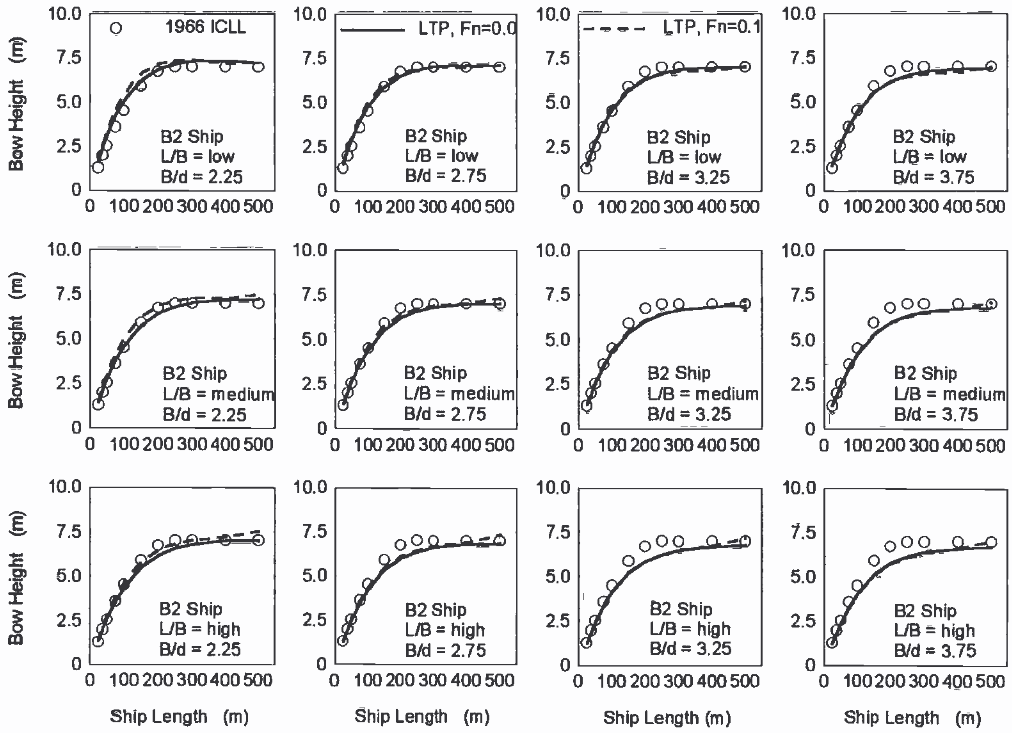

Figure 64 Bow Heights of B2 Ships for Averaged LTP's

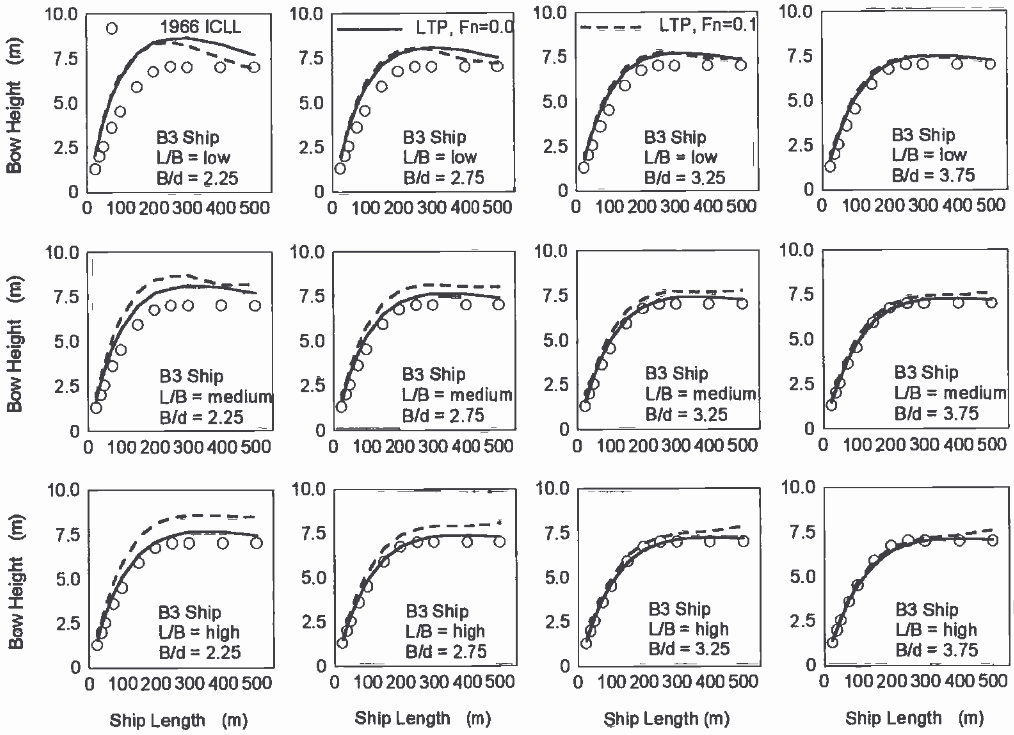

Figure 65 Bow Heights of B3 Ships for Averaged LTP's

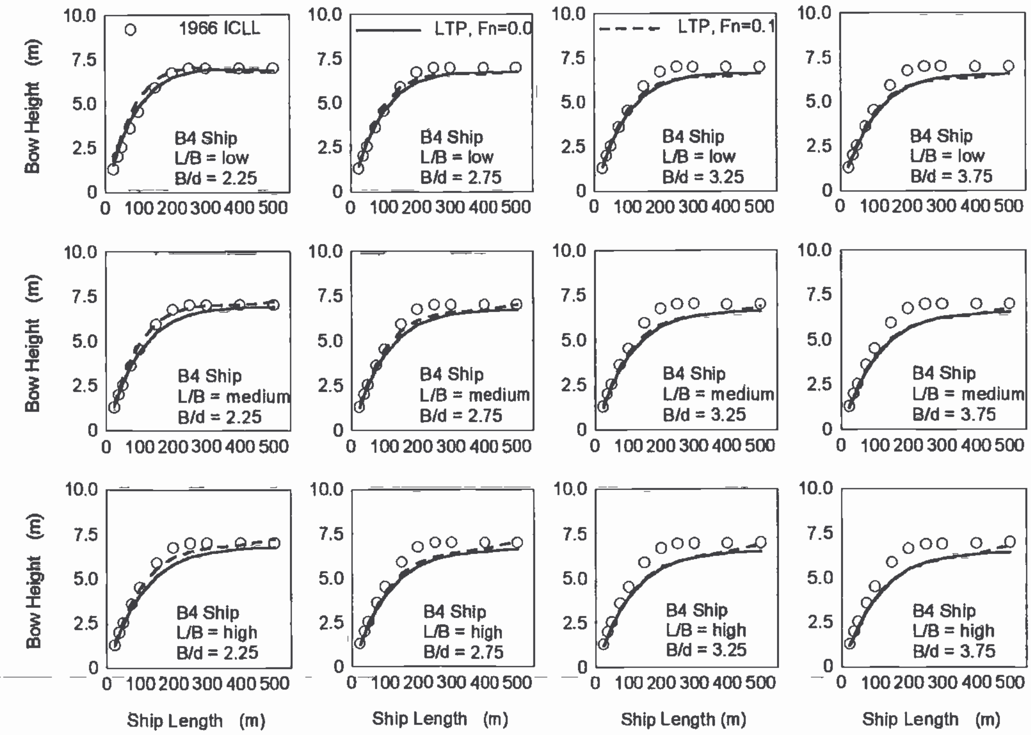

Figure 66 Bow Heights of B4 Ships for Averaged LTP's

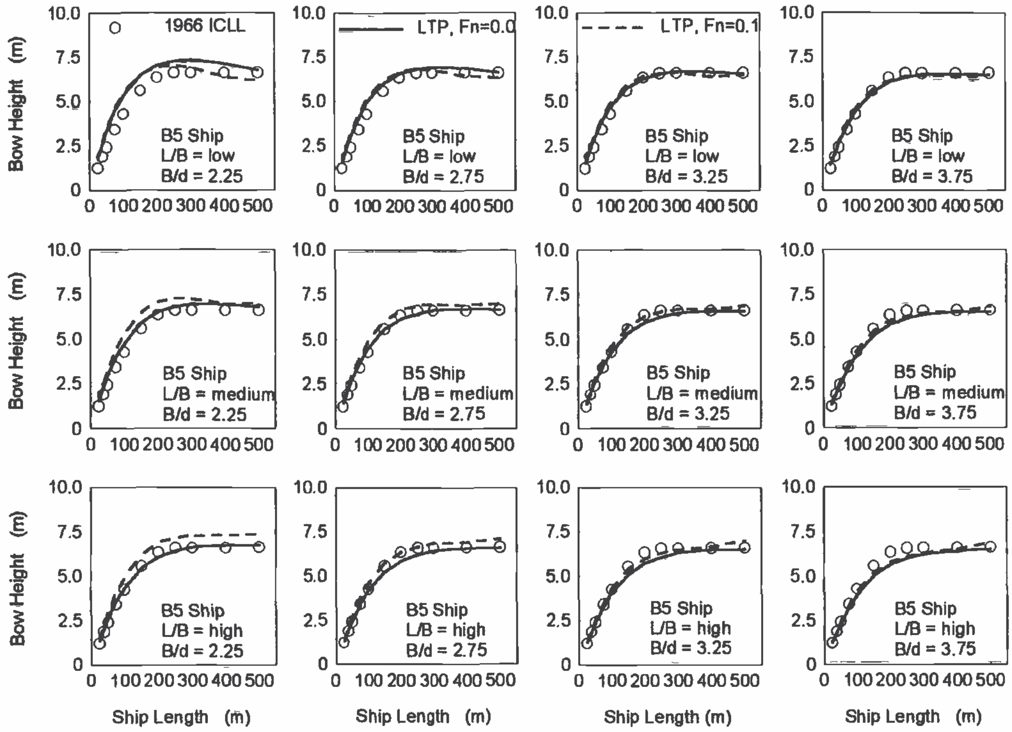

Figure 67 Bow Heights of B5 Ships for Averaged LTP's

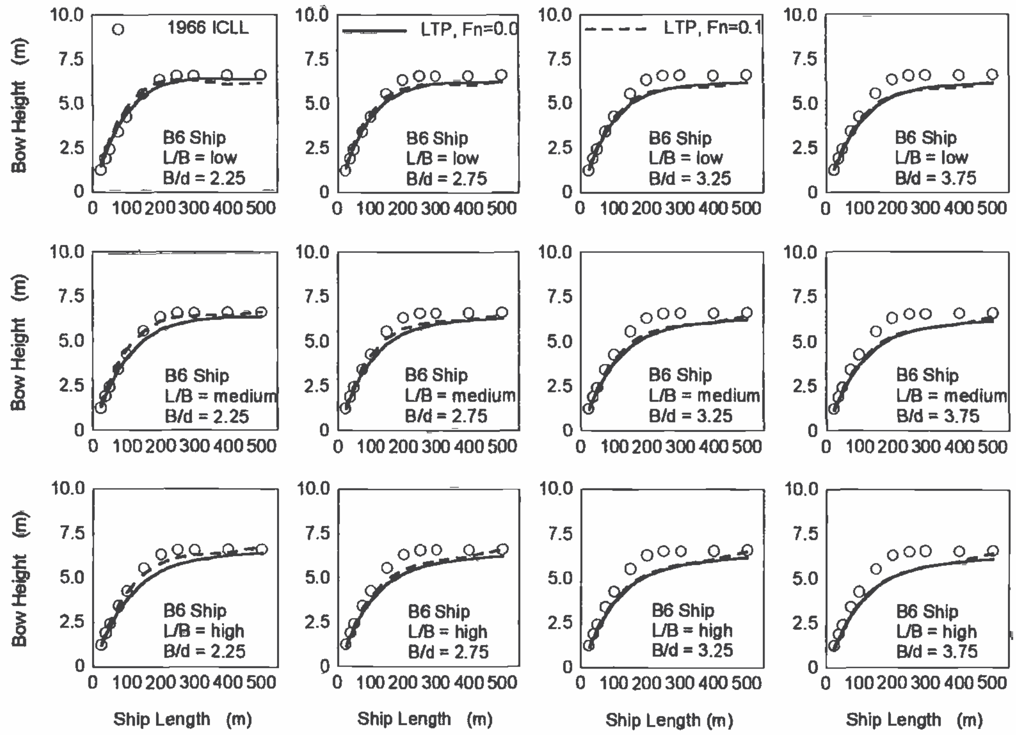

Figure 68 Bow Heights of B6 Ships for Averaged LTP's

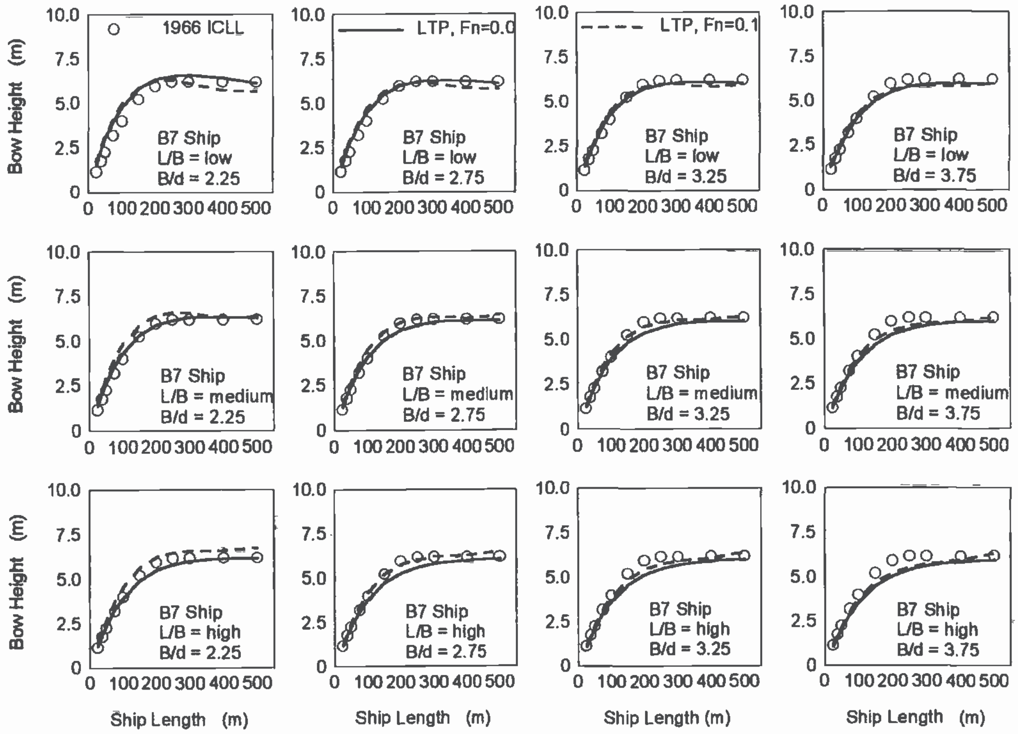

Figure 69 Bow Heights of B7 Ships for Averaged LTP's

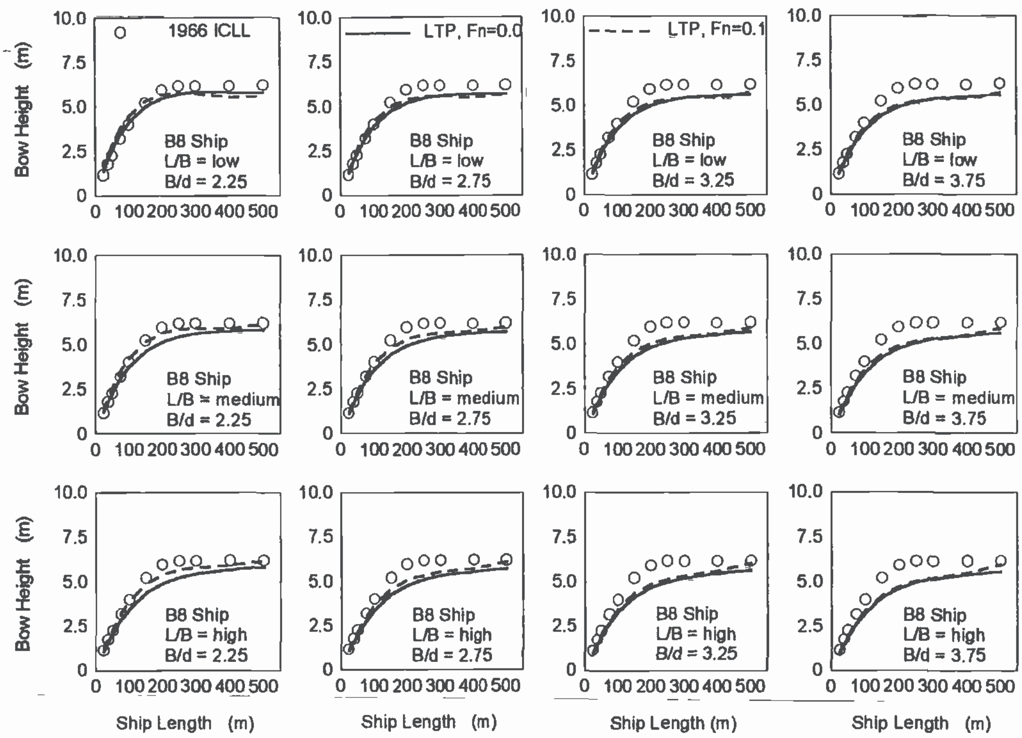

Figure 70 Bow Heights of B8 Ships for Averaged LTP's

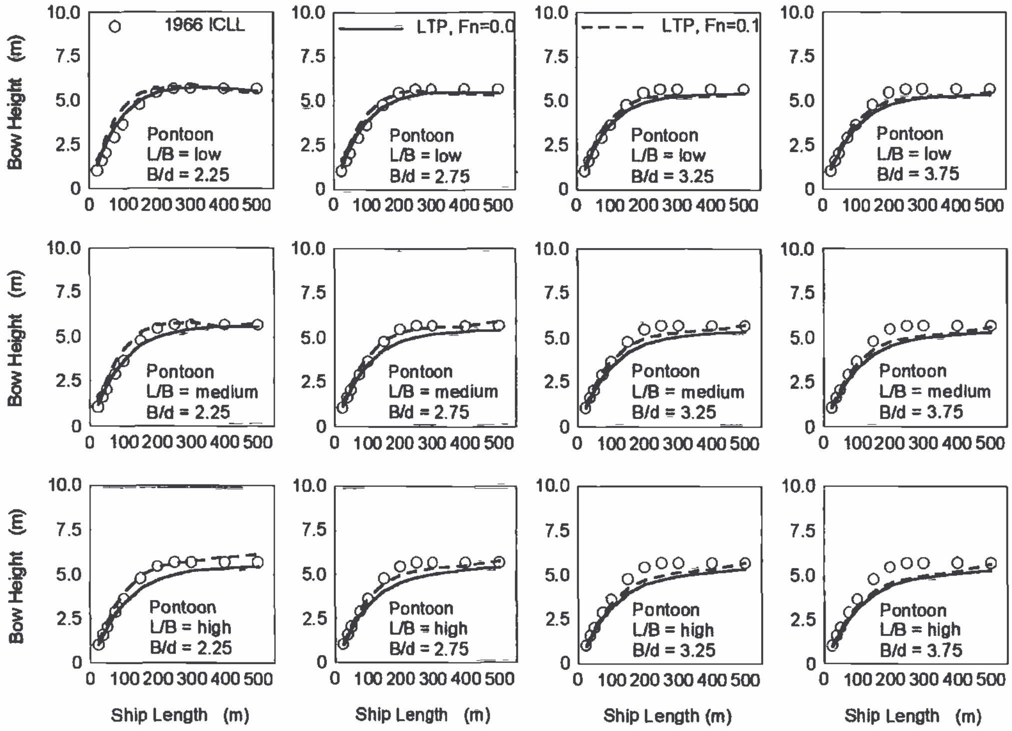

Figure 71 Bow Heights of Rectangular Pontoons for Averaged LTP's

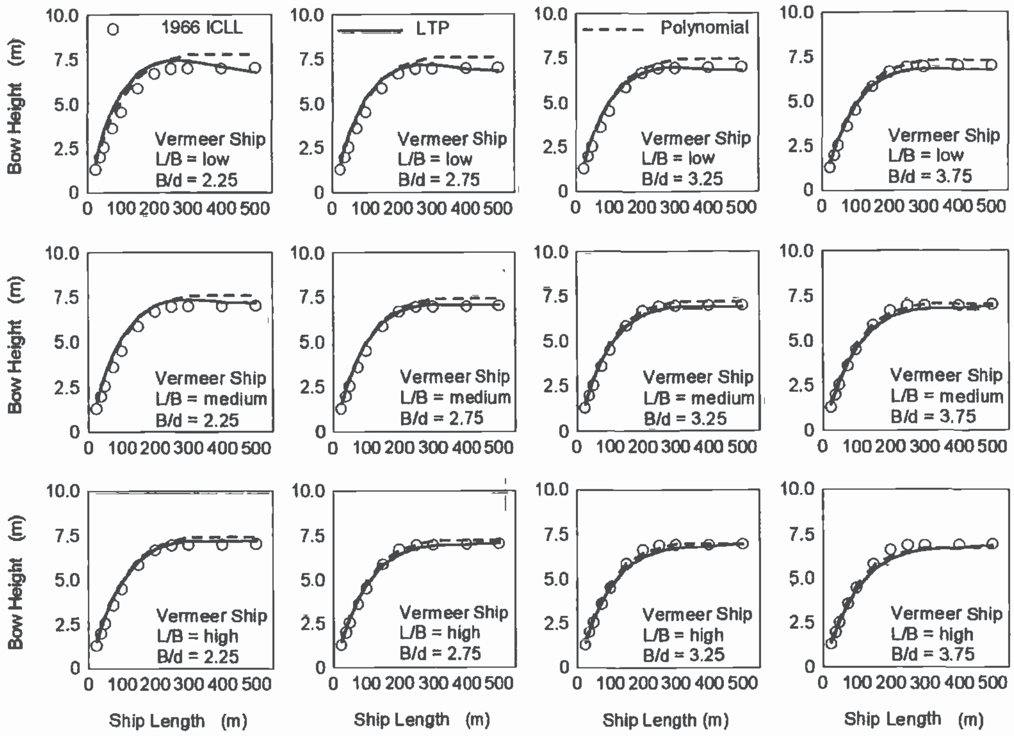

Figure 72 LTP and Polynomial Bow Heights of Vermeer Ships

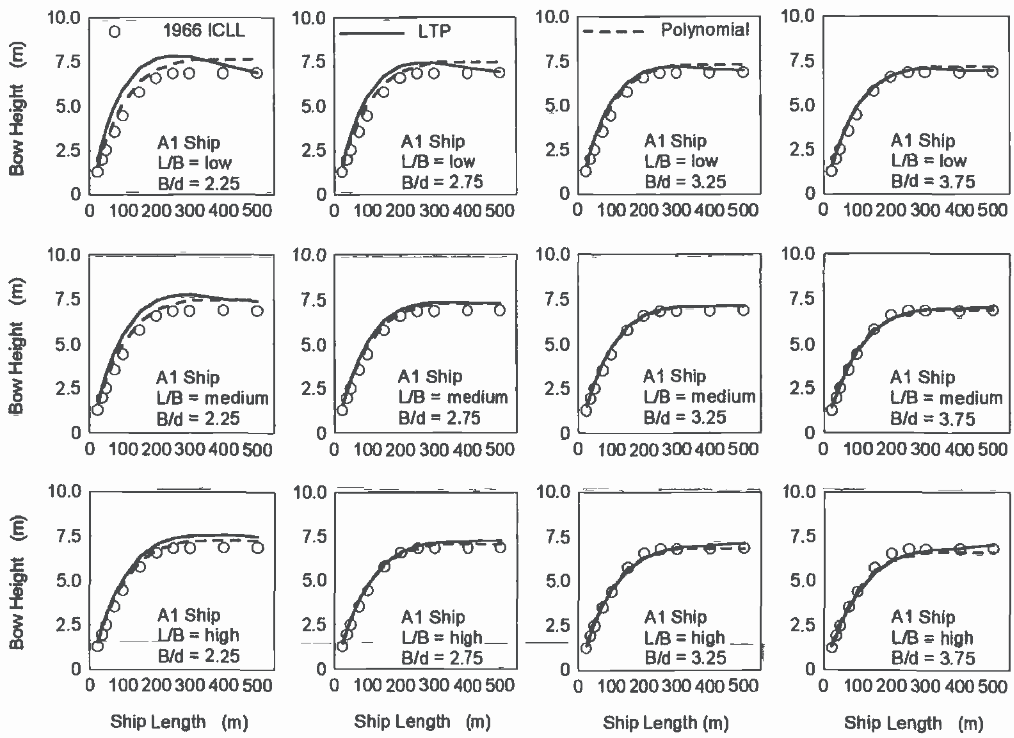

Figure 73 LTP and Polynomial Bow Heights of A1 Ships

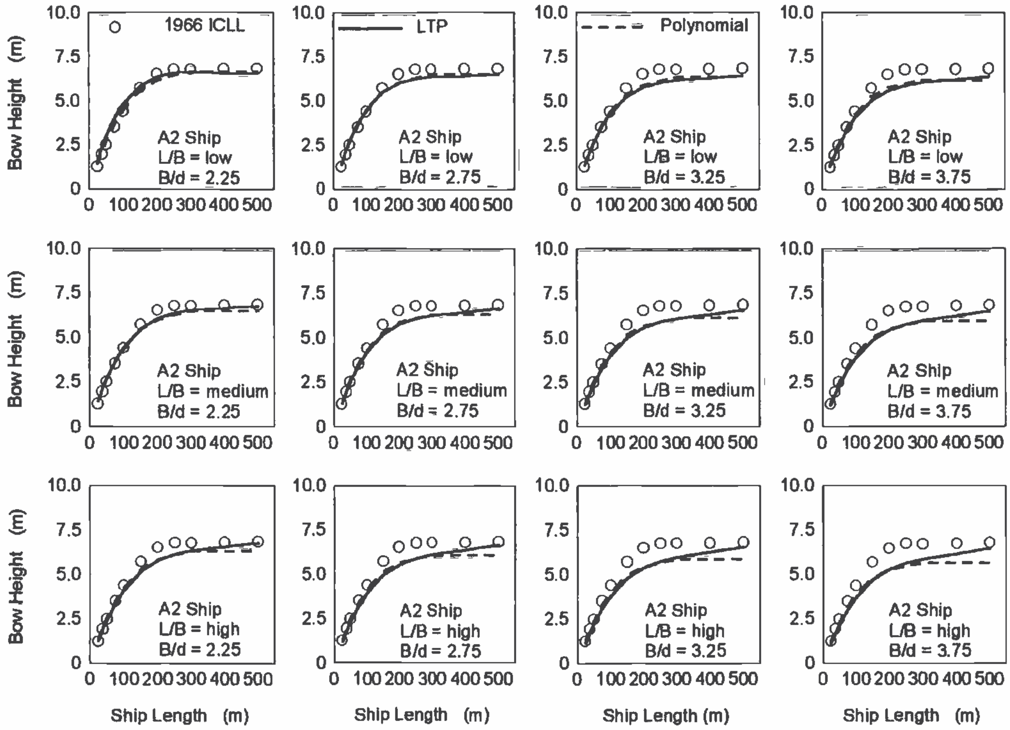

Figure 74 LTP and Polynomial Bow Heights of A2 Ships

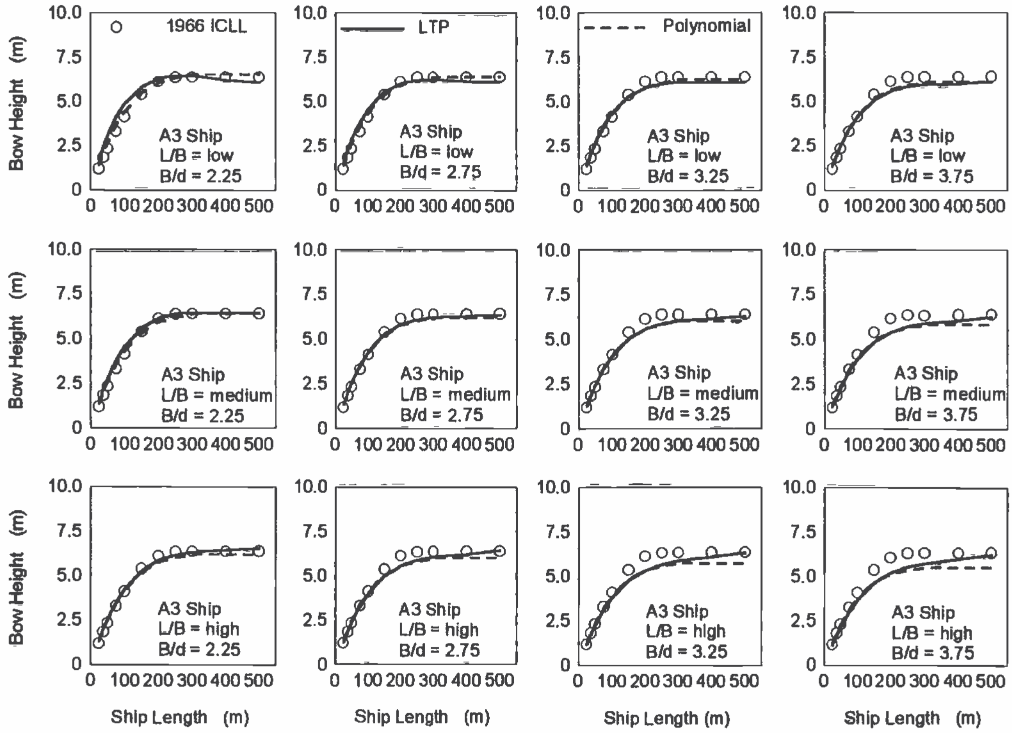

Figure 75 LTP and Polynomial Bow Heights of A3 Ships

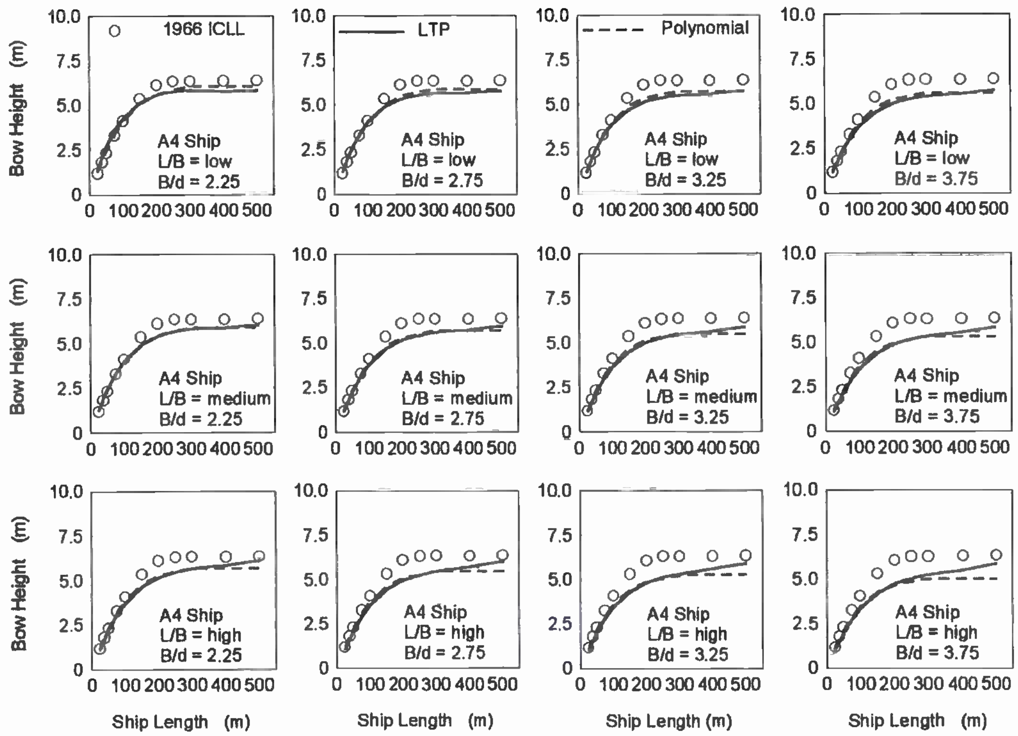

Figure 76 LTP and Polynomial Bow Heights of A4 Ships

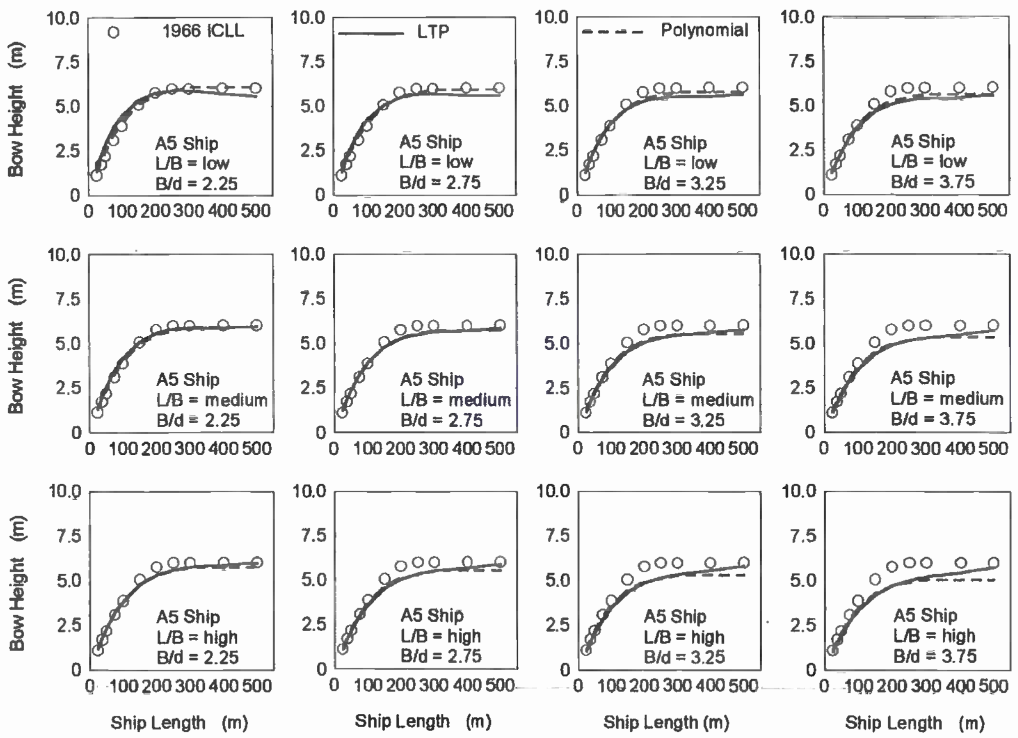

Figure 77 LTP and Polynomial Bow Heights of A5 Ships

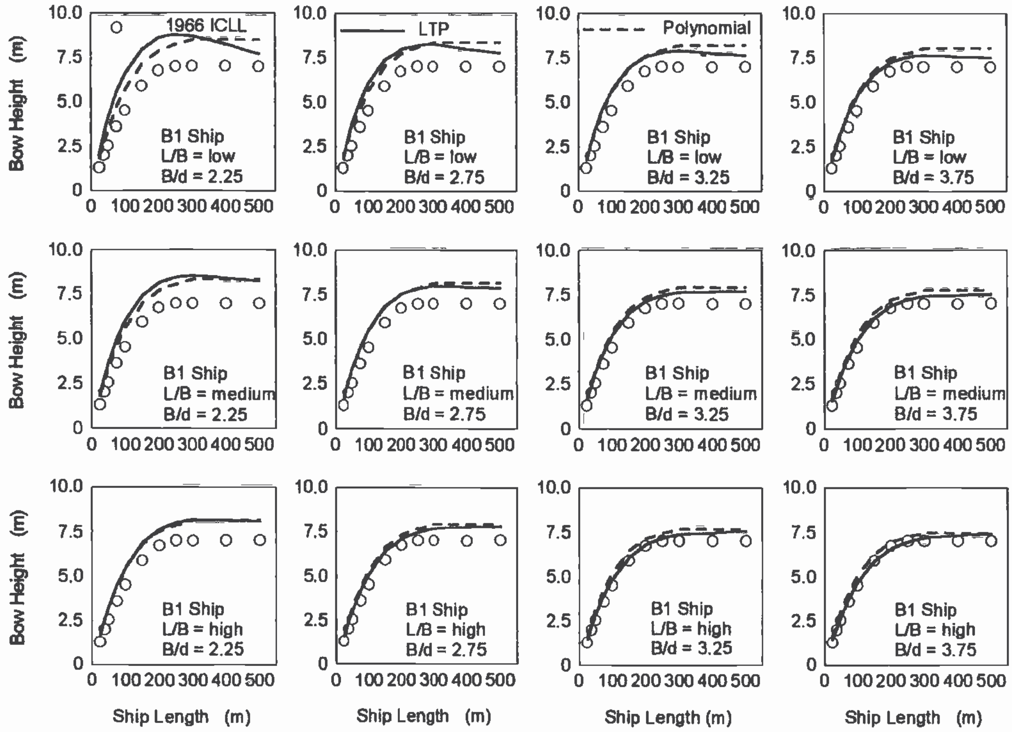

Figure 78 LTP and Polynomial Bow Heights of B1 Ships

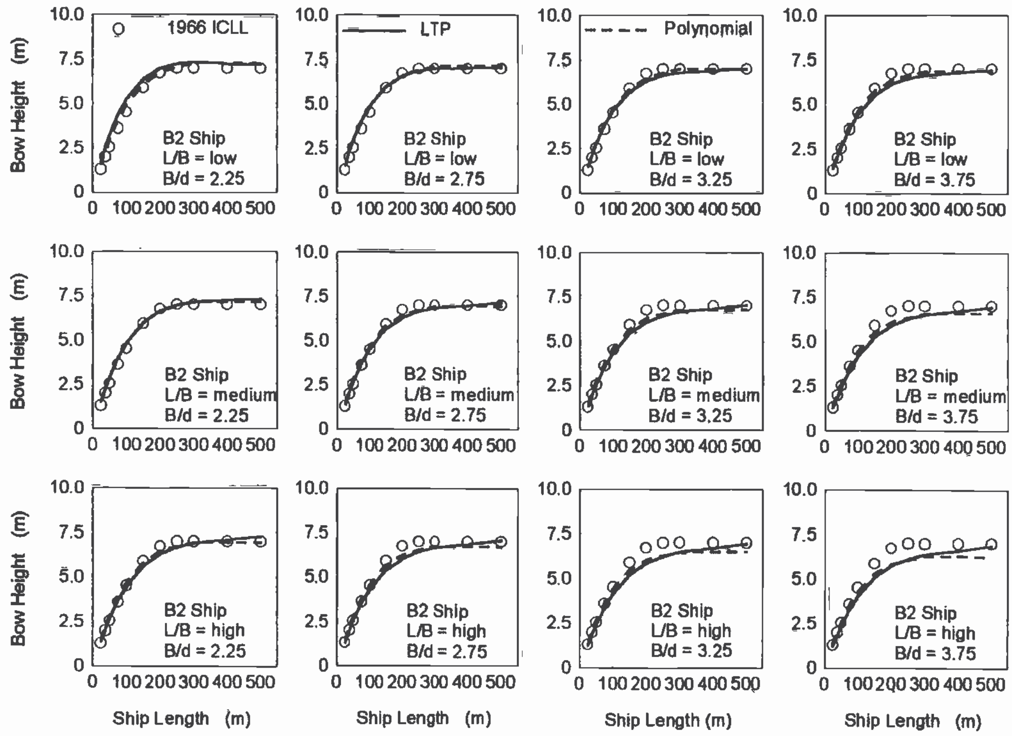

Figure 79 LTP and Polynomial Bow Heights of B2 Ships

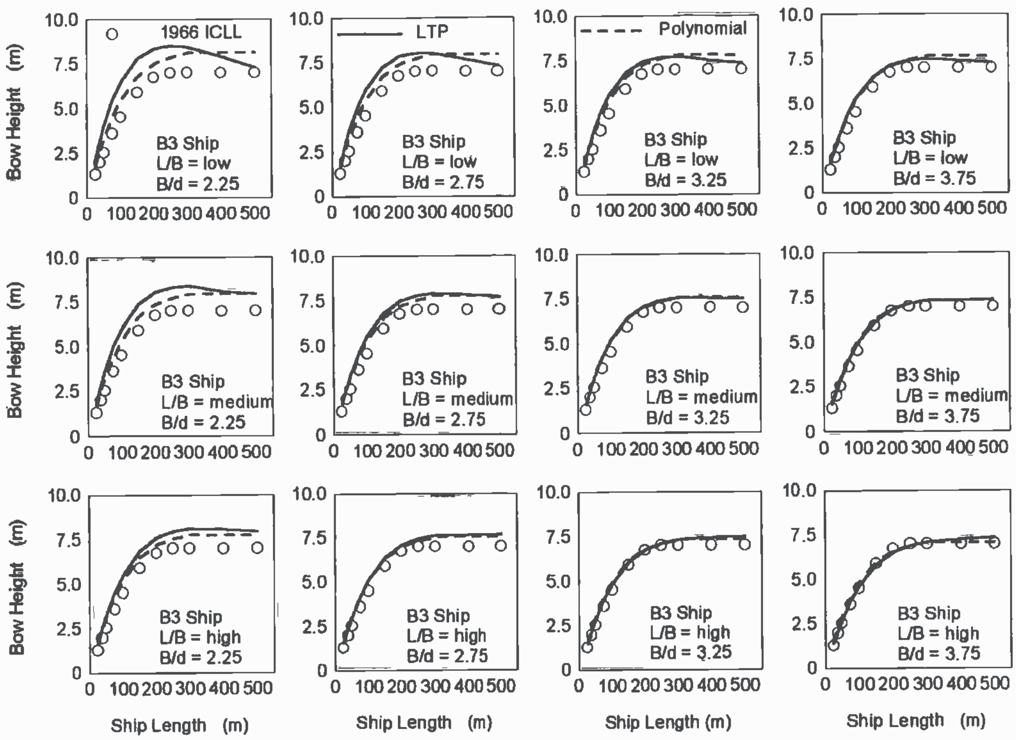

Figure 80 LTP and Polynomial Bow Heights of B3 Ships

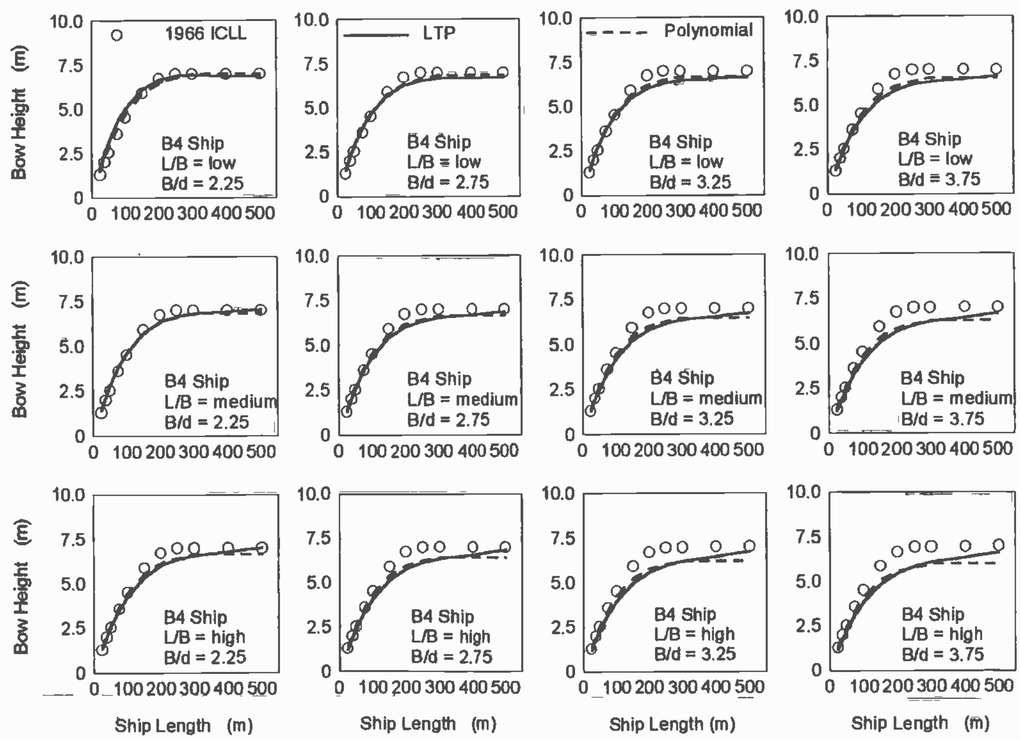

Figure 81 LTP and Polynomial Bow Heights of B4 Ships

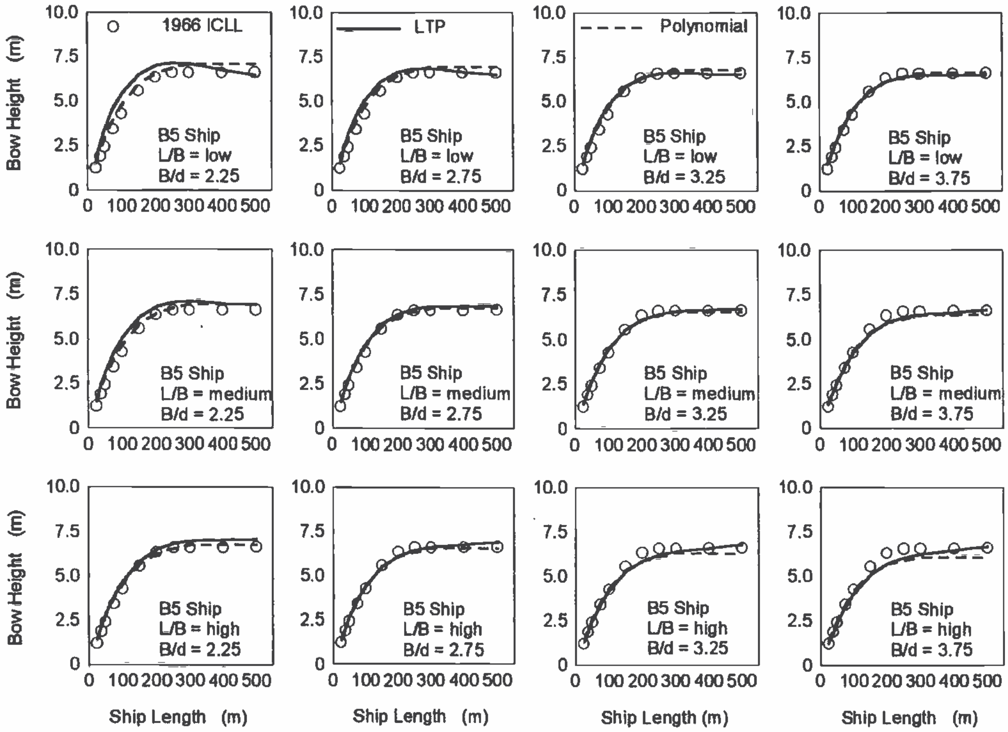

Figure 82 LTP and Polynomial Bow Heights of B5 Ships

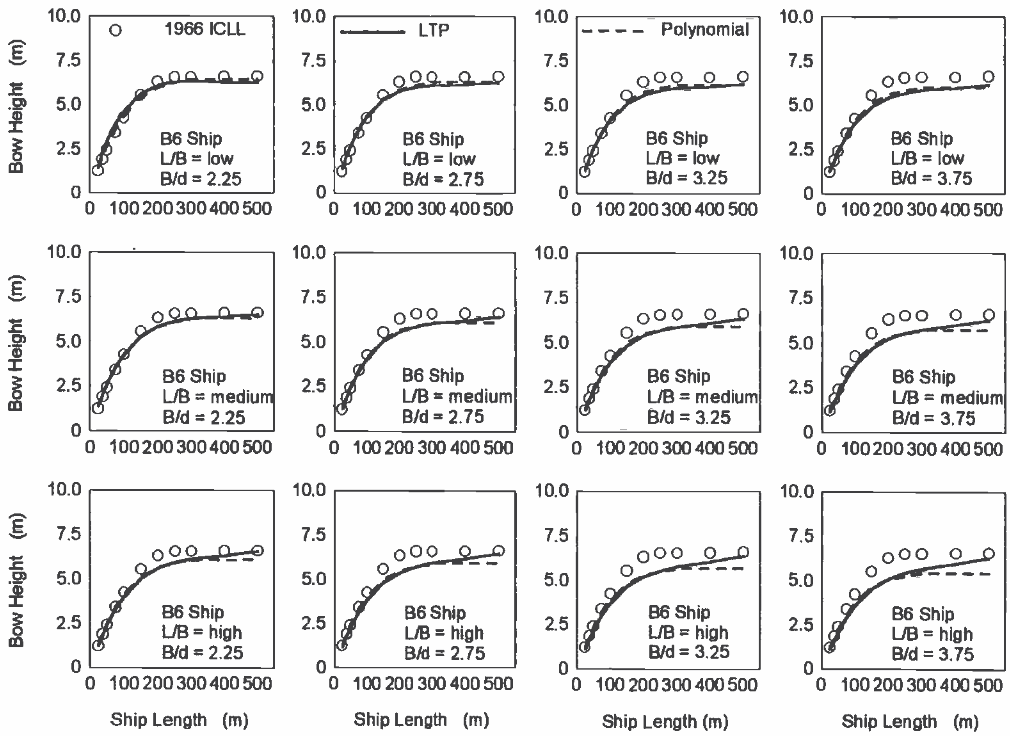

Figure 83 LTP and Polynomial Bow Heights of B6 Ships

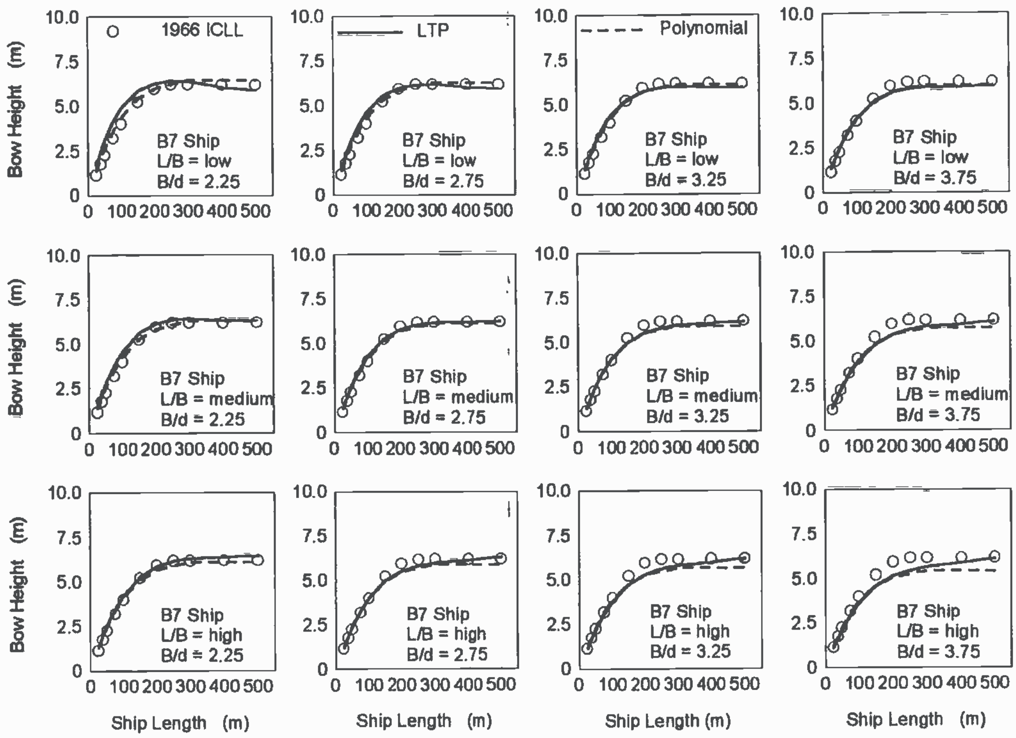

Figure 84 LTP and Polynomial Bow Heights of B7 Ships

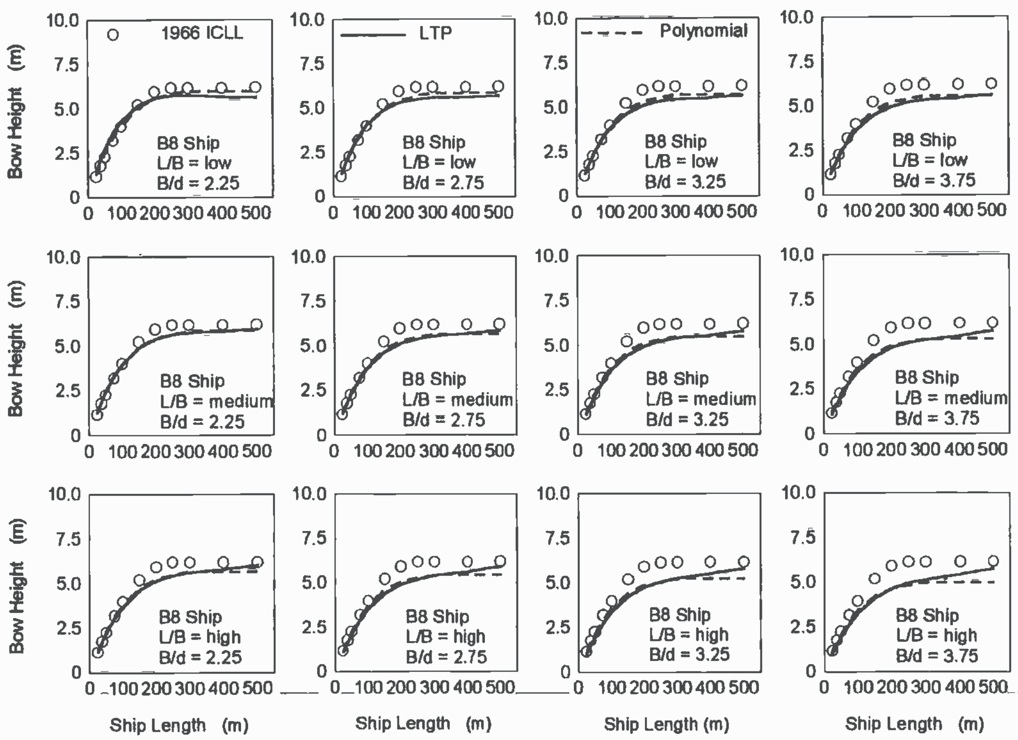

Figure 85 LTP and Polynomial Bow Heights of B8 Ships

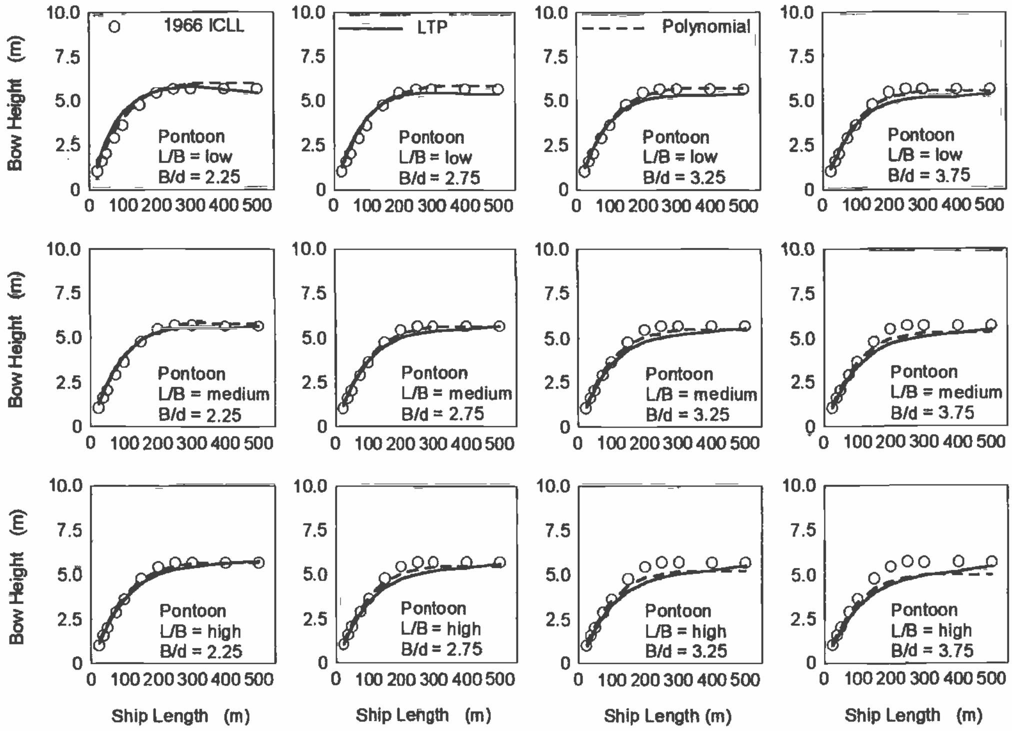

Figure 86 LTP and Polynomial Bow Heights of Rectangular Pontoons

10 Appendix C: Comparison of Bow Height Formulas Based on *d*

In Figure 87 through Figure 101, the bow heights obtained by the new formulas (based on the draught d) of China and the Netherlands have been compared mutually and with the bow heights as obtained by the 1966 ICLL.

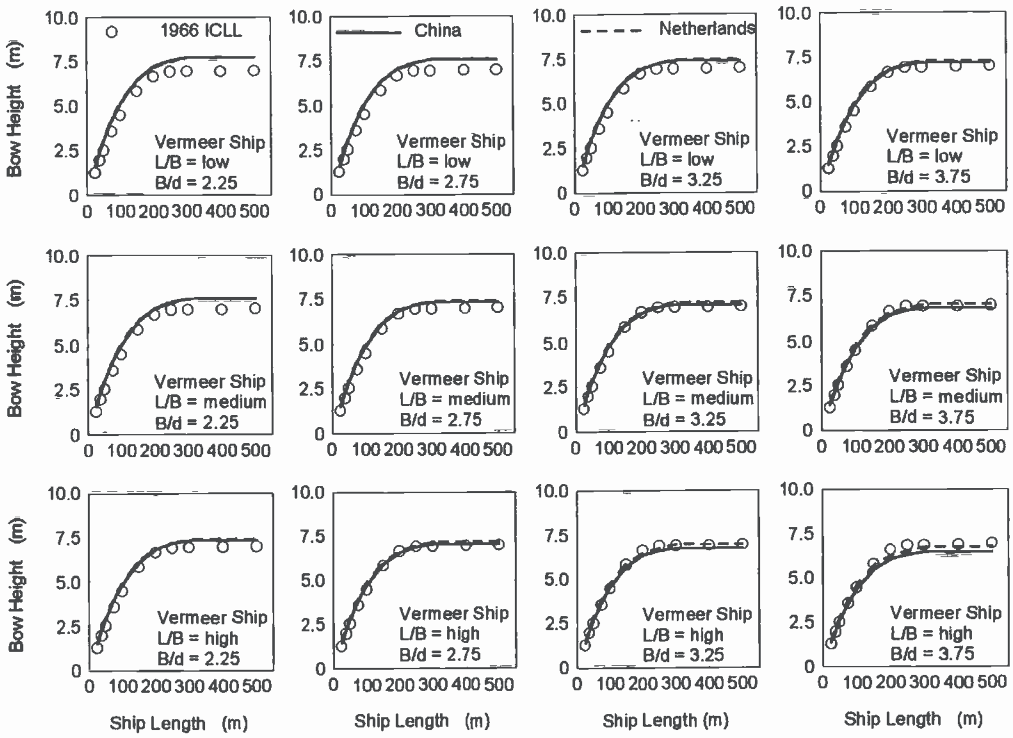

Figure 87 Bow Height Polynomials of China and NL of Vermeer Ships

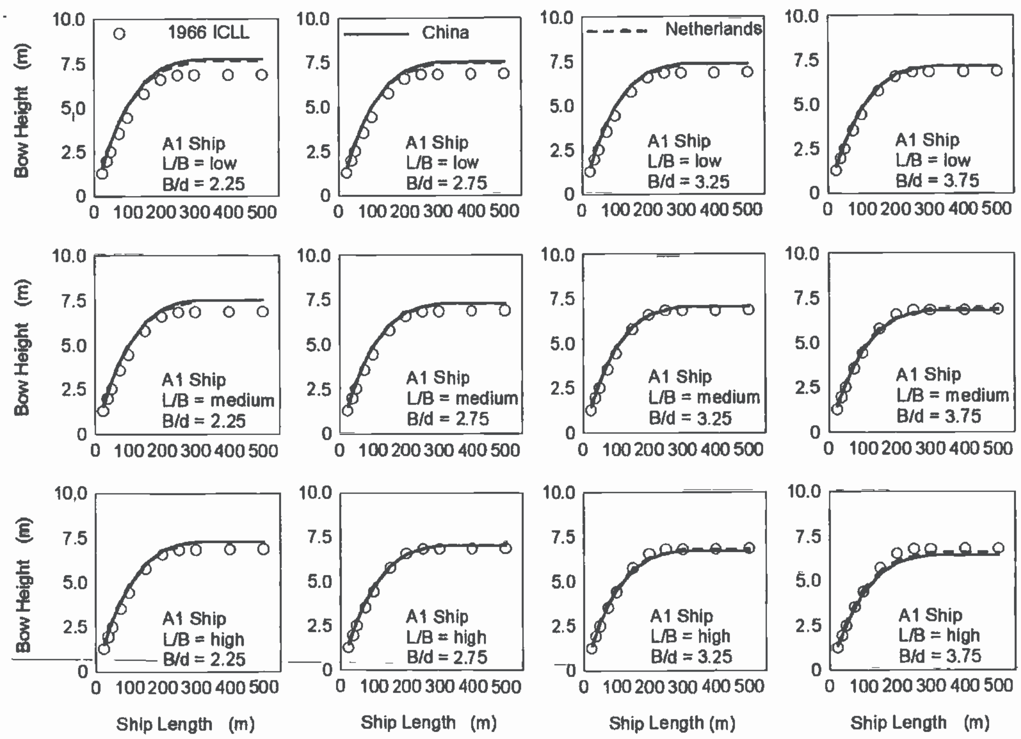

Figure 88 Bow Height Polynomials of China and NL of A1 Ships

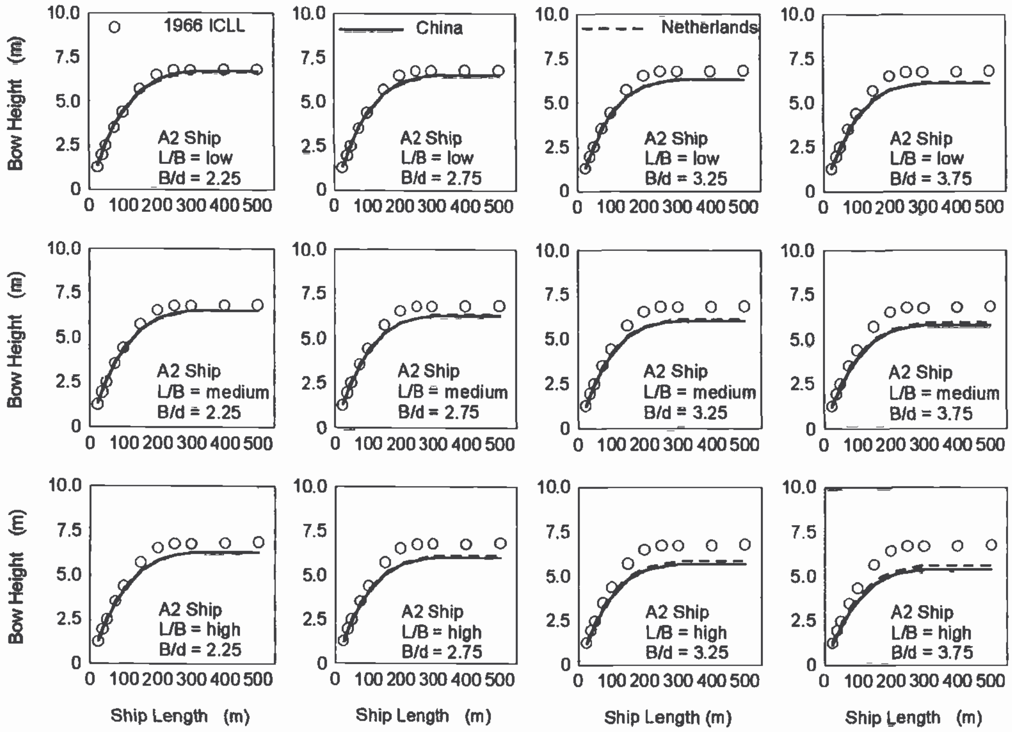

Figure 89 Bow Height Polynomials of China and NL of A2 Ships

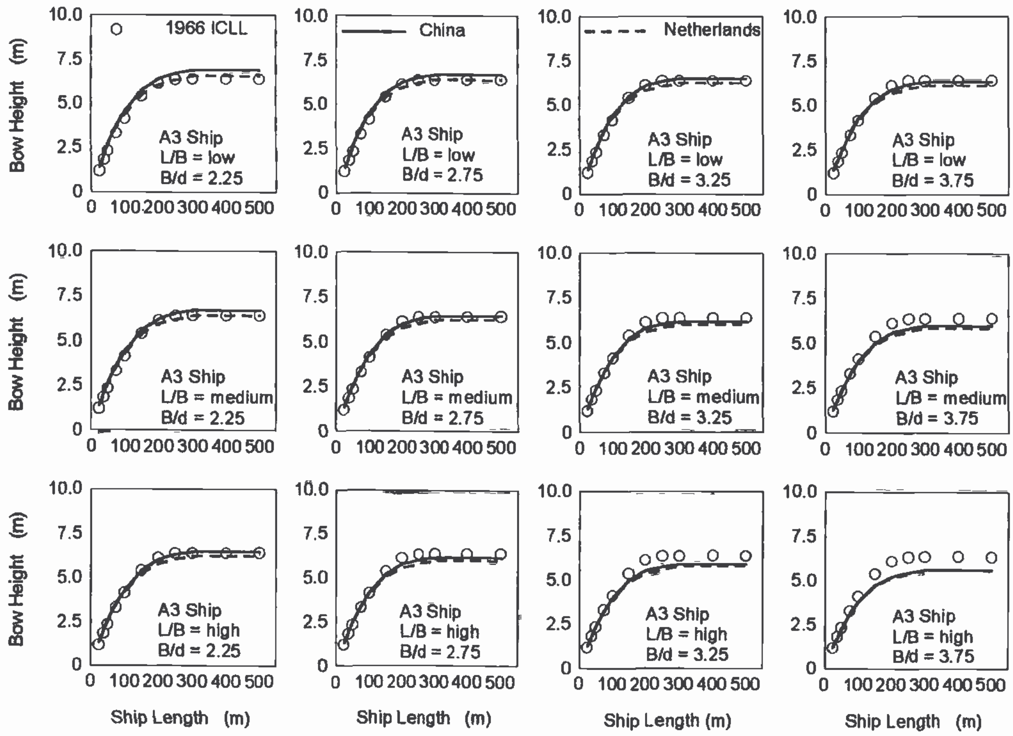

Figure 90 Bow Height Polynomials of China and NL of A3 Ships

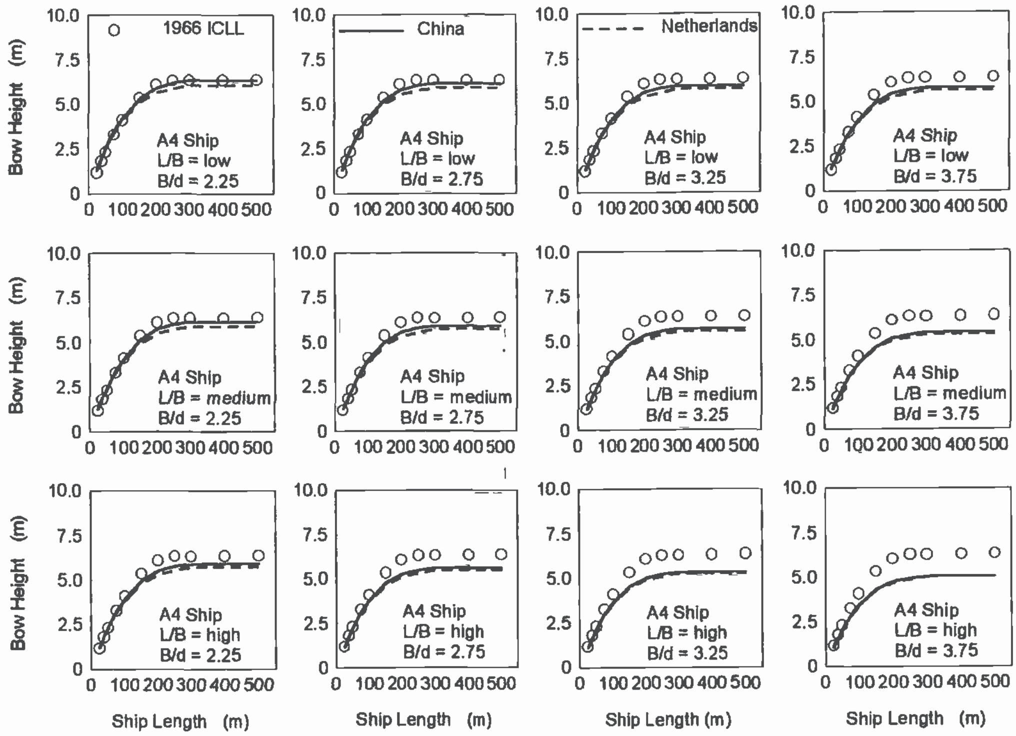

Figure 91 Bow Height Polynomials of China and NL of A4 Ships

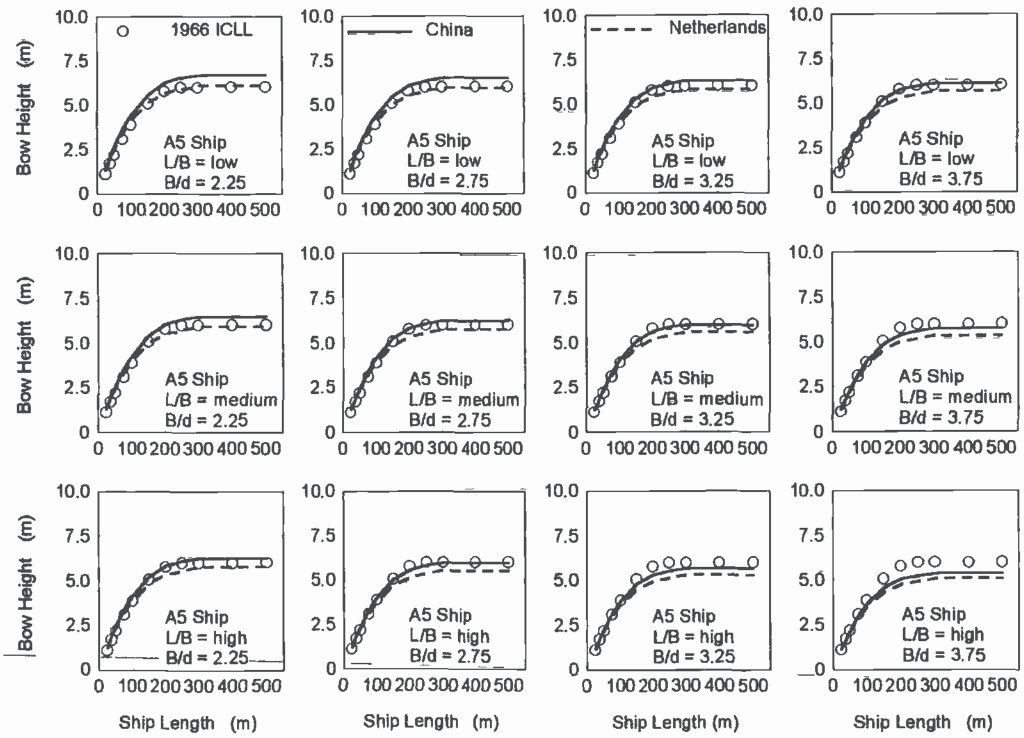

Figure 92 Bow Height Polynomials of China and NL of A5 Ships

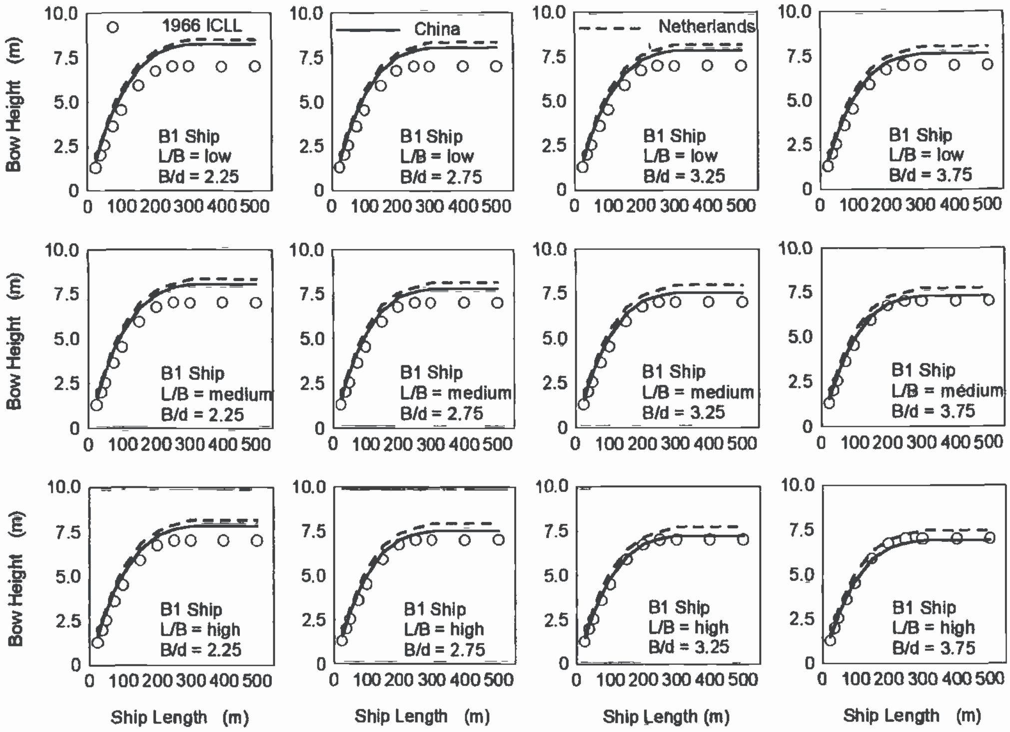

Figure 93 Bow Height Polynomials of China and NL of B1 Ships

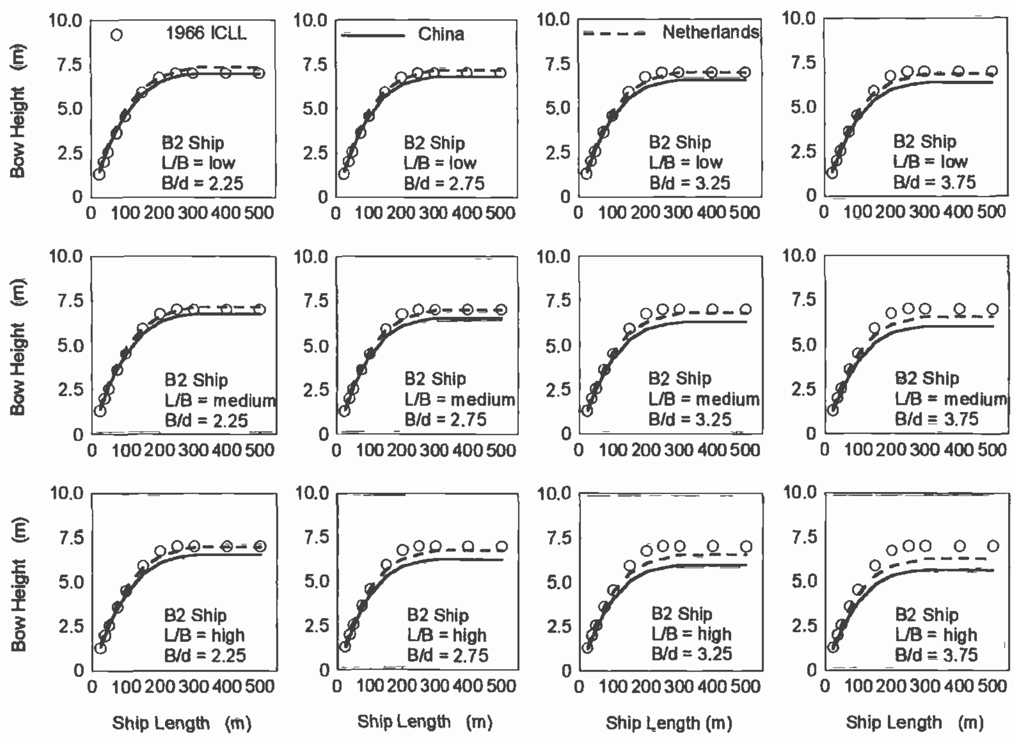

Figure 94 Bow Height Polynomials of China and NL of B2 Ships

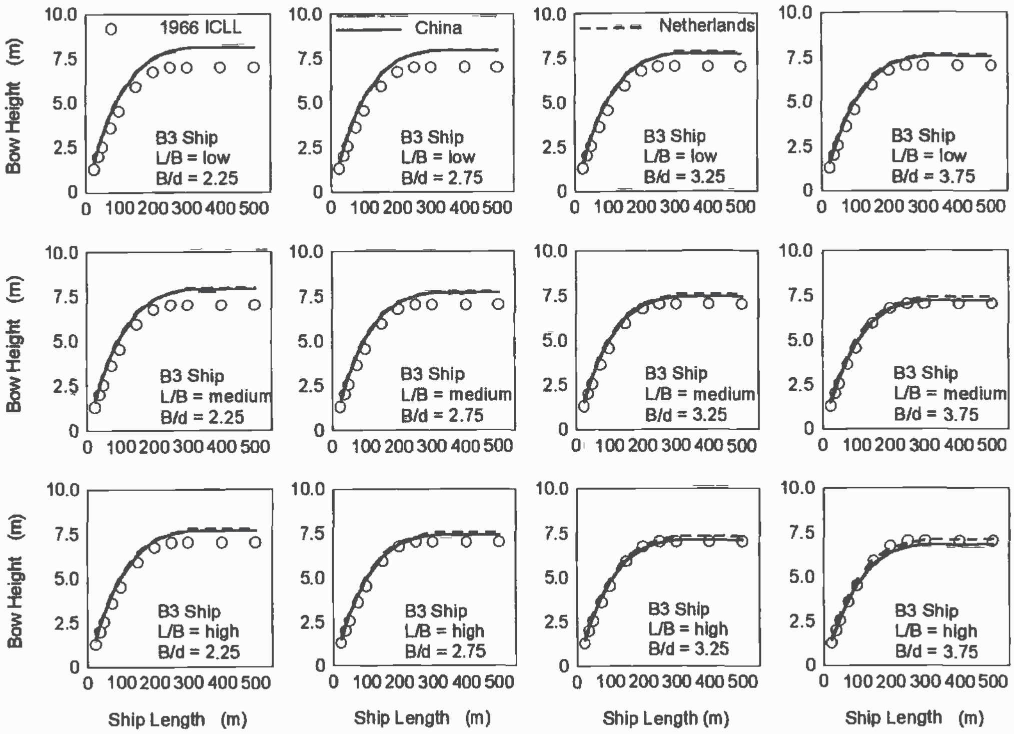

Figure 95 Bow Height Polynomials of China and NL of B3 Ships

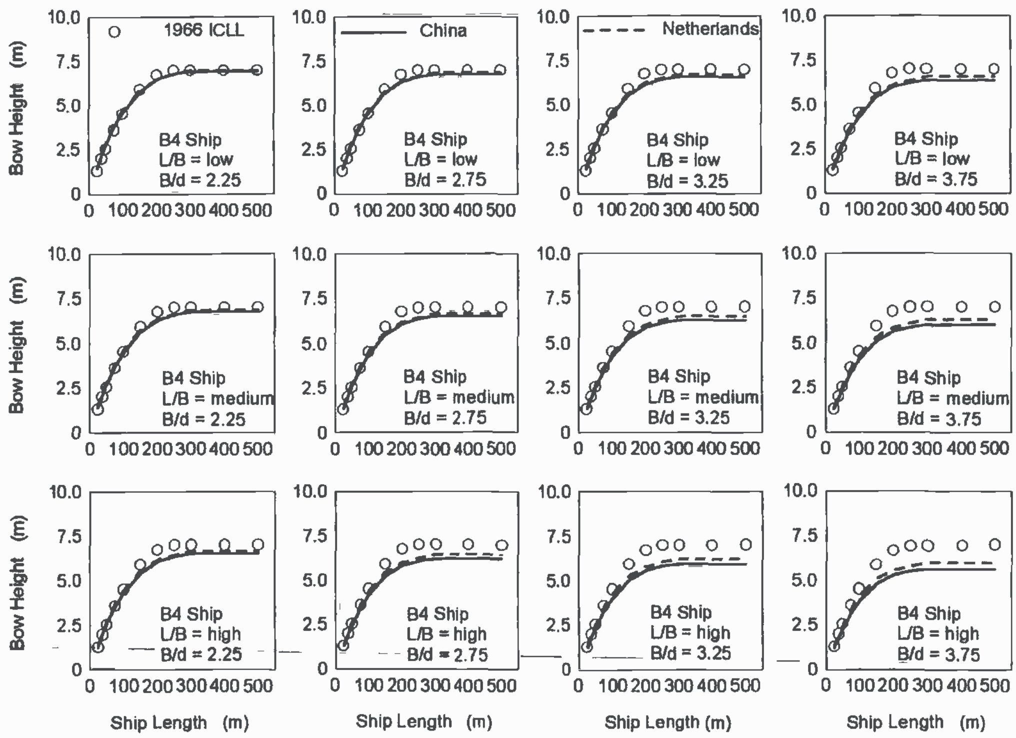

Figure 96 Bow Height Polynomials of China and NL of B4 Ships

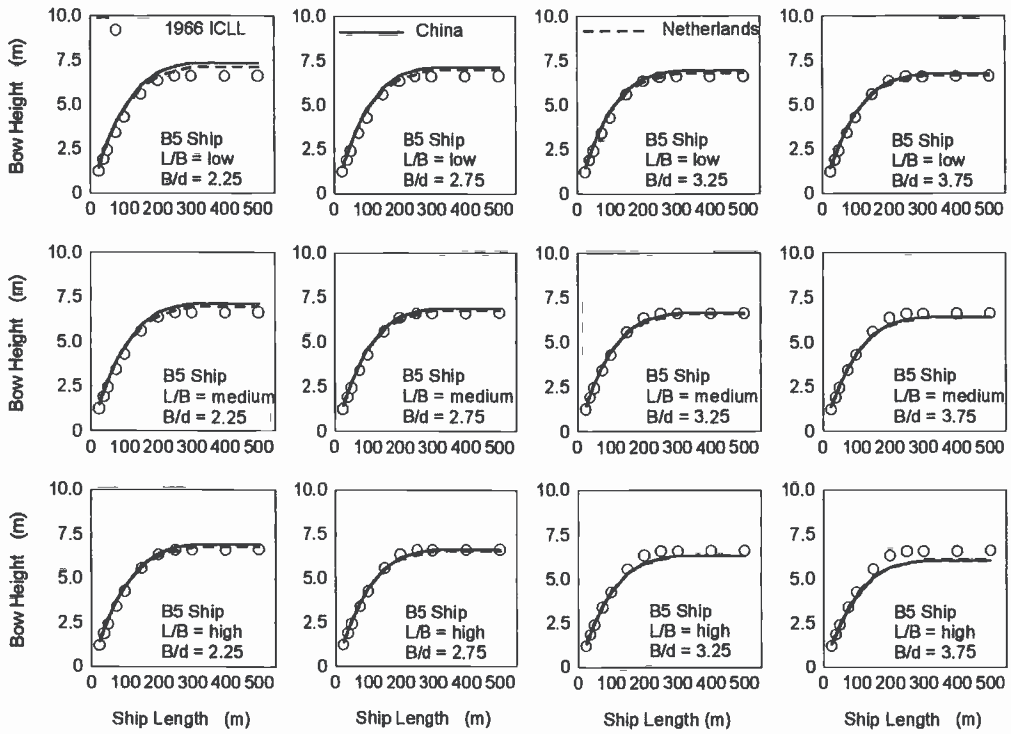

Figure 97 Bow Height Polynomials of China and NL of B5 Ships

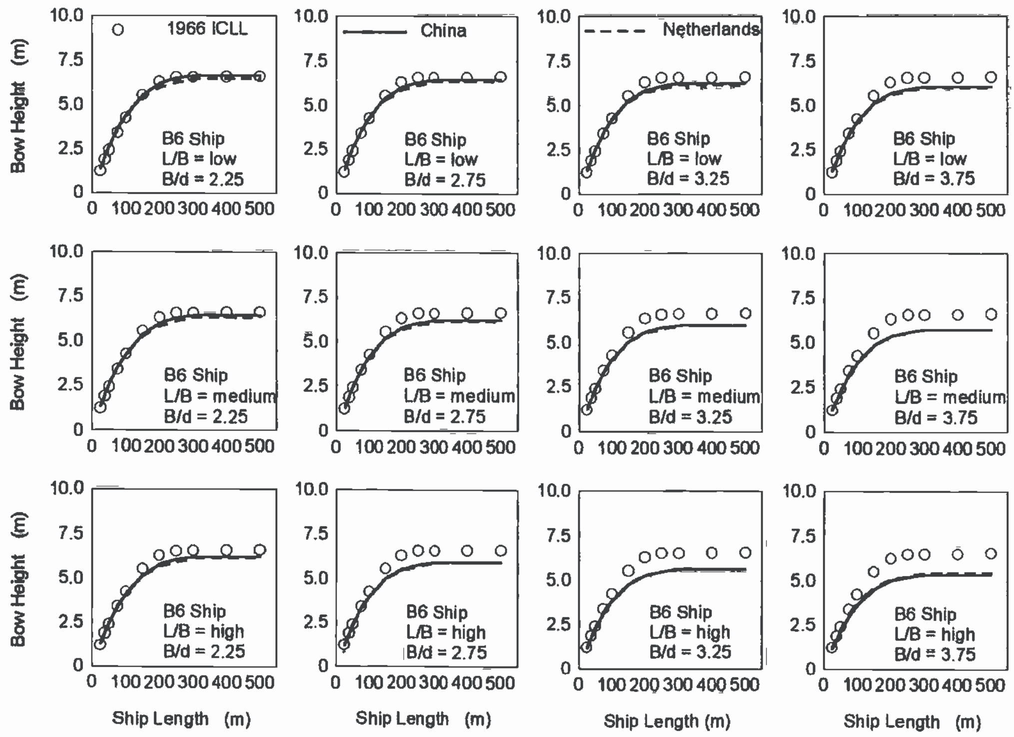

Figure 98 Bow Height Polynomials of China and NL of B6 Ships

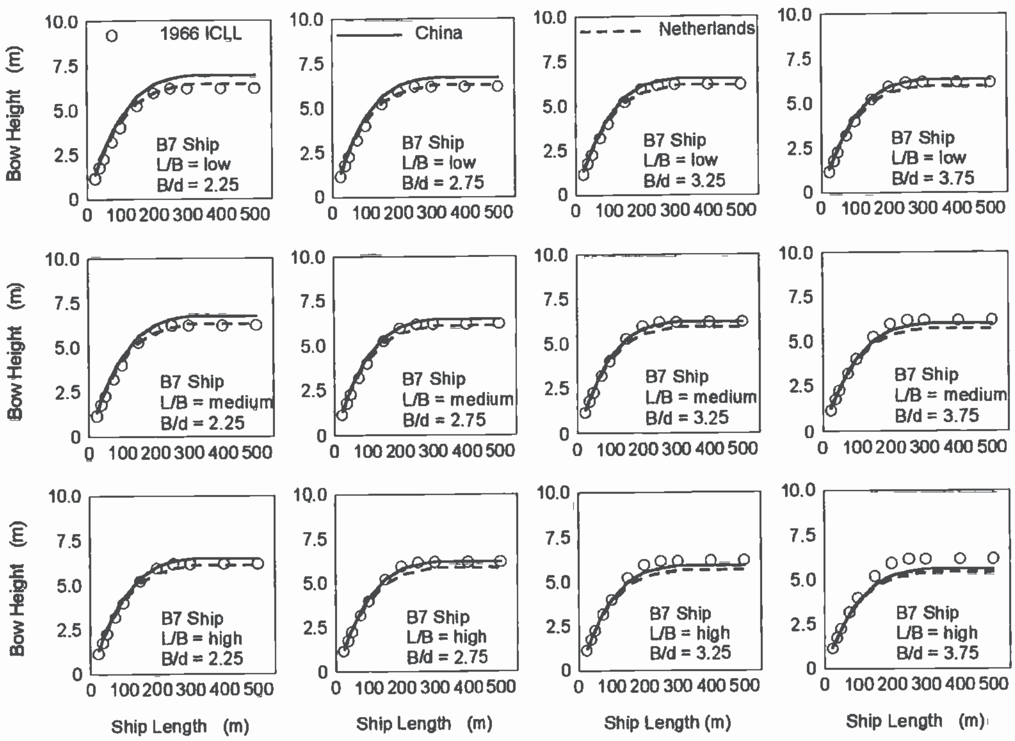

Figure 99 Bow Height Polynomials of China and NL of B7 Ships

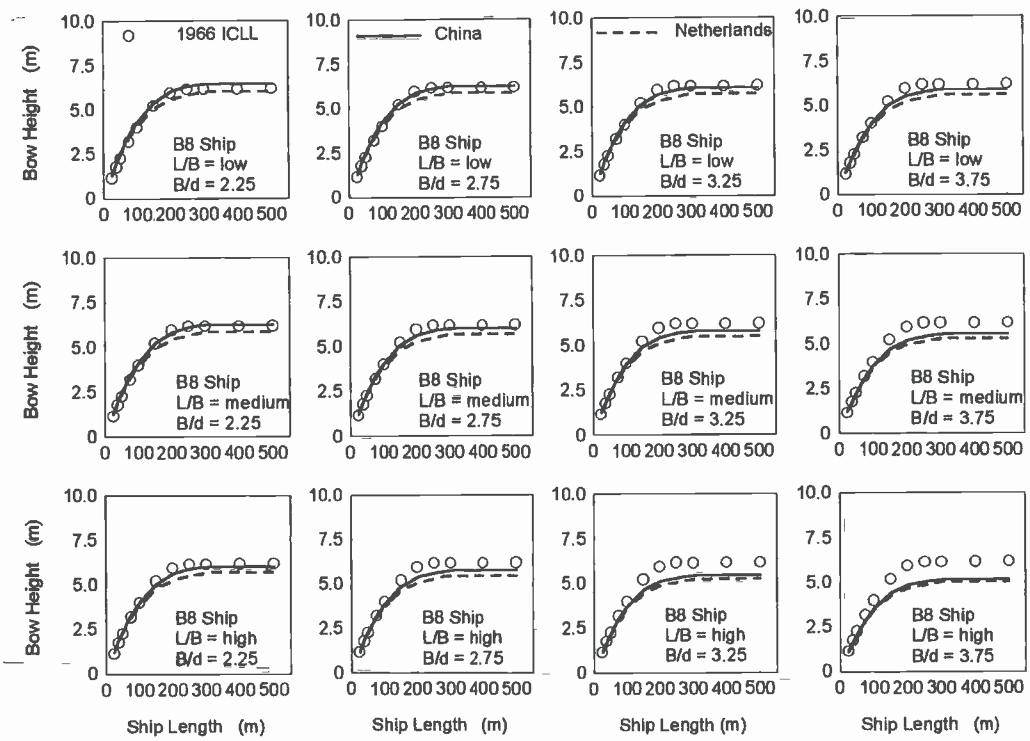

Figure 100 Bow Height Polynomials of China and NL of B8 Ships

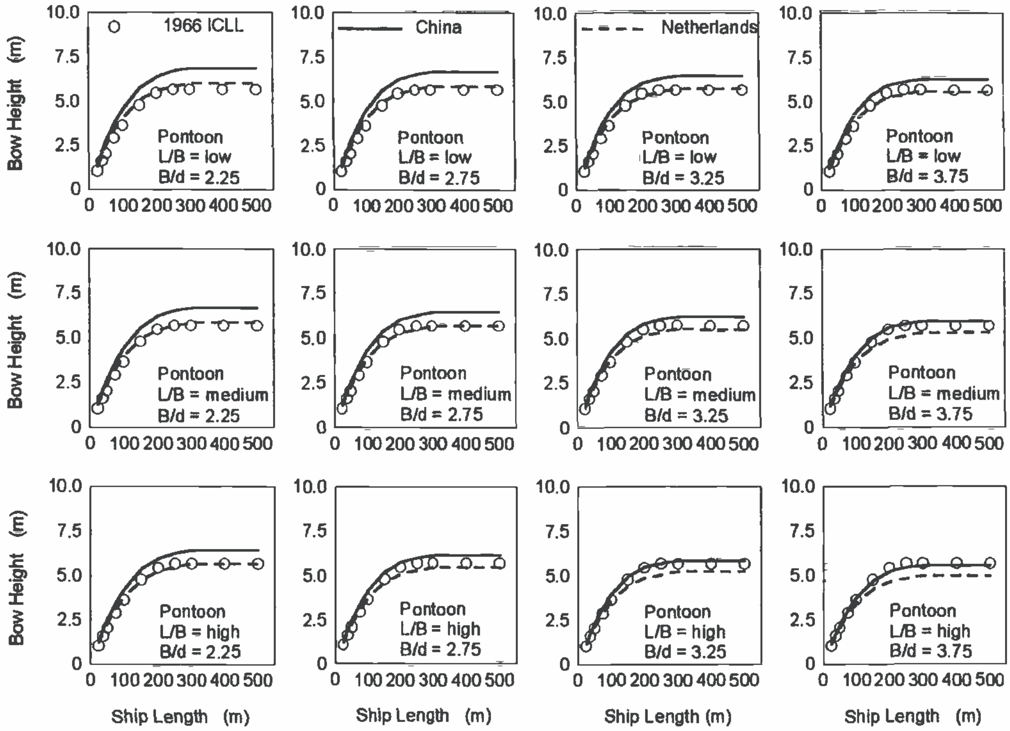

Figure 101 Bow Height Polynomials of China and NL of Rectangular Pontoons