MERCHANT SHIPS DESIGN HANDBOOK

BOOK 3 (BASIC DESIGN)

THE KANSAI SOCIETY OF NAVAL ARCHITECTS, JAPAN

MERCHANT SHIPS DESIGN HANDBOOK

BOOK THREE
BASIC DESIGN

(This book was prepared with the subsidy of Japan Shipbuilding Industry Foundation. (Nippon Sempaku Shinko Kai))

CONTENTS

CHAPTER III. BASIC DESIGN

Page

Page

Page

CHAPTER III BASIC DESIGN

1. BASIC CALCULATION

1.1. Displacement and Trim Calculation

1.1.1. Hydrostatic Calculation

Normally, all hydrostatic properties are calculated about bare (molded) hull and those for the appendages are additionally calculated if necessary.
Keel drafts (extreme drafts from the lowest point of the keel at the midship) are adopted for hydrostatic curves as the scale of draft.

(1) Displacement

$$\Delta = \rho g \nabla = \gamma L B d C_b \text{ (t) } (L, B, d: \text{m}, \ \nabla: \text{m}^3)$$

$$= \frac{\nabla}{C} = \frac{L B d C_b}{C} \text{ (L.T) } (L, B, d: \text{ft}, \ \nabla: \text{ft}^3)$$

	Sea Water	Fresh Water
$\gamma (t/m^3)$	1·025	1·000
$C (ft^3/L.T)$	35	36

Displacement of the lower curved body of the ship is to be calculated by use of the planimeter or based on the offsets of the buttock lines. Center of buoyancy of the ship is estimated by Morrish's or Hayase's Formula (Fig.176), or the integrater is used for more precise calculation.
Appendage includes the shell plates, bar keels, bilge keels, propellers, propeller bosses, bare propeller shafts, rudders and shaft brackets. The negative parts due to inclination of the stem and propeller aperture are not taken as negative appendage. Displacement of the sea chests is calculated as negative appendage and that of cruiser stern and bulbous bow is included in the molded displacement.

(2) Fineness coefficient

Block coefficient	$C_b = \nabla / (LBd)$
Prismatic coefficient	$C_p = \nabla / (A_{\text{ⓧ}} L) = C_b / C_{\text{ⓧ}}$
Midship coefficient	$C_{\text{ⓧ}} = A_{\text{ⓧ}} / (Bd)$
Water plane coefficient	$C_w = A_w / (LB)$
Vertical prismatic coefficient	$C_v = \nabla / (A_w d) = C_b / C_w$

(3) Transverse metacentric radius

$$BM = I / \nabla$$

where I = Moment of inertia of waterplane about ship's center line.
BM : See Fig.178

(4) Longitudinal metacentric radius

$$LBM = I_l / \nabla$$

where I_l = Moment of inertia of waterplane about transverse axis through center of floatation.

LBM : See Fig.180

(5) Center of floatation (Center of waterplane)
Normally, center of floatation is measured from ⓧ by horizontal distance ⓧF with aftwards plus and forewards minus.

(6) Tons per centimeter immersion

$$TPC = \gamma A_w/100 = 1{\cdot}025\,A_w/100 \qquad (t) \quad (A_w: m^2)$$

Tons per inch immersion

$$TPI = A_w/(12\,C) = A_w/(12 \times 35) \qquad (LT) \quad (A_w: ft^2)$$

$$TPC = 0{\cdot}399\,947\ TPI, \quad TPI = 2{\cdot}500\,33\ TPC$$

(7) Moment to change trim 1 cm (MTC)

$$MTC = \Delta \times LGM/(100L) \fallingdotseq 1{\cdot}025\,I_L/(100L) \qquad (t-m)$$

Normally, LGM ≑ LBM

Moment to change trim 1 inch (MTI)

$$MTI = \Delta \times LGM/(12L) \qquad (LT-ft)$$

$$MTC = 0{\cdot}121\,904\ MTI, \quad MTI = 8{\cdot}203\,19\ MTC$$

(8) Wetted surface area
Wetted surface area is obtained by integration of girth length below the waterline along ship center line.
Wetted surface area of appendages is calculated separately.
For approximation of wetted surface area, 6.2.2.(1) is to be referred to.

1.1.2. Calculation of Fore and Aft Draft by Displacement and Center of Gravity

For a certain displacement, the corresponding d, $\otimes F$, $\otimes B$ and LKM (or MTC) are found out on the chart of hydrostatic curves, then

$HBG = \otimes G - \otimes B$, $LGM = LKM - KG$

Trim $\quad t = \dfrac{HBG}{LGM} \times L\,(m)$

or $\quad t = \dfrac{\Delta \times HBG}{MTC}\,(cm)$

and, Fore draft $\quad d_f = d - \dfrac{t}{L}\left(\dfrac{L}{2} + \otimes F\right)$

Aft draft $\quad d_a = d + \dfrac{t}{L}\left(\dfrac{L}{2} - \otimes F\right)$

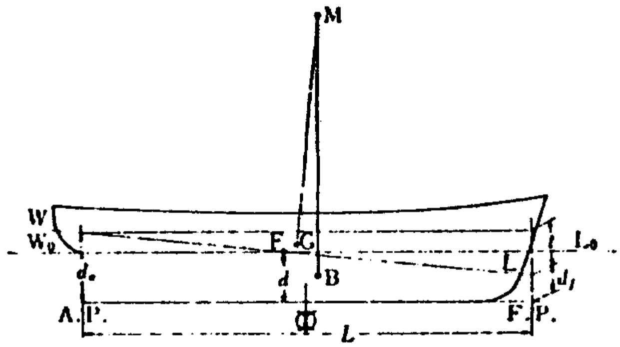


Fig. 1

The sign of $\otimes F$, $\otimes B$, $\otimes G$ is assumed to be plus for afterside of ship's body.

1.1.3. Change of Trim due to shifting, loading or unloading of a heavy weight (Fig. 2)

Change of trim $\quad t = \dfrac{wl \times L}{\Delta \times LGM}\,(m)$

or $\quad t = \dfrac{wl}{MTC}\,(cm)$

where, w = Weight
l = Distance of shift (in case of shifting), or distance between the center of floatation F and the position of the weight (in case of loading and unloading)

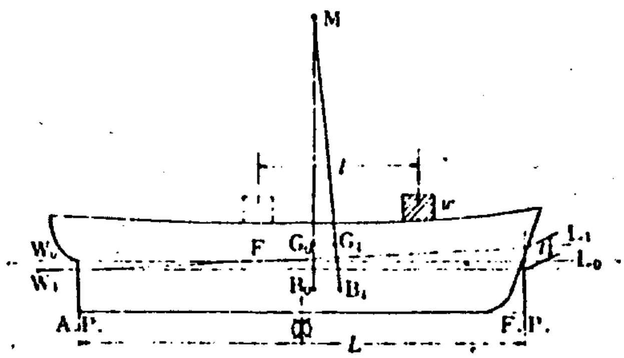


Fig. 2

For LCM, MTC and Δ , each figure for new displacement after loading or unloading is applied.

1.1.4. Displacement of a ship afloat at certain drafts

(1) Correction to fore and aft drafts (Fig. 3)

(a) Fore draft

$$d_f = d_f' - \frac{(d_a' - d_f')\, l_f}{L - l_a - l_f}$$

(b) Aft draft

$$d_a = d_a' + \frac{(d_a' - d_f')\, l_a}{L - l_a - l_f}$$

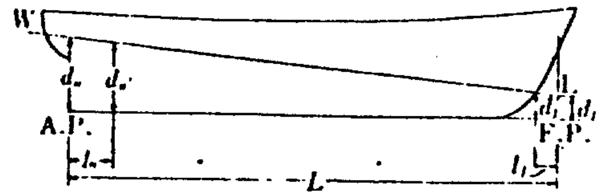


Fig. 3

(2) Correction for bending deflection (Fig. 4)

(a) $d_\otimes$ = Mean draft at $\otimes$ (to be decided by drafts of the both sides)

Deflection of hull $\quad \delta = \frac{d_a + d_f}{2} - d_\otimes$

$\delta > 0$: Hogging, $\delta < 0$: Sagging } in this case

Mean draft $\quad d_m = \frac{1}{8}(d_a + 6\, d_\otimes + d_f)$

or $\quad d_m = \frac{d_a + d_f}{2} \pm \frac{3}{4}\delta$

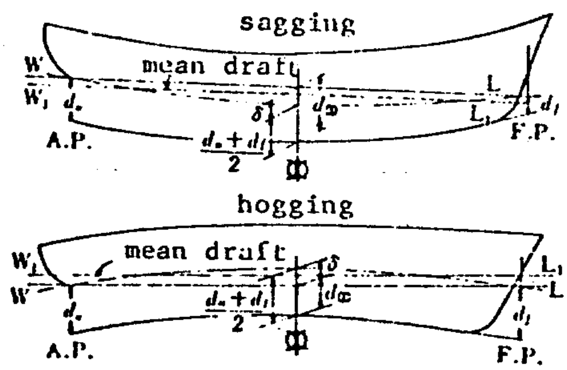


Fig. 4

where, + and - should be applied in case of sagging and hogging respectively.

(b) For displacement correction per cm deflection, $(TPC - \frac{4MTC}{L})$ may be alternatively applied.

(c) Ohgushi's Formula

Correction to displacement $= \gamma L B \delta K,\ K = \frac{2}{3}\left\{1 - \frac{3(1-C_w)^2}{3-2C_w}\right\}$

(3) Correction for trim

Corresponding draft is obtained from mean draft and draft difference between $\otimes$ and center of floatain F, i.e., $\Delta d = (d_a - d_f) \times \otimes F / L$

Corresponding draft $\quad d = d_m + \Delta d$

Sign of Δd is as per Fig. 5

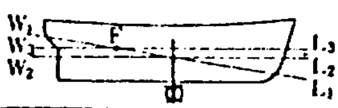
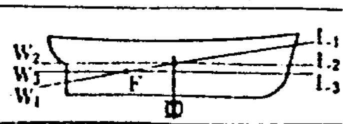
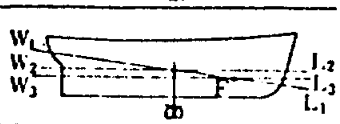
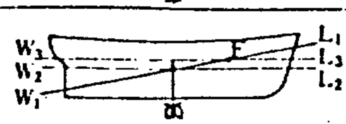
Sign of Δd			
Condition	Sign	Condition	Sign
	+		-
	-		+

Fig. 5

(4) Correction for difference of specific gravity of the water in which the ship is afloat.

In case the specific gravity γ of the water in which the ship is afloat is different from the standard value 1.025 for sea water, the displacement is corrected by the following formula.

$$\Delta = \frac{\gamma}{1{\cdot}025}\Delta_0$$

where, Δ_0 = Displacement for the corresponding draft d corrected by above steps (to be found out on the chart of hydrostatic curves).

Example (Fig. 6)

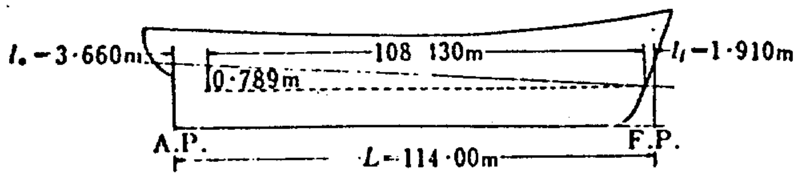


Fig. 6

		Port side	Starboard side	Mean	Corrected draft
Draft (m)	Fore	3·012	3·012	3·012	2·998
	Aft	3·796	3·806	3·801	3·828
	Mean				3·413
	Midship	3·334	3·382	3·358	3·358

Correction to fore draft	$1{\cdot}910 \times 0{\cdot}789/108{\cdot}43 = 0{\cdot}014$ m
Correction to aft draft	$3{\cdot}660 \times 0{\cdot}789/108{\cdot}43 = 0{\cdot}027$ m
Trim	$3{\cdot}828 - 2{\cdot}998 = 0{\cdot}830$ m
Initial trim	0
Total trim	$0{\cdot}830 - 0 = 0{\cdot}830$ m
Deflection at midship	$3{\cdot}413 - 3{\cdot}358 = 0{\cdot}055$ m
Mean draft corrected for deflection	$3{\cdot}413 - \frac{3}{4} \times 0{\cdot}055 = 3{\cdot}372$ m
Center of floatation	$-0{\cdot}655$ m
Draft at center of floatation	$3{\cdot}372 - 0{\cdot}830 \times \frac{0{\cdot}655}{114{\cdot}000} = 3{\cdot}367$ m
Displacement	4470·00 t
Specific gravity of water	1·0215
Displacement when measured	$4470{\cdot}00 \times 1{\cdot}0215/1{\cdot}025 = 4454{\cdot}74$ t

1.1.5. Displacement in case of big trim

In case of big trim, following formula is recommendable to calculate the displacement with less error.

$$\Delta = \Delta_0 + 100 \times \mathrm{TPC} \times \mathrm{OF} \times \left(\frac{t}{L}\right) + 50\, L\, \frac{\delta(\mathrm{MTC})}{\delta d}\left(\frac{t}{L}\right)^2 + \cdots (t)$$

$$\Delta' = \Delta_0' + 12 \times \mathrm{TPI} \times \mathrm{OF} \times \left(\frac{t'}{L'}\right) + 6\, L' \frac{\delta(\mathrm{MTI})}{\delta d'}\left(\frac{t'}{L'}\right)^2 + \cdots (\mathrm{LT})$$

where, t = Trim
Δ_0, Δ_0' = Displacement at mean draft

For more precise and direct calculation of displacement, the use of Bonjean Curves is more recommendable.

1.1.6. Change of Draft and Trim by Flooding (Fig. 7)

(1) Change of draft

Homogeneous sinkage $\delta = v/(A_w - \mu a)$

where, A_w = Waterplane area of ship before flooding
a = Waterplane area of flooded compartment
μ = Surface permeability of flooded compartment
v = Net lost buoyancy of flooded compartment

(2) Change of trim

Change of trim $t = Lvl/I'$

where, l = Horizontal distance from the center of volume b' of the buoyancy gained by sinkage δ excluding the net lost buoyancy to the center of volume b of the net lost buoyancy

I' = Longitudinal moment of inertia of the intact waterplane $(A_w - \mu a)$ about a transverse axis through its center of floatation F'

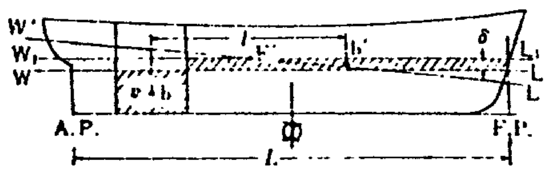


Fig. 7

1.2. Capacity and Volume Calculation

1.2.1. Cargo Hold

(1) Bale and grain (Fig. 8)

(a) Bale capacity (Capacity for packed cargo)

Boundaries for bale capacity are,
bottom : top surface of the sheathing on the inner bottom plates
side : inner side of the battens on the frames or bulkhead stiffeners
ceiling: under side of the deck girders or hatch girders (top end of the coamings in case of steel hatch cover)

Normally, the volume of brackets, longitudinals, pillars, stiffeners of the bulkheads without sparring is not calculated, but assumed to be 0.2% of the volume of cargo hold and reduced therefrom. In principle, the concave part of the corrugated bulkhead is included in the bale capacity.

(b) Grain capacity (Capacity for bulk cargo)
Boundaries for grain capacity are,

bottom : top surface of the sheathing on the inner bottom plates
side : inner side of shell plate or bulkheads
ceiling: under side of deck plates and top end of the coaming of hatch cover.

Deduction factor for frames, girders, pillars etc. is normally assumed 0.5%.

(c) For above both cases (a) and (b), the volume of inner structures such as ventilation trunks or shelves is to be deducted from the hold capacity.

(2) Capacity for each independent cargo hold

(a) General cargo hold ... bale and grain capacity to be calculated. Center of volume to be represented by that for bale cargo.

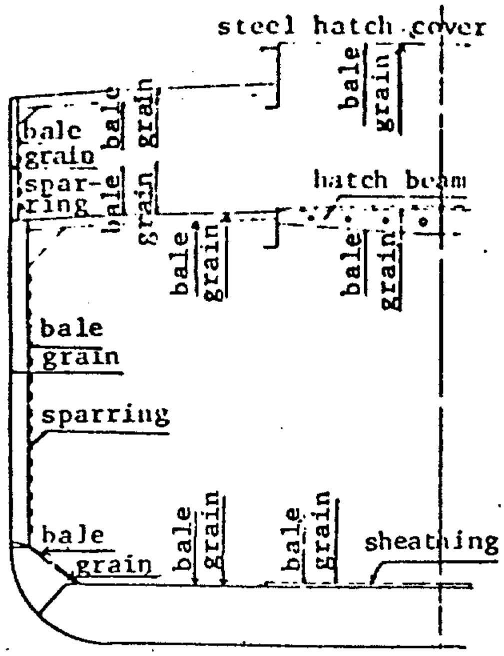


Fig. 8 Bale and Grain

(b) Bulk cargo hold ... grain capacity only to be calculated, in principle.

(c) Refrigirated cargo hold ... bale capacity, i.e. volume inside the protection sparring for cooling pipes or air ducts, to be calculated. But for the calculation of cooling capacity, the total volume inside the insulation should be applied.

(d) Capacity of silk room, mail room, strong room, stores etc. is calculated same as bale capacity.

1.2.2. Water and Oil Tank

(1) Capacity calculation
Following corrections are made to the total capacity which is calculated based on the lines or mold loft offsets. The result of calculation is figured by capacity curves, sounding (or ullage) scale or sounding table. (Fig. 9)

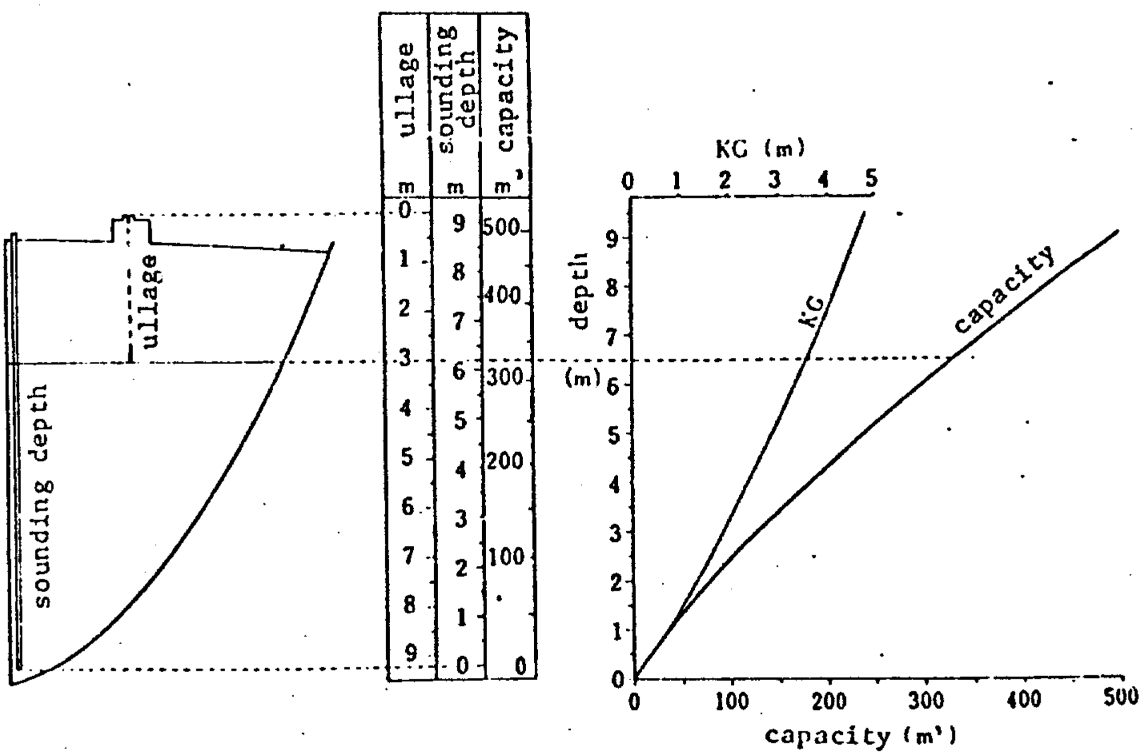


Fig. 9 Capacity Curve & Sounding Scale

(a) Deduction factor for structures, pipings, etc. (Table 1)

The volume of fixed ballast or cement, if any, and cargo oil pipes in the cargo tanks are separately calculated and deducted from the whole volume.

Table 1

Fore and aft peak tanks	1.0 - 1.5%
Double bottom tank	1.5 - 2.0%
Deep tank	1.0%
Cargo tank (center)	0.4 - 0.7%
- do - (wing)	0.6 - 1.0%
Top side tank	0.8 - 1.2%

(b) Deduction factor for thermal expansion

Under normal temperature condition, deduction factor for thermal expansion is as follows.

for gasoline, naphtha	5%
for crude oil, heavy oil, whale oil	2 - 4%

(c) Weight of water and oil in tank

See Table 4 of 1.3.2.

(2) Sounding table

Capacities are tabulated for every 10 mm or 100 mm or 1 inch draft down to the first decimal place in cubic meter or the first place in cubic feet. Different pitch of the draft may be applied for a certain tank.

(3) Correction for trim and heel

Correction for trim is made to the capacity of all oil tanks but not made for miscellaneous tanks and for fresh water tanks, ballast tanks and peak tanks the correction is made only when required. Range of trim to be applied is, normally, from -1 m (trim by bow) to 2 - 3% of *Lpp* .

Correction for heel is normally made only for cargo oil tanks and the range of heeling is up to 2 - 3 degrees.

Correction for trim and heel is carried out separately.

(4) Height of center of gravity of the liquid in the tank can be easily obtained by the method shown in Fig. 10.

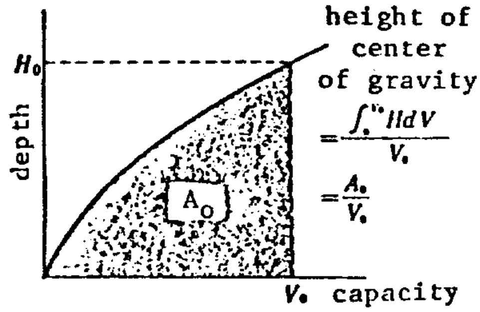


Fig. 10 Capacity Curve and Height of Center of Gravity

1.3. Calculation of Weight, Center of Gravity and Trim

1.3.1. Standard conditions

Light weight, full load and no cargo (or ballast) conditions are standard conditions, and for each standard condition except light weight departure and arrival conditions are taken up for trim calculation. In addition, arrival condition is divided into two cases by fuel oil consumption, i.e., 100% and 80% consumption. At the stage of preliminary calculation arrival condition for 80% fuel oil consumption only is calculated normally.

1.3.2. Standard loading condition of deadweight

At departure condition, fuel oil and fresh water are fully loaded or partially loaded corresponding to the navigation condition and the deadweight for cargo and temporary structures is decided by reducing the weight of consumables and constants from the remaining deadweight. For all conditions, fittings like derricks and life boats and goods in stores are assumed to be stored in their normal positions, the crew to be on their duty and the passengers in their cabins.

(1) Crew, passengers and their effects
Weight of a person is assumed 60 kg and the total weight including its effects is as per Table 2.

Table 2 Weight of a Person and its Effects (kg)
(The Guideline for Ship Inspection)

Navigation area	Crew	Passenger
Ocean going & major coasting area	120	110
Coasting area	100	90
Limited coasting & smooth water area	80	70

Center of gravity of a person and its effects is assumed 1 m above the floor. The weight of passengers' baggages stored in the baggage room, if any, is calculated separately. For a sightseeing boat cruising in smooth water area or a ship without a crew's room, the weight of a person is to be 60 kg including effects.

(2) Goods in stores
Actual weight, if measured, is applied. For guidance, total weight (t) of goods in stores of hull, machinery and electric parts excluding spare propeller and spare propeller shaft is approximately,

0.2 - 0.3% of ship's gross tonnage (GT),
or 0.25 - 0.5% of main engine horse power
or $Lpp^2/1000$

(3) Water and oil of machinery part
Water and oil which are included in the deadweight such as auxiliary boiler water, sea and fresh water, fuel oil and lubricating oil etc. in miscellaneous tanks, auxiliary machinery and pipings in engine room, and also fuel oil for engines for emergency use and lubricating oil for deck machinery are treated as water and oil of machinery part.

(4) Provisions
Daily consumption rate per person is assumed 2.5 kg for a Japanese ship and 4.5 kg for other ship. Normally provisions of large ship are treated as constants in trim calculation.

(5) Drinking water and fresh water for general use
Daily consumption rate stipulated in governmental rules is shown in Table 3. The consumption rate depends on navigation route and period and season, the average daily consumption rate per person of fresh water is approximately,

for crew .... 300 - 500 kg (Standard 350 kg)
passengers .... 100 - 300 kg

Table 3 Daily Consumption Rate of Fresh Water per Mariner Required by Rules (kg)

	Japanese Mariner's Law	U.K. DOT	U.S. Sanitary Rule
Drinking water	20	4.5 (1 gal)	30.3 (8 U.S. gal)
General-use water		45.5 (10 gal)	83.3 (22 U.S. gal)
Total		50 (11 gal)	113.6 (30 U.S. gal)

(6) Water and oil in hull tanks
Each tank should be fully loaded or empty as much as possible. Number of tanks partially loaded should be minimized. Specific weight or volume are as per Table 4.

Table 4 Specific Weight and Volume of Water and Oil

	Fresh water	Sea water	Diesel oil	Bunker oil	Lubricating oil
Specific weight (standard value) t/m³	1·0	1·025	0·88~0·90 (0·90)	0·90~0·98 (0·935)	0·90~0·93 (0·92)
Specific volume ft³/LT	36	35	(40)	(38·5)	(39)

(7) Cargos (10.12 Table 111 & 112 to be referred to)
In principle, a homogeneous cargo is fully loaded in a cargo hold. For a special cargo, a certain stowage factor is used. Cargos in a strong room or superstructure are treated same as cargos in cargo holds. For a liner or single-purposed ship, special loading conditions for each actual navigation route are frequently used for trim calculation. Loading of bulk cargos should be in accordance with rules and regulations such as Grain Loading Regulation (see 10.12.2). As for on-deck loading of timbers, 2.9.2 and 4.5.2 are to be referred to.

(8) Temporary structures
Dunnage, temporary partition walls for grain loading, temporary pillars for timber loading, lashing etc.

(9) Ballast
In case of no-cargo navigation, a ship is ballasted for easy navigation to an extent of 1/5 - 1/2 total deadweight and trimmed by stern about 2 - 2.5% of ship's length. At arrival condition with full loading, the ship may be ballasted to get proper trim and stability condition for the port (ex. in case of on deck loading of lumber) but ballast water should not be loaded in the empty tanks for fresh water or fuel oil.

1.3.3. Calculation Method (Table 5)

Table 5 Calculation Table of Weight, Center of Gravity and Trim

Item \ Condition		Light condition	Full load departure	Full load arrival, 80% consumption	Full load arrival, 100% consumption	No load departure	No load arrival, 100% consumption
Light weight (t)		5240	5240	5240			
Constants	Crew, passenger and their effects	0	10	10	See 1.3.2.(1), Table 2		
	Goods in stores	0	32	32	" (2)		
	Water & oil of machinery part	0	88	88	" (3)		
Consumable	Provisions	0	15	3	" (4)		
	Fresh water for drinking & general use	0	240	48	" (5), (6), Table 3&4		
	Fresh water for boilers	0	45	9	See 1.3.2.(6), Table 4		
	Fuel oil	0	1540	308	" (6), Table 4		
Cargoes	General cargo	0	8540	8540	" (7), Table 111&112		
	Silk	0	50	50	" (7)		
	Refrigerated cargo	0	250	250	See Chapter V, 18.4.4.		
Temporary structures		0	10	10	See 1.3.2.(8)		
Ballast		0	0	50	" (6), Table 4, (9)		
Total deadweight (t)		0	10820	9398			
Displacement (t)		5240	16060	14638			

Item	Unit	Light condition	Full load departure	Remarks
Corresponding draft	(m)	3.15	8.36	To be found out on the chart of hydro-static curves
T K M	(m)	10.50	8.05	- do -
K G	(m)	8.13	6.99	To be obtained by calculation of weight and center of gravity
T G M	(m)	2.37	1.06	TKM-KG
G G_O	(m)	0	0.06	Effect of free liquid surface (See 1.3.5 and 4.1.2)
T G_O M	(m)	2.37	1.00	TGM-GG_O
L K M	(m)	335.5	172.2	To be found out on the chart of hydro-static curves
L G M	(m)	327.37	165.21	LKM-KG
⊗ B	(m)	-0.16	0.56	To be found out on the chart of hydro-static curves (-: Forward from ⊗; +: Aftward from ⊗)
⊗ G	(m)	2.41	0.98	To be obtained by calculation of weight and center of gravity (-: Forward from ⊗; +: Aftward from ⊗)
H B G	(m)	2.57	0.42	⊗G − ⊗B (-: Forward from ⊗; +: Aftward from ⊗)
⊗ F	(m)	-0.13	2.73	To be found out on the chart of hydro-static curves (-: Forward from ⊗; +: Aftward from ⊗)
Trim (aft)	(m)	1.10	0.36	See 1.1.2
Fore draft	(m)	2.60	8.17	"
Aft draft	(m)	3.70	8.53	"
Mean draft	(m)	3.15	8.35	1/2 (Fore draft + Aft draft)
T P C	(t)	18.98	19.63	To be found out on the chart of hydro-static curves
M T C	(t-m)	122.53	189.52	$(\Delta \times LGM)/(100L)$

1.3.4. "Constants" customarily used by crew.
Weight to be treated as "constants", though slightly different depending on crew's custom, is remaining weight after reducing the weight of fuel oil, drinking water, fresh water for general use, fresh water for boiler, spare lubricating oil, cargoes, temporary structures, etc. from the deadweight. Namely, "constants" weight just after building of a ship is equivalent to the total weight of crew and their effects, provisions, store goods, water of hull part, water and oil of machinery part and bilge water.

1.3.5. Effect of free liquid surface (Table 6)
It is notable that requirement on calculation of the effect of free liquid surface is different in each country.

Table 6 Requirement on Effect of Free Liquid Surface

	Full loading	Half loading
Water tank (100%)	to be neglected.	to be calculated
Oil tank (96%)	double bottom .. to be neglected deep tank ...... to be calculated	
Bilge water	to be calculated only in case of large quantity of liquid moving widely over the floor	

1.4. Launching Calculation

1.4.1. Launching particulars

(1) Launching weight and center of gravity
Launching weight is total weight of the ship and cradle. The launching weight and center of gravity are decided in consideration of weight loaded aboard when launching.

(2) Slope of the keel and height of the ship
Slope of the keel is selected between 28/1000 - 52/1000 depending on various factors. For a small ship with launching weight below 1,000t, larger slope is usually adopted. In general, smaller slope is adopted for a larger ship. Height of the keel above the ground should be as low as possible but enough for comfortable working underneath the ship or for construction of the launching slip.

(3) Ground ways
Slope of the ground ways is usually 28/1000 - 55/1000, larger than that of the keel by about 0 - 15/1000 in general. For a small ship with launching weight below 1,000 t, larger slope is adopted. Generally, smaller declivities are used for larger ships. Length of the ground ways is 105 - 125% of the ship's length, and the rate of camber, if applied, may be 150 - 500 mm per 100 m length of the ground ways.

(4) Sliding ways
Length of the sliding ways is 77 - 90% of the ship's length depending on C_b of the ship (shorter length is applied to a ship with smaller C_b). Width of the sliding ways should be so determined as the mean pressure on the launching lubricant does not exceed the allowable limit (Table 7). The spread of the ways (distance between the center of the both ways) is usually 27 - 34% of the ship's beam.

(5) Mean bearing pressure
The mean bearing pressure defined by "Launching weight/(Sliding ways' length x width x number)" varies to relatively much extent, and for large ships with launching weight exceeding 10,000t, 4 lanes of sliding way may be used. Experience of the mean bearing pressure is as per Table 7.

Table 7

Launching weight (t)	500	1000	3000	5000	10000	15000	20000	25000	30000
Mean bearing pressure (t/m^2)	9-17	10.5-18.5	13.0-21.5	14.5-24.5	16.0-30.5	17.0-31.5	17.5-32.0	18.0-32.5	18.5-33.0

Note) 1. Ball launching : Mean load per ball = 1 - 2t (for a ball of 90 mm in diameter)
2. Truck launching: Mean load per truck = 20t axle (Diameter of axle: 100 mm for fore poppet trucks and 80 mm for other trucks)
Limit of launching weight ≒ 1000t

(6) Drag weights
In case the width of channel into which the ship is launched is insufficient, drag weights of 1.5 - 7% (in total) of the launching weight such as anchor chains or concrete blocks are used. Time of releasing the drag weights should not be before complete lift of the stern.

1.4.2. Launching calculation

(1) Drafts during launching (Fig. 11)

- L = Ship's length
- α = Angle of slope of keel (rad)
- l = Length of ground ways
- k = Camber of ground ways
- ρ = Radius of curvature of ground ways
- β = Mean angle of declivity of ground ways (rad)
- θ = Center angle of ground ways (rad)
- ω = Angle of declivity of ground ways at fore end (rad)
- h = Height of extension of keel's bottom surface above water surface at F.P.
- x = Travel of ship
- $\Delta\theta$ = Center angle of travel of ship (rad)
- d_f = Fore draft of ship
- d_a = Aft draft of ship

$$\left.\begin{aligned} d_f &= -h + x\beta - \frac{x(l-x)}{2\rho}, \\ d_a &= -h + x\beta - \frac{x(l-x)}{2\rho} + L\left(\alpha + \frac{x}{\rho}\right) \end{aligned}\right\} \quad (1)$$

where, $\rho = \frac{l^2 + 4k^2}{8k} \fallingdotseq \frac{l^2}{8k}, \quad \theta = \frac{l}{\rho},$

$$\Delta\theta = \frac{x}{\rho}, \quad \omega = \beta - \frac{l}{2\rho}$$

Mean angle of declivity of ground ways up to travel x

$$= \omega + \frac{\Delta\theta}{2} = \beta - \frac{(l-x)}{2\rho}$$

Angle of declivity of ground ways at travel $x = \omega + \frac{x}{\rho}$

Angle of slope of keel at travel $x = \alpha + \frac{x}{\rho}$

In case of no camber, $\rho = \infty$

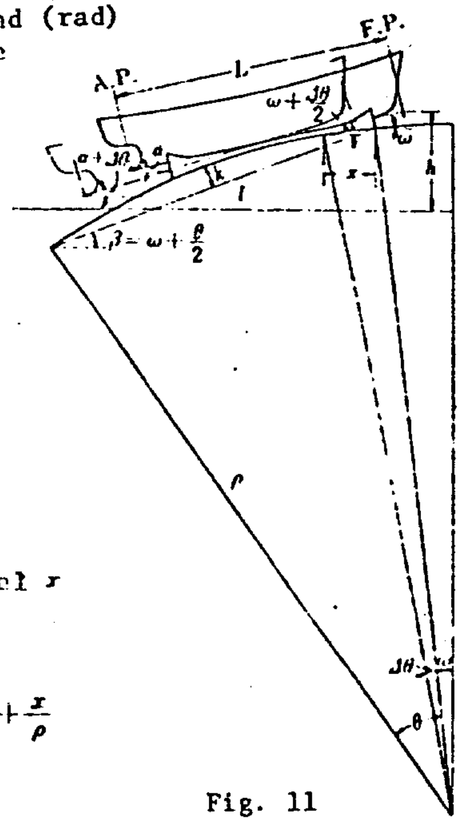


Fig. 11

(2) Calculation of launching curves

W = Launching weight
Δ = Buoyancy (or displacement)
a_1 = Distance from fore poppet to center of buoyancy
a_2 = Distance from fore poppet to center of gravity
y_1 = Distance from aft end of ground way to center of buoyancy
y_2 = Distance from aft end of ground way to center of gravity
(See Fig. 12)

(a) Buoyancy Δ during launching
Buoyancy and the center of buoyancy are obtained from the Bonjean Curves based on the drafts at each travel of the ship calculated by the method mentioned in the preceeding article (1).

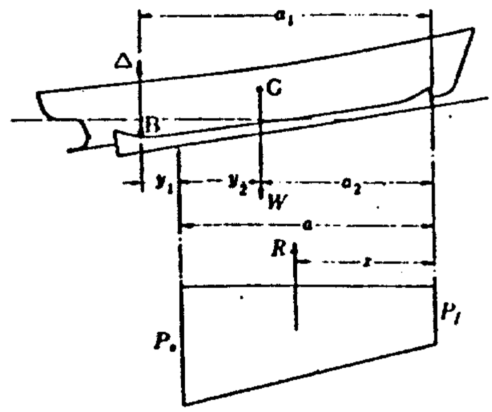


Fig. 12

(b) Moment of launching weight about the fore poppet = Wa_2 (constant)

(c) Moment of buoyancy about the fore poppet = Δa_1

(d) Maximum poppet pressure
Poppet pressure becomes maximum at the same time of lift by stern which occurs when $\Delta a_1 = Wa_2$, which equals to $W - \Delta$ or about 22 - 30% of launching weight.
(See Fig. 13)

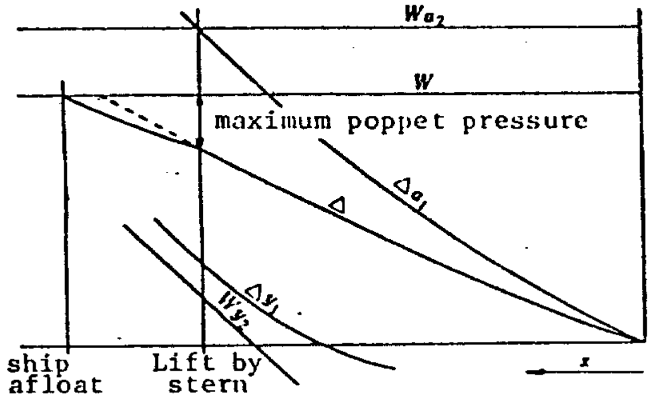


Fig. 13

(e) Buoyancy after lift by stern
After lift by stern the ship is supported by the fore poppet only and the aft draft is unknown. Buoyancy can be obtained by following method:

(i) For each travel of the ship, assume more than 3 aft drafts.

(ii) Calculate buoyancy and the center of buoyancy for each assumed draft.

(iii) Make the buoyancy and buoyancy moment curves as shown in Fig. 14 by plotting the calculated buoyancy and moment for each draft.

(iv) Draft and buoyancy for the crossing point of Δa_1 and Wa_2 show the draft and buoyancy after lift by stern.

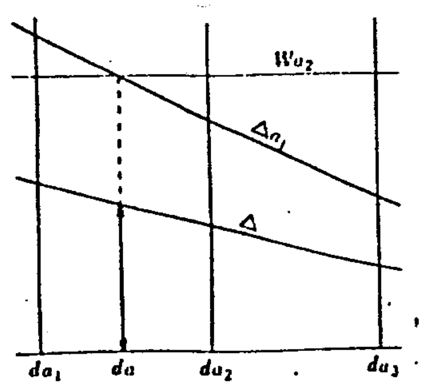


Fig. 14

(f) Distance of travel until ship floats

The ship floats leaving the ways when d_f becomes equal to the fore draft of free condition afloat, then x of formula (1) gives the distance of travel until the condition afloat. If the water depth at the aft end of the ground ways is less than the fore draft of free condition afloat, the ship drops.

(g) Moment of launching weight about the after end of the ground ways $= Wy_2$

(h) Moment of buoyancy about the after end of the ground ways $= \Delta y_1$

(i) Against tipping moment $= \Delta y_1 - W y_1'$

If this moment is positive, tipping does not occur.

(j) Pressure distribution (Fig. 12, Fig. 15)

R = Reaction
P_f = Pressure on the fore end of sliding ways
P_a = Contact pressure of the ground ways and the sliding ways at after end of the contact surface
P_m = Mean contact pressure of the ground ways and the sliding ways
b = Breadth of a sliding way
n = Number of sliding ways
a = Length of contact surface of ground ways and the sliding ways
z = Distance from the fore end of the sliding ways to the center of the reaction

Assuming the pressure distribution linear,

$$P_f = 4P_m - \frac{6P_m z}{a},$$

$$P_a = \frac{6P_m z}{a} - 2P_m$$

where, $R = W - \Delta$, $Rz = Wa_1 - \Delta a_1$,
$P_m = R/nba = (P_f + P_a)/2$

The maximum value of P_a is normally determined below $45\,t/m^2$ in consideration of strength of the ship way and ship's hull.

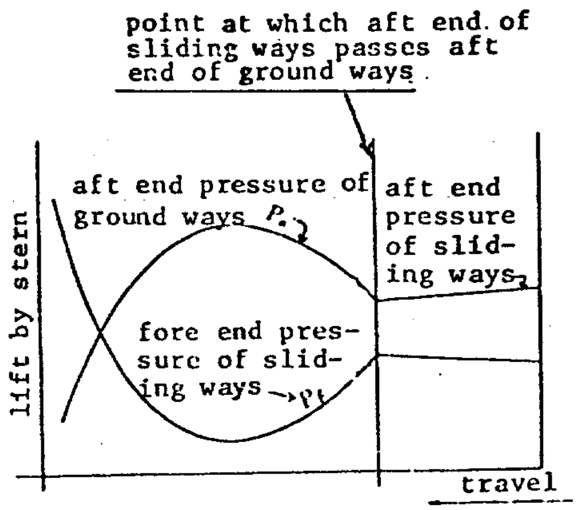


Fig. 15

(k) Initial sliding force $F = W(\sin\beta - \mu\cos\beta)$

where, β = Angle of slope of the ground ways at the center of gravity of the ship at its initial position
μ = Static frictional coefficient between the sliding and ground ways (See Table 8)

For calculation of the trigger load, μ should be assumed to be less (say, about 0.005) to assure safety.

(1) Launching velocity and time

i) From start of sliding to float of ship

Assuming the launching velocity at two positions A_{n-1}, A_n with distance s therebetween on the launching way V_{n-1}, V_n, respectively.

$$V_n^2 = \frac{V_{n-1}^2(W + w - gs\lambda\Delta'^{2/3}) + 2gs(W - \Delta)(\sin\beta - \mu_1) - 2gs\mu_1 w}{W + w + gs\lambda\Delta'^{2/3}} \qquad (2)$$

where, β = Angle of slope of the ground ways at the center of gravity of the ship at position A_{n-1}

g = Acceleration of gravity

V = Launching velocity

w = Weight of moving drags

μ_1 = Dynamic frictional coefficient between the sliding and ground ways

μ_2 = Dynamic frictional coefficient between the drags and the drag surface (See Table 8)

λ = Water resistance coefficient (See Fig. 16)

λ is estimated based on the result of actual launchings as it can be determined by formula (2) assuming μ_1, μ_2 constant.

Table 8

	Fat	Ball	Truck
μ	0·02～0·03	0·02～0·025	0·035
μ_1	0·015～0·025	0·01～0·02	0·028

μ_2	between anchor chain and flat concrete bed	between concrete block and flat concrete bed	between anchor chain and flat soil ground bed	between anchor chain or concrete block and flat (wet) sand on the concrete bed
	0·38～0·39	0·24～0·25	0·6～0·7	0·46～0·50

Time of travel between A_{n-1} and A_n

$$t = \frac{s}{(V_{n-1}+V_n)/2}$$

By formula (2), launching velocity can be obtained from the start and until the end of launching, but following simplified method can be applied after the ship floats.

ii) After float of ship

V_0 = Velocity of ship when it leaves the ways to float.

x' = Distance of travel after float of ship.

t' = Time after float of ship

$$V = a\tan(q_0 - akt'),$$

$$x' = \frac{\log_{10}\{\cos(q_0 - akt')/\cos q_0\}}{0{\cdot}4343\,k} \qquad (3)$$

where, $k = \lambda\Delta^{2/3}g/W$, $a^2 = \mu_2 w/\lambda\Delta^{2/3}$,

$q_0 = \tan^{-1}(V_0/a)$ (rad)

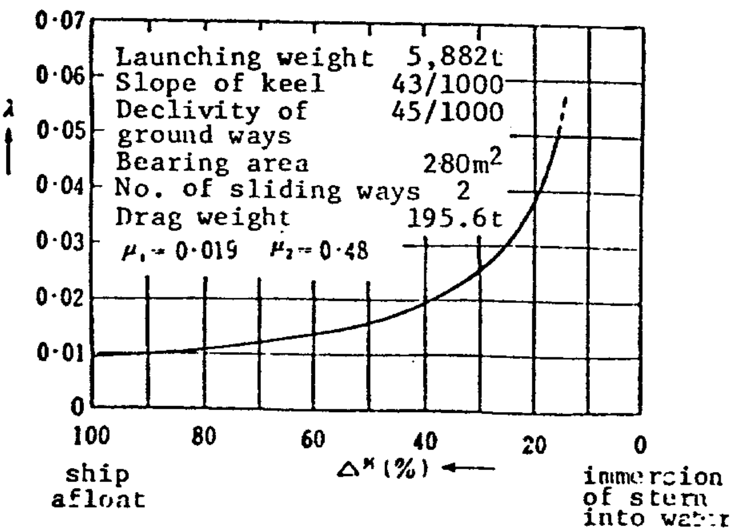


Fig. 16 An Example of λ obtained by Formula (2)

ii-1) In case of no drag

V, x', the corresponding velocity and distance to formula (3) are

$w = 0$

$V = V_0/(V_0 k t' + 1)$, $x' = \log_{10}(V_0 k t' + 1)/0{\cdot}4343\,k$

ii-2) In case all drags are draged when the ship floats

Time until the ship stops $t' = q_0/ak$

Distance of travel until the ship stops $x' = \dfrac{\log_{10}(1/\cos q_0)}{0{\cdot}4343\,k}$

For an intermediate case, the velocity and distance are obtained from formula (3) by giving a certain time t'

ii-3) In case the drag is draged one after another

x_1 = Distance of travel from a point the ship begins to drag one drag to the point where the next drag begins to be dragged

t_1' = Time during travel of x_1.

V_1 = Launching velocity when the ship begins to drag one drag

V_2 = Launching velocity before the ship drags the next drag

then, $\cos(q_1 - akt_1) = e^{kx_1}\cos q_1$ (4)

where, $t_1 = (q_1 - q_2)/ak$

putting $q_1 = \tan^{-1}(V_1/a)$ (rad), $q_2 = q_1 - akt_1$ (rad)

$V_2 = a\tan q_2$

Same calculation is repeated for the following drags until the right side of equation (4) exceeds 1, when the ship stops at intermediate position of the section corresponding to the two drags in question. Thereafter, method of ii-2) is applied.

(m) GM at lift by stern (Fig. 17)

$GM = (GM_0 \times \Delta - PG \times R)/W$

where, $GM_0 = KB + BM_0 - KG = KB + (I/\nabla) - KG$

I = Moment of inertia of water plane about ship's center line.

∇ = Displacement in volume at lift by stern

PG = Distance from the fore poppet to the center of gravity of the ship

$R = W - \Delta$ (Maximum poppet pressure)

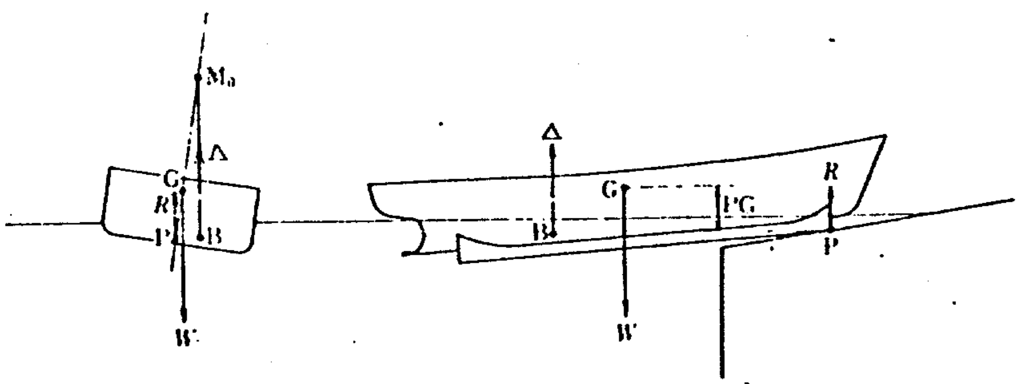


Fig. 17

2. FREEBOARD

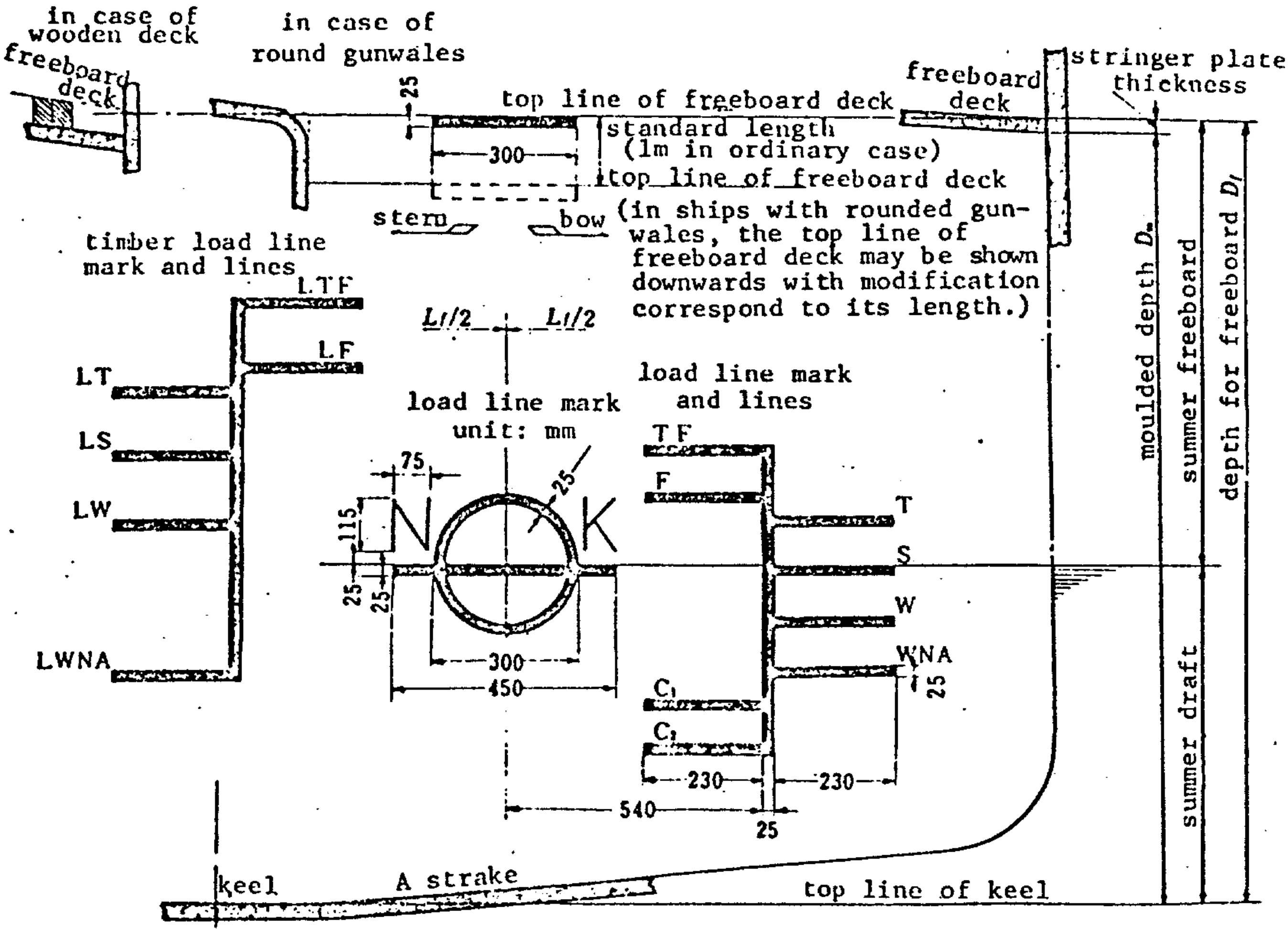
2.1. Application of International Convention on Load Lines (1966)

The present Convention shall apply to ships engaged on international voyages and of not less than 24 meters in length (L_f : refer to 2.3.1.) excluding the following ships.

(1) ships of war
(2) existing ships of less than 150 tons gross
(3) pleasure yachts not engaged in trade
(4) fishing vessels (factory ships and transport ships shall not be included).

Refer to 2.12. for freeboard of ships engaged on coastal voyages.

2.2. Load Line Mark and Lines



S	Summer Load Line	TF	Tropical Fresh Water Load Line
W	Winter Load Line	LS	Summer Timber Load Line
WNA	Winter North Atlantic Load Line	LW	Winter Timber Load Line
T	Tropical Load Line	LWNA	Winter North Atlantic Timber Load Line
F	Fresh Water Load Line		
LT	Tropical Timber Load Line		
LF	Fresh Water Timber Load Line in Summer		
LTF	Fresh Water Timber Load Line in the Tropical Zone		

(1) Load line mark and lines to be used (Fig.18).

(2) The Winter North Atlantic Freeboard shall apply to ships of not more than 100 meters in length (L_f) which enter any part of the North Atlantic.

(3) Load line marks and lines may be partially omitted to ships with limits of navigational routes or seasonal periods.

(4) Load line marks shall be marked at the position of $L_f/4$ from the stem to ships with initial trim as well.

(5) Subdivision load line are shown with C_1, C_2······ according to each condition. (refer to Japanese MOT Ordinance No. 97, 1952)

2.3. Definitions of Terms and Units for Freeboard Calculations

2.3.1. Definitions of Terms (Regulations 3)

Note) Regulations means LLC 1966 hereinafter.

(1) Length (L_f)
In the following (a), (b), the greater length shall be applied.

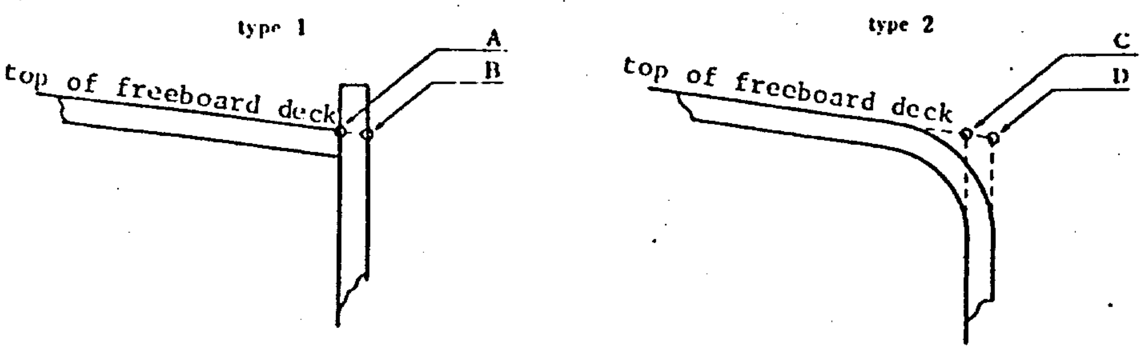
(a) 96 per cent of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel.

(b) The length from the fore side of the stem to the axis of the rudder stock on that waterline.

(2) Moulded depth (D_m)
The moulded depth is the vertical distance measured from the top of the keel to the top of the freeboard deck beam at side. In ships having round gunwales, the moulded depth shall be measured to the point of intersection of the moulded lines of the deck and side shell plating, the lines extending as though the gunwale were of angular design.

(3) Depth for freeboard (D_f)
The depth for freeboard (D_f) is the moulded depth amidship of L_f plus the thickness of the freeboard deck stringer plate. (Table 9)

Table 9 Standards of Freeboard Deck



	NK	LR	AB	NV
type 1	A	A	B	A
type 2	C	C	D	C

If the exposed freeboard deck is sheathed, the following figures shall be added.

(a) In case of being completely sheathed $T(L_f - S)/L_f$

(b) In case of being partially sheathed $(T \times l)/L_f$

where, T = Mean thickness of the exposed sheathing clear of deck openings (mm)
S = Total length of superstructures (m)
l = Total length of freeboard deck sheathed from side to side of the ship (m)

The depth for freeboard (D_f) in a ship having a rounded gunwale with a radius greater than 4 per cent of the breadth or having topsides of unusual form is the depth for freeboard of a ship having a midship section with vertical topsides and with the same round of beam and area of topside section equal to that provided by the actual midship section.

(4) Freeboard deck

(a) The freeboard deck is normally the uppermost complete deck.

(b) In a ship having a discontinuous freeboard deck, the lowest line of the exposed deck and the continuation of that line parallel to the upper part of the deck is taken as the freeboard deck.

(c) At the option of the owner and subject to the approval of the Administration, a lower deck may be designated as the freeboard deck.

(d) In a ship with a very large freeboard and subject to the approval of the Administration, a virtual deck may be designated as the freeboard deck.

2.3.2. Units and Significant Figures for Calculations (NK)

(1) The length and breadth such as those of a ship and the superstructures are shown in meter down to the second decimal place.

(2) The depth such as moulded depth, height of superstructures, sheathing thickness and sheer height are shown in meter down to the third decimal place.

(3) The figures such as C_b, E/L_f, $L_f/15$ are shown down to the third decimal place.

(4) The percentage is shown down to the first decimal place.

(5) The figures directly related to the freeboard by addition and subtraction are shown in millimeter and in integer.

The figures mentioned above are rounded to the lowest decimal places.

2.4. Determination of Freeboard

2.4.1. Summer Freeboard

The summer freeboard shall be taken as form draft (refer to 2.6), draft corresponding to the condition after flooding in the flooding calculations (refer to 2.7) or draft corresponding to the minimum bow height (refer to 2.8), whichever is the greatest.

2.4.2. Winter, Tropical, Winter North Atlantic and Fresh Water Freeboard (Table 10) (Regulations 40, 45)

Table 10 Determination of Freeboard in Various Conditions

Freeboard \ Item	Typical Freeboard	Timber Freeboard
Summer Freeboard (f_s)	f_s	f_{ts}
Winter Freeboard (f_w)	$f_s + \frac{1}{48} d_s$	$f_{ts} + \frac{1}{36} d_{ts}$
Tropical Freeboard (f_r)	$f_s - \frac{1}{48} d_s$	$f_{ts} - \frac{1}{48} d_{ts}$
Winter North Atlantic Freeboard ($L_f \leq 100$ m)	$f_w + 50$	$f_w + 50$
Summer Fresh Water Freeboard	$f_s - \frac{\Delta}{4T}$	$f_{ts} - \frac{\Delta}{4T}$
Tropical Fresh Water Freeboard	$f_r - \frac{\Delta}{4T}$	$f_{tr} - \frac{\Delta}{4T}$

Note) 1. d_s ; Molded summer draft (mm)
2. d_{ts} ; Molded summer timber draft (mm)
3. Δ ; Displacement in salt water in tons at the summer load waterline
4. T ; Tons per centimeter in the same condition
5. If Δ and T are not clear, $d_s/48$ may be applied instead of $\Delta/(4T)$.

2.4.3. Others

(1) In case that the planned draft is smaller than the maximum draft defined by International Convention on Load Line, the assigned draft may be allowed subject to the ship owner's requirement. In this case, the relaxations from Regulations 10 to 26 may be granted on condition that the Administration is satisfied with the safety conditions provided. (Regulation 2)

(2) The freeboard in salt water shall not be less than 50 millimeters. For ships having hatchways without pontoon or weathertight covers made of mild steel or other equivalent material on freeboard decks, raised quarter decks or exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular, the freeboard shall be not less than 150 millimeters. (Regulation 40)

(3) Ships whose features are such as to render the application of the provisions of Regulations unreasonable or impracticable, shall be assigned freeboards as determined by the Administration. (Regulation 2)

2.5. Types of Ships

2.5.1. Type 'A' Ships

A type 'A' ship is one which is designed to carry only liquid cargoes in bulk, and in which cargo tanks have only small access openings closed by watertight gasketed covers of steel or equivalent material. Such a ship necessarily has the following inherent features (Regulation 26 & 27).

(1) Machinery casings shall be protected by an enclosed poop or bridge of at least standard height, or by a deckhouse of equal height and equivalent strength, provided that machinery casings may be exposed if double doors are provided at the entrances.

(2) An efficiently constructed fore and aft permanent gangway of sufficient strength shall be fitted at the level of the superstructure deck between the poop and the midship bridge or deckhouse where fitted, or equivalent means of access shall be provided to carry out the purpose of the gangway, such as passages below deck. Elsewhere, arrangements to the satisfaction of the Administration shall be provided to safeguard the crew in reaching all parts used in the necessary work of the ship.

(3) Exposed hatchways on the freeboard and forecastle decks or on the tops of expansion trunks shall be provided with efficient watertight covers of steel or other equivalent material.

(4) Type 'A' ships with bulwarks shall have open rails fitted for at least half the length of the exposed parts of the weather deck or other effective freeing arrangements. Where superstructures are connected by trunks, open rails shall be fitted for the whole length of the exposed parts of the freeboard deck.

(5) The upper edge of the sheer strake shall be kept as low as practicable.

2.5.2. Type 'B' Ships

All ships which do not come within the provisions regarding type 'A' ships shall be considered as type 'B' ships.

2.6. Calculation of Form Freeboard

Form freeboard

f = tabular freeboard f_t (including correction of block coefficient) (2.6.1)
- correction amount for superstructure δf_e (2.6.2)
+ correction amount by depth length ratio δf_D (2.6.3)
± correction amount for position of deck line δf_L (2.6.4)
+ correction amount for sheer δf_s (2.6.5)

2.6.1. Correction for Tabular Freeboard and Block Coefficient

(1) Tabular freeboard f_0 (Table 11, 12)
Tabular freeboard shall comply with Table 13.

In type 'B' Ships, the following conditions shall be followed according to divisions in Table 13.
In case of ⑤ ⑦
(a) the measures provided for the protection of the crew are adequate.
(b) the freeing arrangements are adequate.
(c) the covers on freeboard and superstructure decks are weathertight ones of mild steel or other equivalent material and have adequate strength. Special care shall be given to their sealing and securing arrangements.

In case of ⑥ ⑧
(a), (b) and (c) mentioned above and inherent features of Type 'A' ships (excluding item (3)) shall be applied.

Table 11 Freeboard Table for Type 'A' Ships

Unit: L_f(m), f_0(mm)

L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0	L_f	f_0
		46	396	86	926	126	1 563	166	2 212	206	2 669	246	2 986	286	3 202	326	3 347
		47	408	87	940	127	1 580	167	2 226	207	2 678	247	2 993	287	3 207	327	3 350
		48	420	88	955	128	1 598	168	2 240	208	2 687	248	3 000	288	3 211	328	3 353
		49	432	89	969	129	1 615	169	2 254	209	2 696	249	3 006	289	3 215	329	3 355
		50	443	90	984	130	1 632	170	2 268	210	2 705	250	3 012	290	3 220	330	3 358
		51	455	91	999	131	1 650	171	2 281	211	2 714	251	3 018	291	3 224	331	3 361
		52	467	92	1 014	132	1 667	172	2 294	212	2 723	252	3 024	292	3 228	332	3 363
		53	478	93	1 029	133	1 684	173	2 307	213	2 732	253	3 030	293	3 233	333	3 366
		54	490	94	1 044	134	1 702	174	2 320	214	2 741	254	3 036	294	3 237	334	3 368
		55	503	95	1 059	135	1 719	175	2 332	215	2 749	255	3 042	295	3 241	335	3 371
		56	516	96	1 074	136	1 736	176	2 345	216	2 758	256	3 048	296	3 246	336	3 373
		57	530	97	1 089	137	1 753	177	2 357	217	2 767	257	3 054	297	3 250	337	3 375
		58	544	98	1 105	138	1 770	178	2 369	218	2 775	258	3 060	298	3 254	338	3 378
		59	559	99	1 120	139	1 787	179	2 381	219	2 784	259	3 066	299	3 258	339	3 380
		60	573	100	1 135	140	1 803	180	2 393	220	2 792	260	3 072	300	3 262	340	3 382
		61	587	101	1 151	141	1 820	181	2 405	221	2 801	261	3 078	301	3 266	341	3 385
		62	600	102	1 166	142	1 837	182	2 416	222	2 809	262	3 084	302	3 270	342	3 387
		63	613	103	1 181	143	1 853	183	2 428	223	2 817	263	3 089	303	3 274	343	3 389
24	200	64	626	104	1 196	144	1 870	184	2 440	224	2 825	264	3 095	304	3 278	344	3 392
25	208	65	639	105	1 212	145	1 886	185	2 451	225	2 833	265	3 101	305	3 281	345	3 394
26	217	66	653	106	1 228	146	1 903	186	2 463	226	2 841	266	3 106	306	3 285	346	3 396
27	225	67	666	107	1 244	147	1 919	187	2 474	227	2 849	267	3 112	307	3 288	347	3 399
28	233	68	680	108	1 260	148	1 935	188	2 486	228	2 857	268	3 117	308	3 292	348	3 401
29	242	69	693	109	1 276	149	1 952	189	2 497	229	2 865	269	3 123	309	3 295	349	3 403
30	250	70	706	110	1 293	150	1 968	190	2 508	230	2 872	270	3 128	310	3 298	350	3 406
31	258	71	720	111	1 309	151	1 984	191	2 519	231	2 880	271	3 133	311	3 302	351	3 408
32	267	72	733	112	1 326	152	2 000	192	2 530	232	2 888	272	3 138	312	3 305	352	3 410
33	275	73	746	113	1 342	153	2 016	193	2 541	233	2 895	273	3 143	313	3 308	353	3 412
34	283	74	760	114	1 359	154	2 032	194	2 552	234	2 903	274	3 148	314	3 312	354	3 414
35	292	75	773	115	1 376	155	2 048	195	2 562	235	2 910	275	3 153	315	3 315	355	3 416
36	300	76	786	116	1 392	156	2 064	196	2 572	236	2 918	276	3 158	316	3 318	356	3 418
37	308	77	800	117	1 409	157	2 080	197	2 582	237	2 925	277	3 163	317	3 322	357	3 420
38	316	78	814	118	1 426	158	2 096	198	2 592	238	2 932	278	3 167	318	3 325	358	3 422
39	325	79	828	119	1 442	159	2 111	199	2 602	239	2 939	279	3 172	319	3 328	359	3 423
40	334	80	841	120	1 459	160	2 126	200	2 612	240	2 946	280	3 176	320	3 331	360	3 425
41	344	81	855	121	1 476	161	2 141	201	2 622	241	2 953	281	3 181	321	3 334	361	3 427
42	354	82	869	122	1 494	162	2 155	202	2 632	242	2 959	282	3 185	322	3 337	362	3 428
43	364	83	883	123	1 511	163	2 169	203	2 641	243	2 966	283	3 189	323	3 339	363	3 430
44	374	84	897	124	1 528	164	2 184	204	2 650	244	2 973	284	3 194	324	3 342	364	3 432
45	385	85	911	125	1 546	165	2 198	205	2 659	245	2 979	285	3 198	325	3 345	365	3 433

Note) Freeboards at intermediate lengths L_f shall be obtained by linear interpolation.

Table 12 Freeboard Table for Type 'B' Ships

Unit: L_f(m), f_o(mm)

L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o	L_f	f_o
		46	396	86	996	126	1 815	166	2 640	206	3 363	246	3 965	286	4 467	326	4 909
		47	408	87	1 015	127	1 837	167	2 660	207	3 380	247	3 978	287	4 478	327	4 920
		48	420	88	1 034	128	1 859	168	2 680	208	3 397	248	3 992	288	4 490	328	4 931
		49	432	89	1 054	129	1 880	169	2 698	209	3 413	249	4 005	289	4 502	329	4 943
		50	443	90	1 075	130	1 901	170	2 716	210	3 430	250	4 018	290	4 513	330	4 955
		51	455	91	1 096	131	1 921	171	2 735	211	3 445	251	4 032	291	4 525	331	4 965
		52	467	92	1 116	132	1 940	172	2 754	212	3 460	252	4 045	292	4 537	332	4 975
		53	478	93	1 135	133	1 959	173	2 774	213	3 475	253	4 058	293	4 548	333	4 985
		54	490	94	1 154	134	1 979	174	2 795	214	3 490	254	4 072	294	4 560	334	4 995
		55	503	95	1 172	135	2 000	175	2 815	215	3 505	255	4 085	295	4 572	335	5 005
		56	516	96	1 190	136	2 021	176	2 835	216	3 520	256	4 098	296	4 583	336	5 015
		57	530	97	1 209	137	2 043	177	2 855	217	3 537	257	4 112	297	4 595	337	5 025
		58	544	98	1 229	138	2 065	178	2 875	218	3 554	258	4 125	298	4 607	338	5 035
		59	559	99	1 250	139	2 087	179	2 895	219	3 570	259	4 139	299	4 618	339	5 045
		60	573	100	1 271	140	2 109	180	2 915	220	3 586	260	4 152	300	4 630	340	5 055
		61	587	101	1 293	141	2 130	181	2 933	221	3 601	261	4 165	301	4 642	341	5 065
		62	601	102	1 315	142	2 151	182	2 952	222	3 615	262	4 177	302	4 654	342	5 075
		63	615	103	1 337	143	2 171	183	2 970	223	3 630	263	4 189	303	4 665	343	5 086
24	200	64	629	104	1 359	144	2 190	184	2 988	224	3 645	264	4 201	304	4 676	344	5 097
25	208	65	644	105	1 380	145	2 209	185	3 007	225	3 660	265	4 214	305	4 686	345	5 108
26	217	66	659	106	1 401	146	2 229	186	3 025	226	3 675	266	4 227	306	4 695	346	5 119
27	225	67	674	107	1 421	147	2 250	187	3 044	227	3 690	267	4 240	307	4 704	347	5 130
28	233	68	689	108	1 440	148	2 271	188	3 062	228	3 705	268	4 252	308	4 714	348	5 140
29	242	69	705	109	1 459	149	2 293	189	3 080	229	3 720	269	4 264	309	4 725	349	5 150
30	250	70	721	110	1 479	150	2 315	190	3 098	230	3 735	270	4 276	310	4 736	350	5 160
31	258	71	738	111	1 500	151	2 334	191	3 116	231	3 750	271	4 289	311	4 748	351	5 170
32	267	72	754	112	1 521	152	2 354	192	3 134	232	3 765	272	4 302	312	4 757	352	5 180
33	275	73	769	113	1 543	153	2 375	193	3 151	233	3 780	273	4 315	313	4 768	353	5 190
34	283	74	784	114	1 565	154	2 396	194	3 167	234	3 795	274	4 327	314	4 779	354	5 200
35	292	75	800	115	1 587	155	2 418	195	3 185	235	3 808	275	4 339	315	4 790	355	5 210
36	300	76	816	116	1 609	156	2 440	196	3 202	236	3 821	276	4 350	316	4 801	356	5 220
37	308	77	833	117	1 630	157	2 460	197	3 219	237	3 835	277	4 362	317	4 812	357	5 230
38	316	78	850	118	1 651	158	2 480	198	3 235	238	3 849	278	4 373	318	4 823	358	5 240
39	325	79	868	119	1 671	159	2 500	199	3 249	239	3 864	279	4 385	319	4 834	359	5 250
40	334	80	887	120	1 690	160	2 520	200	3 264	240	3 880	280	4 397	320	4 844	360	5 260
41	344	81	905	121	1 709	161	2 540	201	3 280	241	3 893	281	4 408	321	4 855	361	5 268
42	354	82	923	122	1 729	162	2 560	202	3 296	242	3 906	282	4 420	322	4 866	362	5 276
43	364	83	942	123	1 750	163	2 580	203	3 313	243	3 920	283	4 432	323	4 878	363	5 285
44	374	84	960	124	1 771	164	2 600	204	3 330	244	3 934	284	4 443	324	4 890	364	5 294
45	385	85	978	125	1 793	165	2 620	205	3 347	245	3 949	285	4 455	325	4 899	365	5 303

Note) Freeboards at intermediate lengths L_f shall be obtained by linear interpolation.

Table 13 Application of Tabular Freeboard and Conditions of Flooding Calculation

Type of Ships	No.	Ship Length & Type of Hatch Cover		Flooding Condition: Flooding Compartment	Flooding Condition: Permeability	Tabular Freeboard
Type 'A' ships	①	$24m \leq L_f \leq 150m$				A
	②	$150m \leq L_f \leq 225m$		Anyone of empty compartments	0.95	A
	③	$L_f > 225m$		Machinery space in addition to the above 2.	0.85	A
Type 'B' ships	④	Ships having pontoon covers or steel hatch covers with gaskets and clamping devices				B
	⑤	Ships having steel hatch covers with gaskets and clamping devices	$100m < L_f \leq 225m$	One cargo compartment	0.95	B-0.6x (B-A)
	⑥			Any two adjacent fore and aft compartments excluding machinery space	0.95	A
	⑦		$L_f > 225m$	⑥ plus the machinery space	0.85	B-0.6x (B-A)
	⑧					A
	⑨*	Ships having in position 1 wooden hatch covers				(B)

* (B) = $B + \delta f_h$ (δf_h is referred to Table 14. Ships above 200 meters in length shall be dealt with by the Administrations.)

Position 1: Upon exposed freeboard and raised quarter decks, and upon exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular.

(2) Correction for small ships (only for Type 'B' ships)
The tabular freeboard for a ship between 24 meters and 100 meters in length having enclosed superstructures with an effective length of up to 35 per cent of the length of the ship L_f shall be increased by;

$$7 \cdot 5\,(100 - L_f)\,(0 \cdot 35 - E/L_f)\ (\mathrm{mm}),$$

E = effective length of superstructure in meters (Regulation 35)

(3) Correction for ships having wooden hatch covers (Regulation 27)
A ship which, upon exposed freeboard and raised quarter decks, and upon exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular, have hatchways fitted with wooden hatch covers (Regulation 15) shall be assigned freeboards increased by the values given in Table 14.

(4) Correction for block coefficient C_b (Regulation 30)

$$f_t = f_t' \times \frac{C_b + 0 \cdot 68}{1 \cdot 36} \qquad C_b > 0 \cdot 68$$

$$f_t = f_t' \qquad C_b \leq 0 \cdot 68$$

where, $C_b = \nabla/(L_f B d_f)$,
d_f = 85 per cent of the minimum freeboard depth
∇ = Net volume of the molded displacement at draft d_f

Tabular freeboard is obtained by (1) and the correction (4) is done for f_t' with the correction of (2) and (3).

Table 14 Freeboard Increase for a Ship with Wooden Hatch Cover

Unit: L_f(m), δf_h(mm)

L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h	L_f	δf_h
		111	57	121	87	131	131	141	186	151	232	161	267	171	292	181	315	191	339
		112	59	122	91	132	136	142	191	152	236	162	270	172	294	182	318	192	341
		113	62	123	95	133	142	143	196	153	240	163	273	173	297	183	320	193	343
		114	64	124	99	134	147	144	201	154	244	164	275	174	299	184	322	194	346
		115	68	125	103	135	153	145	206	155	247	165	278	175	301	185	325	195	348
		116	70	126	108	136	159	146	210	156	251	166	280	176	304	186	327	196	350
		117	73	127	112	137	164	147	215	157	254	167	283	177	306	187	329	197	353
≤108	50	118	76	128	116	138	170	148	219	158	258	168	285	178	308	188	332	198	355
109	52	119	80	129	121	139	175	149	224	159	261	169	287	179	311	189	334	199	357
110	55	120	84	130	126	140	181	150	228	160	264	170	290	180	313	190	336	200	358

Note) Freeboards at intermediate lengths L_f of ship shall be obtained by linear interpolation.

2.6.2. Correction for Superstructure

(1) Definitions of terms used for superstructure

(a) Superstructure
A superstructure is a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 0.04B. A raised quarter-deck is regarded as a superstructure. An enclosed superstructure is a superstructure with;

i) enclosing bulkheads of efficient construction.

ii) access openings, if any, in these bulkheads fitted with doors complying with the requirements of Regulation 12.

iii) all other openings in sides or ends of the superstructure fitted with efficient weathertight means of closing.

iv) access to reach machinery and other working spaces inside a bridge and poop in addition to access openings in end bulkheads.

(b) Height of superstructure h (Fig. 19) (Regulation 3)
The height of a superstructure is the least vertical height measured at side from the top of the superstructure deck beams to the top of the freeboard deck beams.

(c) Standard height of superstructure (Table 15) (Regulation 33)

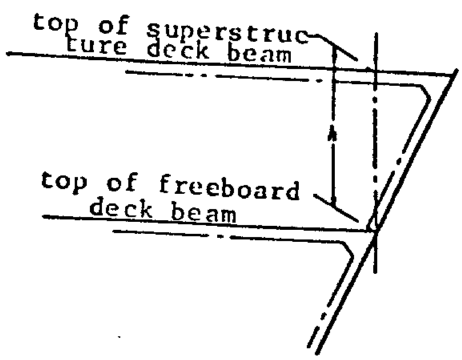


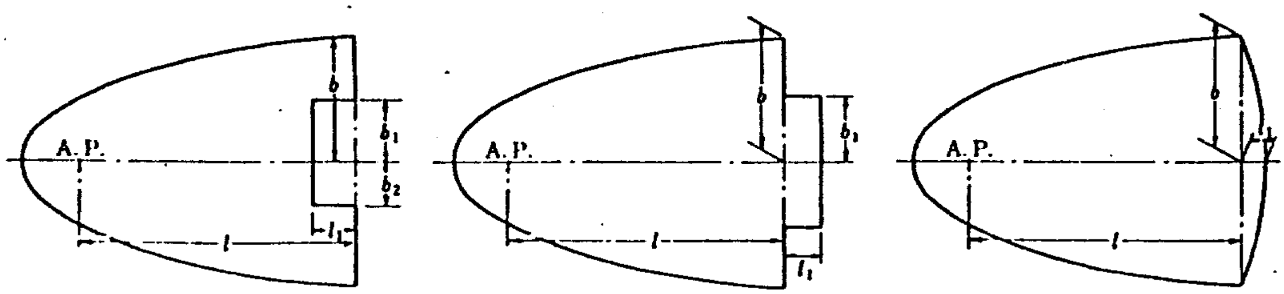
Fig. 19

Table 15 Standard Height of Superstructure

	Raised quarter deck	All other superstructures and trunk
$L_f \leq$ 30 m	0.90 m	1.80 m
$L_f =$ 75 m	1.20 m	1.80 m
$L_f \geq$ 125 m	1.80 m	2.30 m

Note) The standard height at intermediate lengths of the ship shall be obtained by linear interpolation.

(d) Length of superstructure S (Regulation 34)
The length of a superstructure shall be the mean length of the parts of the superstructure which lie within the length (L_f). Where the end bulkhead of an enclosed superstructure have concavo-convex forms, the corrections shall be made. (Table 16)



$b_1 > b_2$;

$S = l - \frac{b_1 \cdot l_1}{b}$

$S = l + l_1\left[1 - \frac{1}{3}\left(\frac{b}{b_1}\right)^2\right]$

where, $l_{1max} = \frac{b_1^2}{b}$

$S = l + \frac{2}{3} l_1$

where, $l_{1max} = b$

Note) The b_1 shall be set in not less than 0.04B and $b_1 > 0{\cdot}3B$

(e) Effective length of superstructure E

E = Length of superstructure (including correction for concavo-convex parts) x b/B_s (in superstructure with set-in part) x Height of superstructure/standard height of superstructure (only for the ratio not more than 1)

where, B_s = Breadth of the ship at the middle of the length of the superstructure

b = Breadth of the superstructure at the middle of its length

The effective length of a raised quarter deck, if fitted with an intact front bulkhead, shall be its length (up to a maximum of $0{\cdot}6L_f$). Where the bulkhead is not intact, the raised quarter deck shall be treated as a poop of less than standard height. Superstructures which are not enclosed shall have no effective length.

(f) Trunks

i) A trunk or similar structure which does not extend to the sides of the ship shall be regarded as efficient on the following conditions:

1. Breadth of the trunk $\geq 0{\cdot}6B$
2. Length of the trunk $\geq 0{\cdot}6L_f$
3. Regulation 36 (1)(a) - (f)

ii) The full length of an efficient trunk reduced in the ratio of its mean breadth to B shall be its effective length.

iii) The standard height of a trunk is the standard height of a superstructure other than a raised quarter deck.

iv) Where the height of a trunk is less than the standard height, its effective length shall be reduced in the ratio of the actual to the standard height. Where the height of hatchway coamings on the trunk deck is less than the standard height, a reduction from the actual height of trunk shall be made which corresponds to the difference between the actual and the required height of coaming.

(2) Deduction for superstructures (Regulation 37)
Correction amount δf_s = basic correction amount (Tably 17)
x deduction coefficient (Table 18)

Table 19 shall be applied for "B" type ship. Long poop combined with bridge shall be treated as poop in stead of bridge. (NK)

Table 17 Basic Correction Amount

Unit: mm

$L_f = 24$ m	$L_f = 85$ m	$L_f \geq 122$ m
350	860	1070

Note) The values at intermediate lengths (L_f) shall be obtained by linear interpolation.

Table 18 Superstructure Coefficient

Type of ship		Type of superstructure	R_s = Total effective length of superstructure/L										
			0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Type 'A' ship		All types of superstructure	0	0.07	0.14	0.21	0.31	0.41	0.52	0.63	0.753	0.877	1.0
Type 'B' ship	I	Ships with forecastle and without detached bridge	0	0.05	0.10	0.15	0.235	0.32	0.46	0.63	0.753	0.877	1.0
	II	Ships with forecastle and detached bridge	0	0.063	0.127	0.19	0.275	0.36	0.46	0.63	0.753	0.877	1.0

Note) Superstructure coefficient at intermediate lengths of superstructures shall be obtained by linear interpolation.

Table 19 Superstructure Coefficient of Type 'B' Ship

Length of superstructures and bridges		Superstructure coefficient
$f > 0{\cdot}4\,L_f$		II
$0{\cdot}4\,L_f > f \geqq 0{\cdot}07\,L_f$	$b=0$	I
	$0 < b < 0{\cdot}2\,L_f$	$\mathrm{I} + \frac{(\mathrm{II}-\mathrm{I}) \times b}{0{\cdot}2\,L_f}$
	$0{\cdot}2\,L_f \leqq b$	II
$0{\cdot}07\,L_f > f$	$b=0$	$\mathrm{I} - 0{\cdot}05 \times \frac{0{\cdot}07\,L_f - f}{0{\cdot}07\,L_f}$
	$0 < b < 0{\cdot}2\,L_f$	$\mathrm{I} + \frac{(\mathrm{II}-\mathrm{I}) \times b}{0.2\,L_f} - 0{\cdot}05 \times \frac{0{\cdot}07\,L_f - f}{0{\cdot}07\,L}$
	$0{\cdot}2\,L_f \leqq b$	$\mathrm{II} - 0{\cdot}05 \times \frac{0{\cdot}07\,L - f}{0{\cdot}07\,L_f}$

Note) f = Length of forecastle, b = Length of bridge

2.6.3. Correction by Depth Length Ratio (Table 20) (Regulation 31)

Table 20 Correction Amount by Depth Length Ratio δf_D (mm)

Unit: L_f, D_f (m)

L_f	$L_f < 120$ m	$L_f \geqq 120$ m
$D_f > \frac{L_f}{15}$	$\left(D_f - \frac{L_f}{15}\right) \times \frac{L_f}{0{\cdot}48}$	$\left(D_f - \frac{L_f}{15}\right) \times 250$
$D_f \leqq \frac{L_f}{15}$	0	
	In ship having the following conditions, the above $\lvert\delta f_D\rvert$ (or $\lvert\delta f_D\rvert \times h/h_s$ in the height of superstructures and trunks h lower than its standard height) shall be reduced from the freeboard. (1) a ship having an enclosed superstructure covering at least $0{\cdot}6\,L_f$ amidship. (2) a ship having a complete trunk (ɔ) a ship having combination of detached enclosed superstructures and trunks which extend all fore and aft.	

2.6.4. Correction for Position of Freeboard Deck Line (Regulation 32) Where the actual depth D_1 (m) to the upper edge of the freeboard deck line at side is greater than D_f at the middle of L, the modified value obtained from the following formula shall be added to the value from tabular freeboard. Where D_1 is smaller than D_f, the modified value shall be deducted from the tabular freeboard.

Correction value $\delta f_L - 1000\,(D_1 - D_f)$ (mm)

2.6.5. Correction for Sheer (Regulation 38)

(1) Sheer height

(a) The sheer shall be measured from the deck at side to a line of reference drawn parallel to the keel through the sheer line at amidships.

In ships designed with a rake of keel, the sheer shall be measured in relation to a reference line drawn parallel to the design load waterline.

(b) In ships with topsides of unusual form in which there is a step or break in the topsides, the sheer shall be measured in relation to a reference line passing through the point of the equivalent depth amidships.

(c) In flush deck ships and in ships with detached superstructures, the sheer shall be measured at the freeboard deck.

(d) In ships with a superstructure of standard height which extends over the whole length of the freeboard deck, the sheer shall be measured at the superstructure deck. Where the height exceeds the standard, the least difference (Z) between the actual and standard heights shall be added to each end of L_f. Similarly, the intermediate ordinates at distances of $L_f/6$ and $L_f/3$ from each end of L_f shall be increased by 0.444Z and 0.111Z respectively.

(e) Where an enclosed forecastle or poop is of standard height with greater sheer than that of the freeboard deck, or is of more than standard height, the height obtained from the following formula shall be added to the mean height at fore and aft parts of sheer on the freeboard deck. (NK)

$$\frac{1}{3} \times \frac{y \cdot L'}{L_f/2}$$

where, y = difference between actual and standard height of superstructure at the end of sheer

L' = mean enclosed length of poop or forecastle up to maximum length of $0{\cdot}5\,L_f$

(2) Standard sheer and mean standard sheer profile (Table 21) (Regulation 38)

Table 21 Standard Sheer and Standard Sheer Profile (mm) Unit: L_f (m)

Standard sheer height at each 6 equally divided point	S_{o1} (at aft end of L_f)		$25\,(L_f/3+10)$
	S_{o2} (at $L_f/6$ from aft end of L_f)		$11{\cdot}1\,(L_f/3+10)$
	S_{o3} (at $L_f/3$ from aft end of L_f)		$2{\cdot}8\,(L_f/3+10)$
	S_{o4} (at middle of L_f)		0
	S_{o5} (at $L_f/3$ from fore end of L_f)		$5{\cdot}6\,(L_f/3+10)$
	S_{o6} (at $L_f/6$ from fore end of L_f)		$22{\cdot}2\,(L_f/3+10)$
	S_{o7} (at fore end of L_f)		$50\,(L_f/3+10)$
Standard mean sheer height	the whole L_f	S_o	$12{\cdot}51\,(L_f/3+10)$
	the fore part	S_F	$16{\cdot}68\,(L_f/3+10)$
	the aft part	S_A	$8{\cdot}34\,(L_f/3+10)$

(3) Mean sheer height

Mean sheer height $S = (s_1+3s_2+3s_3+2s_4+3s_5+3s_6+s_7)/16$ (mm)

Mean sheer height at the fore part $S_f = (s_4+3s_5+3s_6+s_7)/8$ (mm)

Mean sheer height at the aft part $S_a = (s_1+3s_2+3s_3+s_4)/8$ (mm)

According to the values of S_f, S_a and S_F, S_A, Table 22 shall be applied.

Table 22 Actual Mean Sheer Height   Unit: mm

Relation between S_f, S_a and S_F, S_A		Actual value		
fore part	aft part	fore part	aft part	mean value
$S_f<S_F$	$S_a \leq S_A$	S_f	S_a	$(S_f+S_a)/2$
	$S_a>S_A$		S_A	$(S_f+S_A)/2$
$S_f \geq S_F$	$S_a \geq 0{\cdot}75\, S_A$	S_f	S_a	$(S_f+S_a)/2$
	$0{\cdot}50\, S_A \leq S_a < 0{\cdot}75\, S_A$	S'*		$(S'+S_a)/2$
	$S_a<0{\cdot}50\, S_A$	S_F		$(S_F+S_a)/2$

Note) * After the actual sheer height S_i at each point equally divided in the fore part and the standard sheer height S_{ai} are figured, the mean sheer height S_i shall be calculated by means of the following formula:

$$S_i' = S_{ai} + (S_i - S_{ai})(4\frac{S_a}{S_A} - 2), \quad i = 4 \sim 7$$

In the sheer form of parabola curve, the formula is as follows;

$$S' = S_F + (S_f - S_F)(4\frac{S_a}{S_A} - 2)$$

(4) Correction for sheer δf_s (Table 23)

Table 23 Correction for Sheer δf_s

Unit: δf_s: S, S_0(mm), L_f, E(m)

Relation between S and S_0		δf_s
$S < S_0$		$(S_0 - S)(0{\cdot}75 - 0{\cdot}5\, r_1)$
$S > S_0$		$(S_0 - S)(0{\cdot}75 - 0{\cdot}5\, r_1)\frac{5E}{L_f}$
	Max. limit of $\lvert \delta f_s \rvert$	$1{\cdot}25\, L_f$

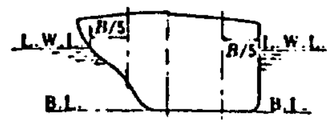
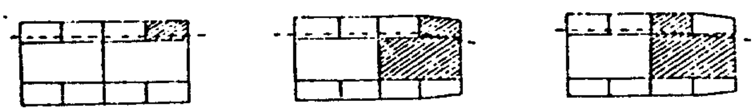
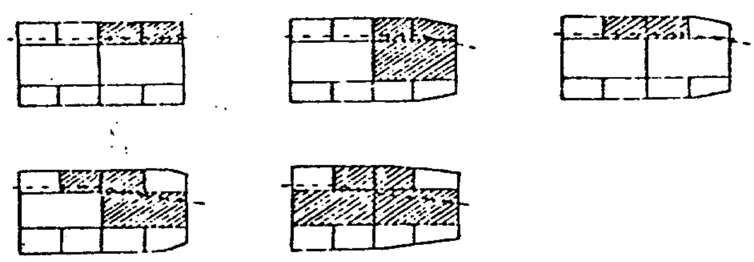
Note) E = Length of enclosed superstructures (except trunks) located within $0{\cdot}1 L_f$ from the middle of L_f

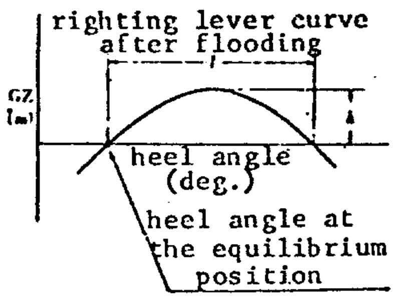
r_1 = Sum of the length of superstructures/L_f

2.7. Flooding Calculation

Flooding calculation shall be done on the basis of the conditions of Table 13 and the assumptions of Table 24 according to the tabular freeboard.

Table 24 Assumptions and Definition of Terms for Flooding Calculation (IMCO A.172 (1968))

	Item	Assumptions and Definitions of Terms
Draft before damage		Summer load waterline·even keel
Extent of Damage, etc.	Vertical direction	to the depth of the ship
Extent of Damage, etc.	Transverse direction	B/5 from the side of the ship at summer load waterline. 
Extent of Damage, etc.	Longitudinal direction	For flooding to two compartments: 3·05m+0·03 L_f, but it shall be max. 10.65 m
Extent of Damage, etc.	Main transverse bulkhead	Regarded not to be damaged
Extent of Damage, etc.	Transverse bulkhead with steps or recesses	If in a transverse bulkhead there is a step or recess of more than 3.05 m in length located within the extent of transverse penetration of damage of B/5, the two compartments adjacent to this bulkhead should be considered as flooded.
Extent of Damage, etc.	Tanks in Engine room	With regard to tanks, such as fuel oil tanks, lubricating oil tanks and fresh water tanks, unless the dynamic stability is required to be investigated, or where the heeling moment due to unsymmetrical flooding of these tanks is appreciable, such tanks may be assumed not to be floodable.
Example of Flooding Compartment	One compartment flooding	
Example of Flooding Compartment	Two compartments flooding	 Dashed lines in the above figures show the lines of B/5 from the side of the ship at the summer loadline.

Item			Assumptions and Definitions of Terms
Cargo loading conditions, etc.	KG		KG is assessed allowing for homogeneous loading of all cargo spaces and 50 per cent of individual total capacity of all tanks and spaces fitted to contain consumable fluids and ship's stores
	Permeability		Cargo space: 0.95 Machinery space: 0.85
	Loading in tank		The distribution of consumable liquids should be effected so as to obtain the greatest possible KG for the tanks which are not taken account of corrections for free surfaces of liquids
	Effect of free surface		For each type of liquid, one transverse pair or a single center line tank where the effect of free surface is the greatest should be taken into account.
	Specific weight of liquids		Salt water: 1.025 Fresh water: 1.000 Oil fuel : 0.950 Diesel oil : 0.900 Lubricating oil: 0.900
Condition to be fulfilled after flooding	Heel angle after flooding θ(deg), etc.		1. $\theta < 15°$ but if the deck line at the side is not immersed, an angle of heel of up to 17° may be accepted. 2. When any part of the deck beyond the limits of flooding is immersed or in any case where the stability in the flooded condition may be considered doubtful, the dynamic stability may be regarded as sufficient with the following conditions. $h \geq 0.1$m and $l \geq 20°$ 
	GM after flooding		$GM \geq 50$ mm
	Waterline after flooding		The final waterline after flooding is to be below the lower edge of any opening described below.
	Opening	Flooding opening	Weathertight doors on the ends of superstructures and bridges, weathertight hatches, weathertight ventilating air pipes, etc.
		Non-flooding opening	Watertight manhole and flush scuttles (Reg. 18), watertight small access opening (Reg. 27.2), watertight door, remotely controlled watertight sliding door, fixed side scuttles (Reg. 23)

2.8. Minimum Bow Height h (Regulation 39)

(1) Definition
The bow height defined as the vertical distance at the forward end of L_f between the assigned summer load waterline and the top of the exposed deck at side shall comply with the figures shown in Table 25.

(2) Condition
The bow height h obtained from Table 25 by sheer or superstructure shall comply with the following conditions.

(a) If obtained by sheer, the sheer shall extend for at least $0.15 L_f$ from the forward end of L_f.

(b) If obtained by fitting a superstructure, the superstructure shall extend abaft from the forward end of L_f to a point at least $0.07 L_f$.
In case of $L_f \leq 100$ m, it shall be enclosed as defined in 2.6.2.(1)(a).
In case of $L_f > 100$ m, it shall be fitted with closing appliances to the satisfaction of the Administration.

Table 25 Min. Bow Height (mm)

Unit: L_f (m)

$L_f < 250$ m	$h \geq 56 L_f \left(1 - \frac{L_f}{500}\right) \frac{1.36}{C_b + 0.68}$
$L_f \geq 250$ m	$h \geq 7000 \frac{1.36}{C_b + 0.68}$

Note) C_b shall be not less than 0.68.

(3) Exception
Ships which, to suit exceptional operational requirements, cannot meet (1) and (2) may be given special consideration by the Administration.

2.9. Timber Freeboards

2.9.1. Special Requirements for Ships Assigned Timber Freeboards (Regulation 43, 44)

(1) Ships shall have a forecastle of at least standard height and a length of at least $0.07 L_f$. In addition, if the ship is less than 100 m in length, a poop of at least standard height, or a raised quarter-deck with a deck-house shall be fitted.

(2) Double bottom tanks where fitted within $\frac{1}{2} L_f$ [illegible] shall have adequate watertight subdivision.

(3) The ship shall be fitted either with permanent bulwarks at least 1 m in height or with efficient rails of the same height.

(4) Efficient provision shall be made for steering in the event of a break-down in the main steering arrangements.

(5) Suitable lashing equipment shall be provided. (Regulation 44)

(6) Guard rails and/or life lines shall be provided on each side of the deck cargo.

(7) The stability of the ship loaded timber cargo shall be sufficiently taken into account. (Refer to 4.5.2)

2.9.2. Special Requirements for On-Deck Loading of Timber

Timber freeboards shall be applied only for ships carrying timber deck cargo in conformity with the prescribed loading conditions. In the part on the freeboard deck where neither the superstructure or the deckhouse is located, the timber shall be stowed to at least the standard height of the superstructure. On a ship within a seasonal winter zone in winter, the height of the deck cargo above the weather deck shall not exceed one-third of the extreme breadth of the ship. Other restrictions on the stowage shall comply with Regulation 44.

2.9.3. Form Freeboard of Ships Assigned Timber Freeboards (Regulation 45)

(1) Correction for superstructure

The correction amount δf_1 shall be computed by substituting the superstructure coefficient in Table 26 for those given in Table 18. (Regulation 45)

Table 26 Superstructure Coefficient for Timber Freeboards

R_1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Superstructure Coefficient	0.20	0.31	0.42	0.53	0.64	0.70	0.76	0.82	0.88	0.94	1.0

Note) Coefficients at intermediate R_1 shall be obtained by linear interpolation.

(2) Determination of freeboard in various conditions (Table 10)

2.10. Requirements on the Structures and Fittings of Ships

2.10.1. Height of Hatchways (Regulation 15, 16)
(Refer to Chapter V, 5.2.1, Table 40)

2.10.2. Coaming Height of Entrances on Machinery Casing (Regulation 17)
(Refer to Chapter V, 5.1.1, Table 39)

2.10.3. Sill Height to Doorways in Companionways (Regulation 18)
(Refer to Chapter V, 5.1.1, Table 39)

2.10.4. Coaming Height of Ventilators (Regulation 19)
(Refer to Chapter V, 17.1.1, Table 143)

2.10.5. Height of Air Pipes for Tanks (Regulation 20)
(Refer to Chapter V, 11.1.1, Table 102)

2.10.6. Scuppers below the Freeboard Deck (Regulation 22)
(Refer to Chapter V, 13.2.1, Table 121)

2.10.7. Side Scuttles (Regulation 23) (Refer to Chapter V, 5.7.1(2))

2.10.8. Freeing Ports on Bulwarks (Regulation 24)

(1) Where bulwarks on the weather portions of freeboard or superstructure decks form wells, the total freeing port area shall be that given by the following formulae, but the cases of (2) and (3) shall be excluded.

(a) On freeboard deck ; $A = 0.7 + 0.035\,l$ (m^2) ($l \leq 20$ m)

$A = 0.07\,l$ (m^2) ($l > 20$ m)

(b) On superstructure deck; one-half of the area given by the above (a)

(c) If the bulwark is more than 1.2 m in average height, the required area shall be increased by adding ΔA in the following formula to A.

$$\Delta A = 0.0004\,l\,(h - 1.2) \ (m^2)$$

where, h = average height of bulwark (m)
l = length of bulwark (to need in no case be taken as greater than $0.7 L_f$)

(2) In ships with no sheer, the A shall be increased by 50 per cent. Where the sheer is less than the standard, the percentage shall be obtained by interpolation.

(3) Where a ship is fitted with a trunk or continuous hatchway coamings between detached superstructure, the minimum area of the freeing port opening shall be calculated from Table 27.

(4) Two-thirds of the freeing port area required shall be provided in the half of the well nearest the lowest point of the sheer curve.

Table 27 Area of Freeing Port (in 2.10.8 (3))

Breadth of hatchway or trunk / Breadth of ship	Area of freeing port / Total area of bulwark
≤ 40 %	20%
≥ 75 %	10%

Note) The value at intermediate breadths shall be obtained by linear interpolation.

2.11. Protection of the Crew

(1) The height of the bulwarks or guard rails shall be in principle at least 1 metre from the deck.

(2) The opening below the lowest course of the guard rails shall not exceed 230 mm. The other courses shall be not more than 380 mm apart. In case of ships with rounded gunwales, the guard rail supports shall be placed on the flat of the deck.

(3) Satisfactory means such as guard rails, life lines, gangways or underdeck passages, shall be provided for the protection of the crew in getting to and from their quarters, the machinery space and all other parts used in the necessary work of the ship.

(4) Effective protection for the crew in the form of guard rails or life lines shall be provided above the deck cargo if there is no convenient passage on or below the deck.

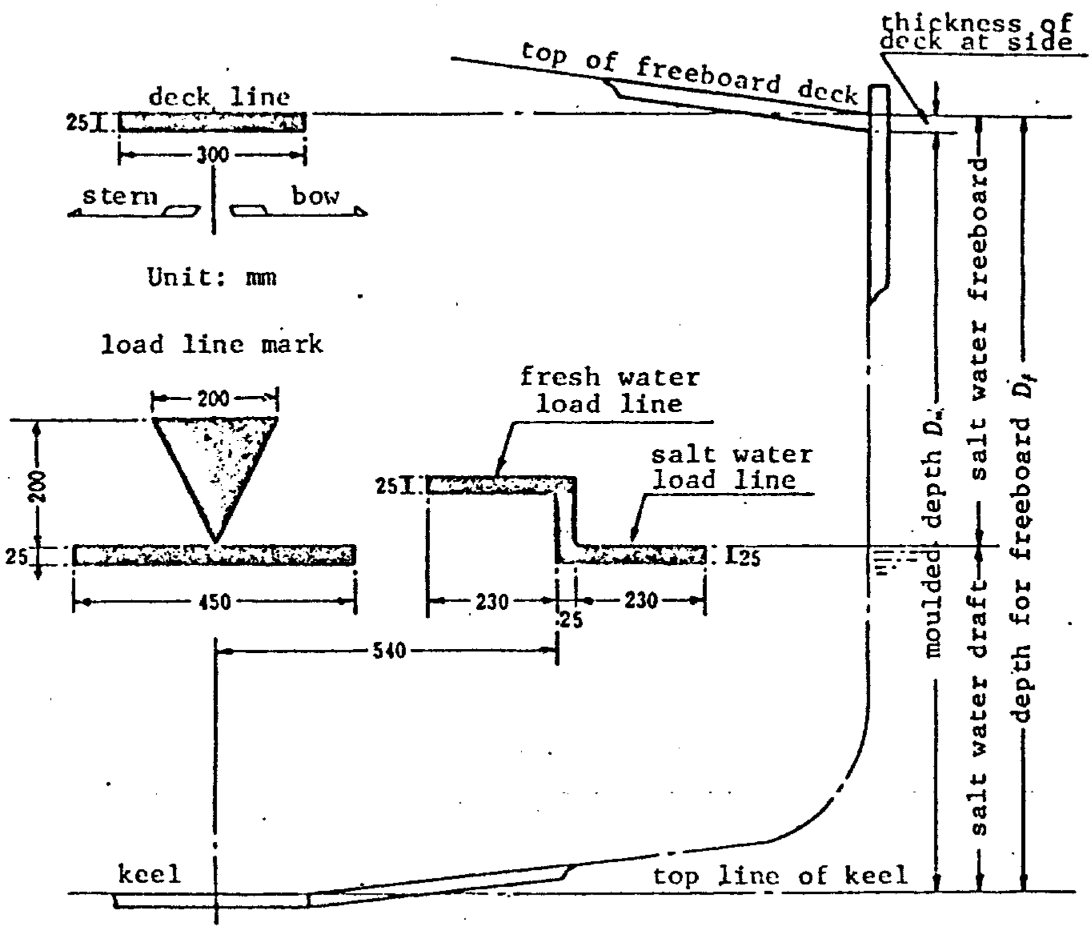
(5) For ships assigned timber freeboards, in addition to the above (4), guard rails or life lines spaced not more than 330 mm apart vertically shall be provided on each side of the deck cargo to a height of at least 1 m above the cargo.

2.12. Freeboard of the Ship engaged on Coastal Voyages

2.12.1. Application

Steel ships of 24 m in length and over which is engaged on coastal voyages. Refer to Regulations No. 33 of Japanese MOT issued in 1968 for ships such as wooden ships fishing vessels engaged on coastal voyages.

2.12.2. Illustration of Load Waterline (Fig. 20)



2.12.3. Definitions of Terms, Units and Significant Figures for Calculations

(1) Definitions of terms (refer to 2.3.1.)

(2) Units and significant figures for calculations

(a) Figures, such as the length and breadth of a ship, the length and height of a superstructure and the sheer height which show the size of a ship, shall be shown to second decimal place with metric unit, but to third decimal place for moulded depth.

(b) The thickness of deck coverings and deck stringer shall be shown by metric unit and to third decimal place.

(c) Figures such as C_b, $(0 \cdot 68 + C_b)/1 \cdot 36$, $L_f/15$, $S/(2L_f)$ shall be shown to third decimal place.

(d) Figures directly related to freeboard by the addition and substruction shall be shown in centimeter to first decimal place.

The figures of the above shall be rounded to the lowest decimal place.

2.12.4. Determination of Freeboard

(1) Freeboard in salt water
The freeboard in salt water shall be obtained from the basic freeboard (refer to 2.12.5.) by taking into account the correction for depth (refer to 2.12.6.), the correction for superstructures, trunks, etc. (refer to 2.12.7.) the correction for sheer (refer to 2.12.8.) and the correction for steel hatch covers (2.12.9.).
The minimum freeboard shall be;

Tankers ; 5 cm
Ships other than tankers; 10 cm

(2) Fresh water freeboard
The following amount shall be deducted from the minimum freeboard in salt water.

$$\frac{\Delta}{40\,T}\ (\text{cm})$$

where, Δ = displacement in salt water at the summer load waterline (t).
T = TPC immersion in salt water at the summer load waterline (t/cm).

When T is not clear, $d_s/48$ may be applied instead of TPC
(d_s = load waterline in salt water)

(3) For ships engaged in certain limited coastal zone, the freeboard may be of the figure multiplied by 0.85 to the above freeboard.

2.12.5. Basic Freeboard

In case of $C_b > 0{\cdot}68$ Basic freeboard = $f_o \times (C_b + 0{\cdot}68)/1{\cdot}36$

In case of $C_b < 0{\cdot}68$ Basic freeboard = f_o

where, C_b = block coefficient
f_o = tabular freeboard (Table 28)

Table 28 Tabular Freeboard f_o (cm)

Unit: L_f(m)

	Tankers	Ships other than tankers
$L_f < 50$ m	$0{\cdot}5\,L_f$	$0{\cdot}8\,L_f$
$L_f \geq 50$ m	$0{\cdot}8\,(L_f/10)^2 + (L_f/10)$	$(L_f/10)^2 + (L_f/10) + 10$

2.12.6. Correction for Depth (Table 29)

Table 29 Correction for Ship's Depth (cm)

Unit: L_f, D_m(m)

	$L_f < 50$ m	$50\text{ m} \leq L_f < 100$ m	$L_f \geq 100$ m
$D_m > L_f/15$	$20\,(D_m - L_f/15)$	$(0{\cdot}1L_f + 15)\,(D_m - L_f/15)$	$25\,(D_m - L_f/15)$
$D_m \leq L_f/15$		0	

2.12.7. Correction for Superstructures, Trunks, etc.

(1) Definitions of terms on superstructures, etc.

(a) Superstructures (refer to 2.6.2.)

(b) Trunks

A trunk shall be regarded as efficient on the following conditions:

i) Width of the trunk $\geq 0{\cdot}4B$

ii) The trunk is at least as strong as superstructure

iii) The hatchways are in the trunk deck and have efficient means of closing.

iv) A permanent working platform fitted with guard rails is provided by the trunk deck, or by detached trunks connected to superstructures by efficient permanent gangways.

(c) Effective length of superstructures and trunks

i) Effective length of superstructures
= Length of superstructure (including correction for concavo-convex parts) x b/B_s (in superstructure with set-in parts)

where, b = Breadth of the superstructure at the middle of its length (m)
B_s = Breadth of the ship at the middle of the length of the superstructure

The superstructure with the second grade closing device may be 70 per cent in length to the above figure.

ii) Effective length of trunks = Mean length of trunks x $(1{\cdot}65b_t - 0{\cdot}65B_s)/B_s$

where, b_t = Breadth of the trunk at the middle of its mean length (m)

iii) For ships under 100 m in length, the length of the superstructures and the trunks where the cargoes are loaded shall be multiplied by $(0{\cdot}5+L_f/200)$ to the figures of the above i), ii).

(d) Height of superstructure and trunk

The height of a superstructure is the least vertical height measured at side from the top of the superstructure deck beams to the top of the freeboard deck beams. The height of a trunk is measured at the side wall of the trunk. Those heights shall not be more than $(1{\cdot}0+0{\cdot}01L)$ (m)

(2) Correction amount for superstructure, etc.

$$= 50(\sum l_s \times h_s)/L \quad \text{(cm)}$$

where, l_s = Effective length of enclosed superstructures and trunks (m)
h_s = Height of enclosed superstructures and trunks (m)

2.12.8. Correction for Sheer

$$\text{Correction amount} = \frac{1}{6}\left\{2{\cdot}5(L+30) - 100(S_f + S_a)\right\}\left(0{\cdot}75 - \frac{S}{2L}\right) \text{(cm)}$$

Where the correction amount is less than $-0{\cdot}125L$, the value shall be $-0{\cdot}125L$

where, S_f = Height of sheer at fore perpendicular (m)
S_a = Height of sheer at aft perpendicular (m)
S = Total length of superstructures (m)

For ships with straight sheers, the parabolic sheers equivalent to the actual sheers in area shall be applied.

2.12.9. Correction for Steel Hatch Covers

For ships having steel hatch covers other than tankers, the deduction from the basic freeboard shall comply with Table 30.

Table 30 Correction Values for Steel Hatch Cover

$L_f \leq 100$ m	$L_f - 110$ m	$L_f - 120$ m	$L_f - 130$ m
4·0	5·0	8·0	12·0

Note) 1. Deductions at intermediate lengths of ship shall be obtained by linear interpolation.

2. Ships above 130 m in length shall be dealt with by the Administrations.

3. WATERTIGHT SUBDIVISION

3.1. Japanese Regulations for Ship's Subdivision (Legislated in 1952, Revised in 1968)

3.1.1. Application (Article 1)

Passenger ships engaged in international voyage.

3.1.2. Definition (Article 2-10, 20-22)

(1) The length of the ship, L: Waterline length at the extremities of the deepest subdivision load line. (m)

(2) The breadth of the ship, B: The extreme width from outside of frame to outside of frame at or below the deepest subdivision loadline. (m)

(3) Bulkhead deck: The uppermost deck to which the transverse watertight bulkheads are carried.

(4) Margin line: A line drawn at least 76 mm below the upper surface of the bulkhead deck at side.
For the determination of margin line, minimum thickness shall be adopted in the vessels with the bulkhead deck of unequal thickness at side, unless the Administration admits especially to adopt the mean thickness of the bulkhead deck throughout the ship's length. (But thickness of the deck shall be limited to 50 mm plus minimum thickness of the deck where it exceeds the said thickness.)

(5) Draft: The vertical distance from the molded base line amidships to the subdivision loadline in question. (m)

(6) Permeability, μ : The percentage of that space which can be occupied by water. (%)

(7) Machinery space: The space taken as extending from the molded base line to the margin line and between the extreme main transverse watertight bulkheads bounding the spaces containing the main and auxiliary propelling machinery, boilers serving the needs of propulsion and all permanent coal bunkers.

(8) Fore (aft) hold space: The hold space below the margin line forward of (abaft) the machinery space.

(9) Passenger spaces/crew spaces: Spaces which are provided for the accommodation and use of passengers/crew, excluding baggage, store, provision and mail rooms.

(10) Cabins: Passenger spaces and crew spaces.

(11) Floodable length: Maximum portion of the length of the ship, having its center at the point in question, which can be flooded without the ship being submerged beyond the margin line under the following assumptions.

(a) The ship shall be afloat at the deepest subdivision loadline.

(b) The space in the ship shall have the permeability determined by the Regulation.

(12) Permissible length: Maximum permissible length of a compartment normally used which is obtained from the floodable length by multiplying the factor of subdivision.

(13) Criterion numeral of service, C_s : The numeral to denote the degree to which a ship is a passenger ship.

3.1.3. Determination of Permiability (Article 14-19)

A uniform average permeability shall be used throughout the whole length of each of the following portions of the ship.

Machinery space
Forward hold space
Aftward hold space

a = Volume of the cabin located in the space in question
c = Volume of between deck spaces which are appropriated for cargo, coal or stores and situated in the space in question
v = Whole volume of the space in question

(1) Machinery space $\mu = 85 + 10\frac{a-c}{v}$

μ = Permiability

(2) Fore (Aft) hold space $\mu = 63 + 35\frac{a}{v}$

(3) Permeability by detailed calculation

In case the ship has the abnormal arrangement of the forward and aftward hold spaces or the permeability of machinery space obtained by detailed calculation is less than the value given in (1), following numeral shall be used as permeability of each space.

Cabin	95%
Holds, stores	60%
Tanks	The value admitted by the Administration
Spaces containing machinery	85%

3.1.4. Factor of Subdivision (Article 22-26)

(1) Criterion numeral of service, C_s

M = Volume of machinery space. Volume of permanent fuel oil tanks on and above the double bottom in forward and aftward hold spaces shall be added, if any.
P = Whole volume of cabins below the margin line.
V = Whole volume of the ship below the margin line.
N = Number of passengers for which the ship will be certified.
K = 0.056L (m^3)
P_1 = Assumed volume = KN

Where the value of KN is greater than T which is the sum of P and the whole volume of the actual passenger spaces above the margin line, the figure to be taken as P_1 is T or $\frac{2}{3}KN$, whichever is the greater.

$$C_s = 72\frac{M+2P_1}{V+P_1-P} \quad \text{where} \quad P_1 > P$$

$$C_s = 72\frac{M+2P}{V} \quad \text{where} \quad P_1 \leq P$$

(2) Factor of subdivision, F

(a) $L \geq 131\,\mathrm{m}$

$F = \dfrac{58 \cdot 2}{L-60} + 0 \cdot 18 \equiv A,$	where	$C_s \leq 23$
$F = \dfrac{30 \cdot 3}{L-42} + 0 \cdot 18 \equiv B$	where	$C_s \geq 123$
$F = A - \dfrac{(A-B)(C_s-23)}{100}$	where	$23 < C_s < 123$

In case the factor of subdivision calculated by the above formula is less than 0.4, the value for machinery space only can be increased to 0.4. In case the criterion numeral is not less than 45 and the factor of subdivision calculated by the formula is over 0.5 and not more than 0.65, the factor of subdivision shall be reduced to 0.5.

(b) $79\,\mathrm{m} \leq L < 131\,\mathrm{m}$

$F = 1 \cdot 00,$	where	$C_s \leq \dfrac{3574-25L}{13}$
$F = B \equiv \dfrac{30 \cdot 3}{L-42} + 0 \cdot 18$	where	$C_s \geq 123$
$F = 1 - \dfrac{(1-B)(C_s-S)}{123-S}$	where	$\dfrac{3574-25L}{13} (\equiv S) < C_s < 123$

(c) $L < 79\,\mathrm{m}$ $\quad F = 1 \cdot 00$

(d) When the certified number of passengers does not exceed $L^2/650$ or 50, whichever is the less,

$$F = 1 \cdot 00$$

3.1.5. Special Rules Concerning Subdivision (Article 28-39, 65-68)

(1) Bow part

(a) Collision bulkhead shall be fitted between $0 \cdot 05L$ and $0 \cdot 05L + 3 \cdot 05\,\mathrm{m}$ from F.P.

(b) In ships not less than 100 m length, the distance from F.P. to the bulkhead abaft the collision bulkhead shall not exceed the permissible length.

(2) Stern part
The location of the afterpeak bulkhead is not specified.
The afterpeak bulkhead may be stopped below the bulkhead deck, provided that the degree of the safety of the ship as regards subdivision is not thereby diminished.

(3) Double bottom

(a) The space where the double bottom is fitted

$50\,\mathrm{m} \leq L < 61\,\mathrm{m}$	The space from the front bulkhead of machinery space to the collision bulkhead.
$61\,\mathrm{m} \leq L < 76\,\mathrm{m}$	Above space plus the space from the aft of machinery space to the afterpeak bulkhead.
$L \geq 76\,\mathrm{m}$	The space from collision bulkhead to afterpeak bulkhead.

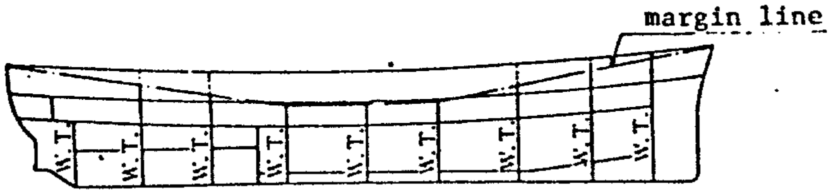
(b) The line of intersection of the outer edge of the margin plate with the bilge plating is not lower at any point than a horizontal plane passing through the point of intersection with the frame line amidships of a transverse diagonal line inclined at 25 degrees to the base line and cutting it at a point one-half the ship's molded breadth from the middle line.

(c) The depth of the bilge well shall in no case be more than the depth less 457 mm of the double bottom at the centerline, nor shall the well extend below the horizontal plane mentioned above.
A well extending to the outer bottom is however, permitted at the after end of the shaft tunnel of screw ships.

(4) Margin line

(a) When the bulkhead deck is made up with two layers of discontinuous decks, the margin line can be drawn as shown in Fig. 21.

Fig. 21



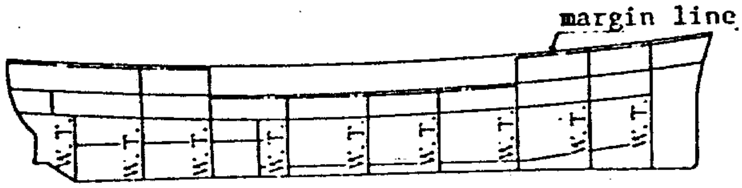
(b) In such cases as follows, the margin line can be decided as shown in Fig. 22.

i) The sides of the ship are extended throughout the ship's length to the higher deck.

ii) All openings in the shell plating below this higher deck meet the requirements of Chapter 8 of the Regulations.

iii) The total length of each compartment adjacent to the "step" in the bulkhead deck does not exceed twice the permissible length based on the lower margin line.

Fig. 22



(5) The compartment which can exceed the permissible length
When neither of the combined length of one compartment (hereinafter called Compartment A) and the forward compartment (hereinafter called Compartment B) adjacent to Compartment A nor that of Compartment A and the afterward compartment (hereinafter called Compartment C) adjacent to Compartment A exceed floodable length and twice the permissible length, the length of the Compartment A may exceed the permissible length.

(6) Recess of the bulkhead
All parts of recess shall lie inboard of vertical surfaces on both sides of ship, situated at a distance not less than one-fifth of the breadth of the ship from the shell plating at the level of the deepest subdivision loadline, unless the paragraph (7) is satisfied.

(7) Step of the bulkhead
A transverse bulkhead may be stepped provided that it meets one of the following conditions:-

(a) The combined length of the compartments at both sides of the step does not exceed either 90% of floodable length or twice the permissible length, except that in ships having a factor of subdivision greater than 0.9, the combined length of the two compartments in question shall not exceed the permissible length.

(b) Additional subdivision is provided in way of the step to maintain the same measure of safety as that secured by a plane bulkhead.

(c) The compartment just under the step does not exceed the permissible length corresponding to a margin line taken 76 mm below the step.

(8) Minimum length of the compartment
If the distance between two adjacent transverse bulkheads is less than $3{\cdot}05\text{m}+0{\cdot}03L$ or 10.67m whichever is the less, only one of these bulkheads is regarded as forming part of the subdivision of the ship.

3.1.6. Stability of Ships in Damaged Condition (Article 40-46)

(1) Final condition of the ship after damage and after equalization measures have been taken shall be as follows.

(a) In case of symmetrical flooding, there shall be a positive metacentric height of at least 0.05 m.

(b) In case of unsymmetrical flooding, the total heel shall not exceed 7 degrees, except that the Administration may allow the final heel up to 15 degrees in special cases.

(c) The margin line shall not be submerged.

(2) Assumed flooded compartment

(a)	$0{\cdot}50 < F \leq 1{\cdot}00$	One compartment (Two adjacent compartments when the transverse bulkhead is stepped)
(b)	$0{\cdot}33 < F \leq 0{\cdot}50$	Two adjacent compartments
(c)	$F \leq 0{\cdot}33$	Three adjacent compartments

3.2. Calculation of Floodable Length
In determining the floodable length, MOT standard method, DOT method or other methods which have the accuracy equivalent to or higher than those methods may be applied.

3.2.1. MOT Standard Method

(1) Curves to be prepared
Displacement curve, LBM curve, ⌀F curve and transverse sectional area curve up to the margin line.

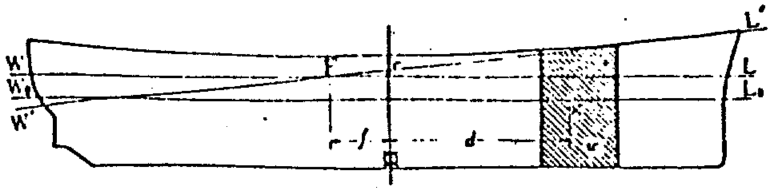


Fig. 23

(2) Relation between the weight of added water in the flooded compartment and position of center of gravity

When the draft of the ship floating at first at the subdivision loadline W_0L_0 varies to $W'L'$ which is tangent to the margin line after the shaded compartment is flooded into as shown on Fig. 23, the weight of added water in the flooded compartment w becomes

$$w = \Delta - \Delta_0$$

Assuming the form of margin line to be $y = \frac{4s}{L^2}x^2 + c$ the distance d from ⊠ to center of gravity of w becomes

(a) $$d = \frac{4\Delta M}{Lw}\left(\sqrt{sc} \mp \frac{2sf}{L}\right) \mp f \qquad c < s$$

(b) $$d = \frac{4\Delta M}{Lw}\left(\frac{2sf}{L} \mp \frac{2sf}{L}\right) \mp f \qquad c = 0$$

(c) $$d = \frac{2\Delta M(c+s)}{w(L \pm 2f)} \mp f \qquad c \geq s$$

where
- Δ = Displacement of the ship floating at waterline WL
- Δ_0 = Displacement of the ship floating at waterline W_0L_0
- M = LBM of the ship floating at waterline WL
- f = Distance from midship to center of floatation of the ship floating at waterline WL
- s = Sheer of the ship
- c = Distance from the waterline WL to the lowest point of margin line of the ship

The sign on the upper side shall be taken when the center of floatation F locates at the opposite side of the center of gravity of w about midship and the sign on the lower side shall be taken when F is at the same side.

(3) Floodable volumetric curve

Floodable volume can be calculated by

$$v = \frac{100(\Delta - \Delta_0)}{1{\cdot}025\,\mu} = \frac{97{\cdot}56}{\mu}(\Delta - \Delta_0)$$

From the above, floodable volumetric curve can be drawn in relation to d.

(4) Determination of floodable length

(a) Integral curve of transverse sectional area integrated from A.P. or F.P. towards midship is drawn by the same scale as floodable volumetric curve.

(b) The proportional volumetric curve, which is the product of floodable volume multiplied by factor R, is drawn.

Where $$R = \frac{1}{12}\left(\frac{5+7r}{1+r}\right)$$

r = Ratio of the transverse sectional area at both ends of the floodable length.

The value of R is usually 0.5 at midship and 0.45 at both ends of the ship. Making use of the above curves, the floodable length can be obtained by the method as shown on Fig. 24.

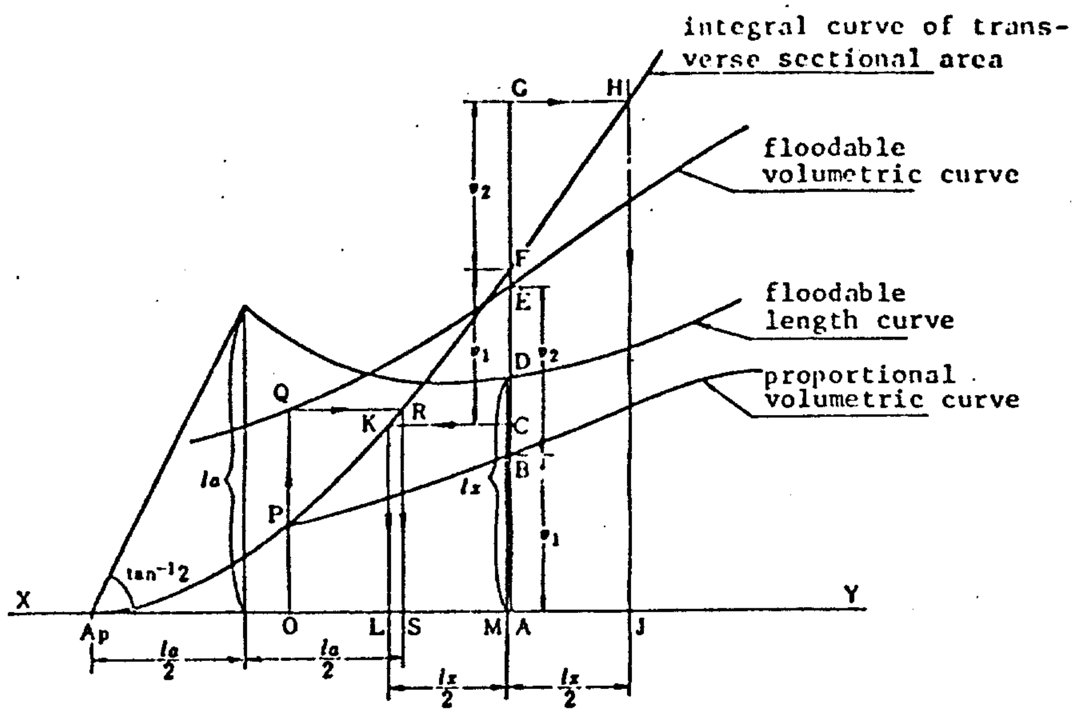


Fig. 24

i) Floodable length at both ends

By drawing a vertical line OQ to base line XY, which passes through point P (cross point of proportional volumetric curve and the integral curve of the transverse sectional area) and QR parallel to XY, the floodable length $\overline{ApS}$, which is the horizontal length between Ap and R, is obtained.

ii) Floodable length except the above

Drawing a vertical Line AG to base line XY at a certain point A, taking $\overline{FC}$ and $\overline{FG}$ equal to $\overline{AB}$ and $\overline{EB}$ respectively on the line AG and then drawing parallel lines CK and GH to base line XY, the floodable length $\overline{LJ}$ at the midst M of $\overline{LJ}$, which is the horizontal distance between K and H on the integral curve of transverse sectional area, is obtained.

3.3. Subdivision Requirements for Passenger Ferry (JG circular 1973, ship inspection code No. 367)

(a)	$L < 45$m	One compartment
(b)	$45\text{m} \leq L < 79$m	Two adjacent compartments for foremost and aftermost parts of the ship One compartment for other parts
(c)	$L \geq 79$m	Two adjacent compartments

L : Ship's length defined by the construction regulations for steel ships

Passenger ferry: Car ferry which accommodates over twelve passengers

On the damaged stability, Japanese Regulations for Ship's Subdivision (Article 36, 40, 41, 43, 44, 45 and 46) shall be applied, excepting that assumed floodable compartments shall be same as mentioned above.

3.4. Subdivision and Damaged Stability for Oil Tankers (Regulation 25 of International Convention for the Prevention of Pollution from Ships, 1973)

(1) Location of damage

(a) $L > 225$m — Anywhere in the ship's length

(b) $150\text{m} < L \leq 225\text{m}$ — Anywhere in the ship's length except involving either after or forward bulkhead bounding the machinery space. The machinery space shall be treated as a single floodable compartment

(c) $L \leq 150$m — Anywhere in the ship's length between adjacent transverse bulkheads with the exception of the machinery space.

For tankers of 100 m or less in length where all requirements of 3.4.(3) can not be fulfilled without materially impairing the operational qualities of the ship, the Administration may allow relaxations from these requirements. All the operational conditions of the ship other than ballast condition shall be considered.

L means the ship's length defined by the International Convention on Load Lines, 1966. (hereinafter L has the same meaning as above)

(2) Extent of damage

(a) As shown on Table 31. However, the longitudinal extent of bottom damage within $0{\cdot}3L$ from F.P. shall be the same as for side damage. If any damage of lesser extent results in a more severe condition such damage shall be assumed.

(b) If the longitudinal extent of damage is the same as the distance between transverse bulkheads, those transverse bulkheads shall be considered effective.

Table 31 Extent of Damage

Side damage	Longitudinal (l_c)	$L^{2/3}/3$ or 14.5 m, whichever is the less	
	Transverse (t_c)	$B/5$ or 11.5 m, whichever is the less	
	Vertical (v_c)	From the base line upwards without limit	
Bottom damage		For $0{\cdot}3L$ from F.P.	For any other part
	Longitudinal (l_s)	$L/10$	$L/10$ or 5 m, whichever is the less
	Transverse (t_s)	$B/6$ or 10m, whichever is the less, but not less than 5m	5 m
	Vertical (v_s)	$B/15$ or 6m from the base line, whichever is the less	same as left

Note) t_c shall be measured from the ship's side toward the ship's centerline at right angles at the designated summer freeboard.

(c) Where the damage between adjacent transverse watertight bulkheads is envisaged as specified in (1)(c), no main transverse bulkhead or a transverse bulkhead bounding side tanks or double bottom tanks shall be assumed damaged, unless:

i) The spacing of the adjacent bulkheads is less than the longitudinal extent of assumed damage specified in (2)(a).

ii) There is a step or a recess in a transverse bulkhead of more than 3.05m in length, located within the extent of penetration of assumed damage. The step formed by the after peak bulkhead and after peak tank top shall not be regarded as a step.

(d) If pipes, ducts or tunnels are situated within the assumed extent of damage, arrangements shall be made so that progressive flooding cannot thereby extend to compartments other than those assumed to be floodable for each case of damage.

(3) Stability criteria at the damaged condition

(a) The final waterline, taking into account sinkage, heel and trim, shall be below the lower edge of any opening through which progressive flooding may take place. Such opening shall include air pipes and those which are closed by means of weathertight doors or hatch covers and may exclude those openings closed by means of watertight manhole covers and flush scuttles, small watertight cargo tank hatch covers which maintain the high integrity of the deck, remotely operated watertight sliding doors, and side scuttles of non-opening type.

(b) In the final stage of flooding, the angle of heel due to unsymmetrical flooding shall not exceed 25 degrees, provided that this angle may be increased up to 30 degrees if no deck edge immersion occurs.

(c) The stability in the final stage of flooding shall meet Fig. 25. Consideration shall be given to the potential hazard presented by protected or unprotected openings which may become temporarily immersed within the range of residual stability.

(d) The stability shall be sufficient during the intermediate stage of flooding.

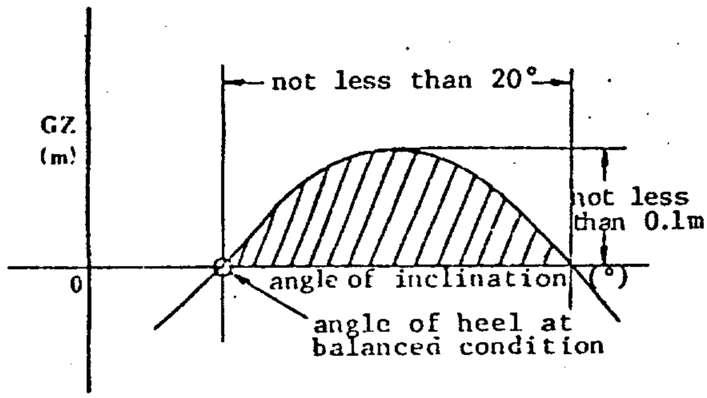


Fig. 25

(4) Calculation method

(a) Account shall be taken of any empty or partially filled tank, the specific gravity of cargos carried, as well as any outflow of liquids from damaged compartment.

(b) Permeability

Voids	95%
Tanks intended for consumable liquid	0 or 95%*
Tanks intended for other liquid	0 to 95%**
Other spaces	refer to 3.1.3 (3)

* Whichever results in the more severe condition

** The permeability of partially filled compartments shall be consistent with the amount of liquid carried.

(c) The buoyancy of any superstructure directly above the side damage shall be disregarded. The superstructure separated from the damaged space by watertight bulkheads may be regarded as the intact compartment taking the requirements of (3)(a) into consideration. Hinged watertight doors may be acceptable in watertight bulkheads in the superstructure.

(d) The free surface effect shall be calculated at an angle of heel of 5 degrees for each individual compartment. The administration may require or allow the free surface corrections to be calculated at an angle of heel greater than 5 degrees for partially filled tanks.

(e) In calculating the effect of free surfaces of consumable liquids, it shall be assumed that for each type of liquid at least one transverse pair or a single centerline tank has a free surface and the tank or combination of tanks to be taken into account shall be those where the effect of free surfaces is the greatest.

3.5. Limitation of Size and Arrangement of Cargo Tanks (Regulation 24 of International Convention for the Prevention of Pollution from Ships, 1973)

(1) Limitation of size and arrangement of cargo tanks (Table 32)

Table 32

<table>
<tr><td>Limitation of hypothetical outflow (O_c, O_s) (Refer to Table 33)</td><td colspan="5">Not more than 30,000 cubic meters or $400\sqrt[3]{DW}$, whichever is the greater, but subject to a maximum of 40,000 cubic meters.</td></tr>
<tr><td rowspan="2">Limitation of individual tank volume</td><td>Center cargo oil tank</td><td colspan="4">Not more than 50,000 cubic meters</td></tr>
<tr><td>Wing cargo oil tank</td><td colspan="4">Not more than 75% of hypothetical outflow mentioned above</td></tr>
<tr><td rowspan="6">Limitation of length of cargo oil tank (10m or the value mentioned right, whichever is the greater)</td><td>Without longitudinal bulkhead</td><td colspan="4">$0{\cdot}1\ L$</td></tr>
<tr><td>With a longitudinal bulkhead</td><td colspan="4">$0{\cdot}15L$</td></tr>
<tr><td rowspan="4">With two or more longitudinal bulkheads</td><td>Wing tank</td><td colspan="3">$0{\cdot}2\ L$</td></tr>
<tr><td rowspan="3">Center tank</td><td>$\frac{b_i}{B} \geq \frac{1}{5}$</td><td colspan="2">$0{\cdot}2\ L$</td></tr>
<tr><td rowspan="2">$\frac{b_i}{B} < \frac{1}{5}$</td><td>Without centerline longitudinal bulkhead</td><td>$(0{\cdot}5\frac{b_i}{B}+0{\cdot}1)L$</td></tr>
<tr><td>With centerline longitudinal bulkhead</td><td>$(0{\cdot}25\frac{b_i}{B}+0{\cdot}15)L$</td></tr>
</table>

Note) 1. DW = Deadweight at the designated summer freeboard (t)
b_i = Width of wing tank measured from ship's side to centerline at right angles at the assigned summer freeboard. (m)

2. The permitted volume of a wing cargo oil tank situated between two segregated ballast tanks, each exceeding l_c in length in Table 31, may be increased to the maximum limit of hypothetical oil outflow provided that the width of the wing tank exceeds t_c in Table 31.

(2) Calculation of hypothetical outflow of oil (Table 33)

Table 33

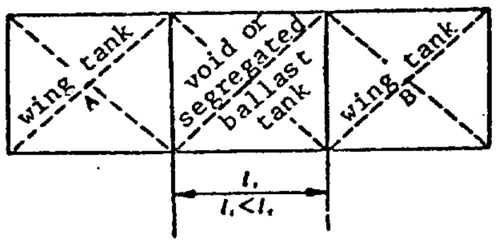
Hypothetical outflow of oil by side damage O_c	$\Sigma W_i + \Sigma K_i C_i$
Hypothetical outflow of oil by bottom damage O_s	$(\Sigma Z_i \cdot W_i + \Sigma Z_i \cdot C_i)/3$ In case where bottom damage simultaneously involves four center tanks $(\Sigma Z_i \cdot W_i + \Sigma Z_i \cdot C_i)/4$

Note) 1. The extent of damage shall be as shown on Table 31. Conceivable location of damage shall extend to the length of the ship.

2. W_i = Volume of a wing tank assumed to be breached by the damage (m^3)
C_i = Volume of a center tank assumed to be breached by the damage (m^3).
and C_i for a segregated ballast tank may be taken equal to zero.
$K_i = 1 - b_i/t_c$, $K_i = 0$ $b_i \geq t_c$
$Z_i = 1 - h_i/v_s$, $Z_i = 0$ $h_i \geq v_s$
h_i = Minimum depth of double bottom (m) (refer to 4.)

3. In the tank arrangement shown right, W_i shall be the actual volume of one such tank (where tank A and B are of equal capacity)or the smaller of the two tanks, A or B (if they differ in capacity), multiplied by S_i

$$S_i = 1 - l_i/l_c$$



4. h_i may be taken as zero in case the double bottom does not extend for the full length and width of the tank involved, or excepting the case double bottom tank is empty or carrying clean water.
If the depth of a suction well exceeds one half of the height of the double bottom tank, h_i shall be taken as
h_i = Depth of double bottom tank - depth of a suction well
(The depth of a suction well shall be neglected if it is not more than one half of the depth of the double bottom tank.)

5. O_s may be calculated by the formula of simultaneous damage in four center tanks mentioned above, provided that the piping system, which is capable of transferring in two hours oil equal to one half of the volume of the largest of the tanks with bottom damage into segregated ballast tanks or cargo oil tanks with sufficient ullage, is installed and in no case the height of the pipe shall be less than the vertical extent of damage .

3.6. Arrangement of Watertight Bulkhead Required by Classification Societies (1974) (Table 34)

Table 34

Collision bulkhead

Class	NK	LR	AB	NV
Collision bulkhead	• $L \leq 200$ m: $0.08L \geq l \geq 0.05L$ • $L > 200$ m: $0.08L \geq l \geq 10$ m	• $L < 90$ m: $0.075L \geq l \geq 0.05L$ • $90\text{m} \leq L \leq 200$m: $0.08L \geq l \geq 0.05L$ • $L > 200$m: $0.08L \geq l \geq 10$ m	• $L < 61$ m: $l \geq 0.05L$ • $61\text{m} \leq L < 200$m: $0.08L \geq l \geq 0.05L$ • $L \geq 200$m: $0.08L \geq l \geq 10$m • For passenger ships $0.05L + 3.05\text{m} \geq l \geq 0.05L$	• $L \leq 200$m: $0.08L \geq l \geq 0.05L$ • $L > 200$m: $0.08L \geq l \geq 10$m

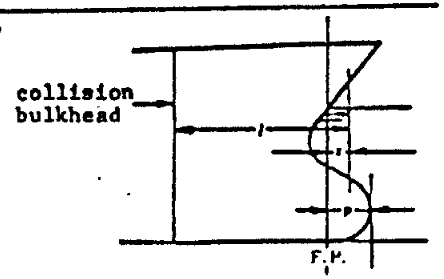
l = Distance from F.P. to collision bulkhead

In case the vessel has any part of the under water body, such as bulbous bow, extending forward of F.P., l may be measured from a reference point located a distance x forward of F.P. The value of x is;

for $L \leq 200$m $\quad p/2$ or $0.015L$, whichever is the less

for $L > 200$m $\quad p/2$ or 3.0 m, whichever is the less

NK requires that l shall be measured from F.P. in all cases. LR admits that l may be within the range of $0.08L$ from F.P., if safety is assured for flooding into the fore peak tank. AB applies above l to all ships not less than 61 m in length.



Aft peak bulkhead

NK, LR, AB: To be arranged at a suitable location so as to enclose the shaft tube in one watertight compartment. Special consideration is made by AB, if such arrangement is impracticable.

NV: To be arranged at a suitable location.

Machinery space bulkhead

To be arranged at the forward and aftward end of the machinery space.

Total No. of watertight bulkhead

NK

L (m) and above	L (m) below	Total No.
	67	3, 4*
67	87	4
87	102	5
102	123	6
123	143	7
143	165	8
165	186	9
186		To be investigated case by case.

LR

L (m) above	L (m) and below	Total No. amidship machinery space	Total No. after machinery space
	65	4	3
65	85	4	4
85	105	5	5
105	115	6	5
115	125	6	6
125	145	7	6
145	165	8	7
165	190	9	8
190		To be investigated case by case.	

AB

L (m) and above	L (m) below	Total No.
61	87	3, 4*
87	102	5
102	198	6
198		7

NV

L (m) above	L (m) and below	Total No. amidship machinery	Total No. after machinery space
	85	4	3
85	105	5	4
105	125	6	5
125	145	7	6
145	165	8	7
165	190	9	8
190	225	10	9
225		To be investigated case by case.	

Note) 1. * shows that the vessel with amidship machinery space shall have four watertight bulkheads and that with after machinery space three watertight ones.

2. NK, when the space of hold bulkheads exceeds 30 m, and LR, when the hold is abnormally long, require to sustain transverse strength by an appropriate way.

3. In addition to the above requirements, AB recommends that

   i) holds bulkheads shall be arranged to divide the hold into approximately equal lengths.

   ii) The first hold bulkhead abaft the collision bulkhead shall be arranged within $0{\cdot}2L$ abaft the stem.

   iii) The first hold bulkhead forward of the after peak bulkhead shall be about $0{\cdot}2L$ to $0{\cdot}25L$ forward of the after perpendicular.

4. AB requires that watertight bulkhead shall extend to a superstructure deck or an additional bulkhead shall be fitted forward and aft of an amidship machinery space and forward of an after machinery space when;

   i) the freeboard is less than $0{\cdot}15d$ in the vessels of 102 m length and below.

   ii) the freeboard is less than $0{\cdot}2d$ in the vessels of 133 m length and above.

   iii) the freeboard is less than $\left(\frac{(L-102)\times 0{\cdot}05}{31}+0{\cdot}15\right)d$ in the vessels between 102 m and 133 m.

5. Following special requirements are made by NK for ore carrier ($120\text{m} \lesssim L \lesssim 230\text{m}$)

   i) Distance between longitudinal watertight bulkhead and side shell plate shall not be less than $4L+500$(mm)

   ii) One transverse watertight bulkhead shall be fitted forward of the center of the ore hold part, unless specially admitted that the omission of said transverse bulkhead does not give bad influence on the hull structure.

6. Regarding the tanker, take Table 35 into consideration as well.

7. No. of watertight bulkhead may be reduced by the approval of classification society, if inconvenience is anticipated from the operational standpoint.

3.7. Limitation of Tank Length and Width of Tankers by Classification Societies (1974) (Table 35)

Table 35

Item \ Class		NK	LR	AB	NV
Width of center tank		Not restricted	Not restricted	Excessive dynamic stresses shall be avoided.	Generally $b_c \leq 0{\cdot}56B$
Tank length	l_T	Same as the limitation of length of cargo oil tank shown in Table 32.	Not more than $0{\cdot}2L$	Excessive dynamic stresses shall be avoided.	Not more than $0{\cdot}2L$
	l_s	For center tanks and inside tanks, not more than $0{\cdot}1L$ or 15m, whichever is the greater.	Not more than $0{\cdot}1L$ or 15m, whichever is the greater.	For center tanks, not more than $0{\cdot}1L$ For wing tanks, not more than $0{\cdot}2L$	Not more than $0{\cdot}1L$ or 12m, whichever is the greater.

Note) 1. L = Ship's length, B = Ship's breadth
b_c = Width of center tank
l_T = Space between transverse oil tight bulkheads
l_s = Space between transverse oil tight bulkhead and swash bulkhead or between two swash bulkheads.

2. LR requires that

i) Side transverses shall be fitted in line with the bottom transverses in the transversely framed vessels at sides with the depth over 11 m or with the tank length (l_s) over 15 m.

ii) Centerline vertical web shall be symmetrical on both sides of the transverse bulkhead in the vessels with tank length l_s over 24.5 m (in case of corrugated bulkheads l_s shall be over 25 m) and without continuous side girders in the center tank.

iii) The horizontal girders on the longitudinal bulkheads shall be reinforced in the vessels with the breadth over 14 m.

iv) Special consideration on the structural arrangement shall be made in the vessels over 250 m in length.

3. AB may require the reinforcement of stiffeners and girders in 1/3 of upper part of transverse bulkheads in the center tank in the vessels with the tank length (l_s) over 15 m (in case of corrugated bulkhead, l_s shall be over 12 m).

4. STABILITY

4.1. Initial Stability

4.1.1. Transverse Inclination

In Fig. 26 the ship is heeled to a very small angle θ and the volume of displacement remains the same.

$$BM = I/\nabla, \quad GM = KM - KG,$$

Moment of statical stability $= \Delta GZ = \Delta GM \sin\theta$

where, I = Moment of inertia of a water plane about the centre line
∇ = Volume of displacement
Δ = Displacement

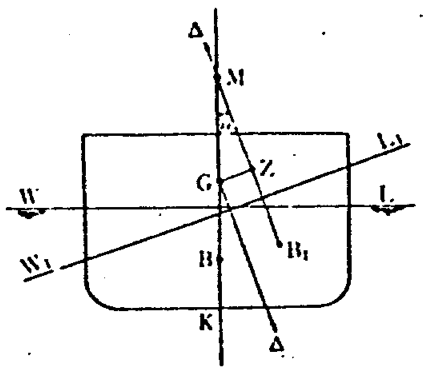


Fig. 26

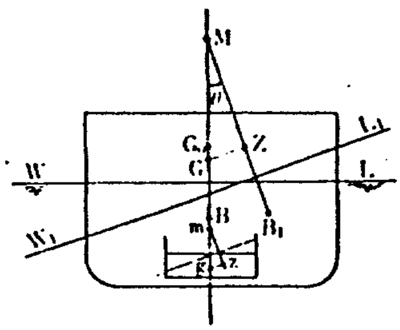


Fig. 27

4.1.2. Effect of Free Water

If there is a free surface of water in the ship as in Fig. 27, the virtual rise of the centre of gravity is,

$$GG_0 = (\rho/\rho_0)(i/\nabla)$$

where, ρ = Specific gravity of liquid in the tank
ρ_0 = Specific gravity of liquid the vessel is floating in
i = Moment of inertia of the free surface of the water in the tank

4.1.3. Effect of Hanging Body

The calculation can be made as the case of the centre of the gravity of the hanging body being fixed at a hanging point. For example, as shown in Fig. 28 and Fig. 29, if the weight w is lifted from the ship's bottom and swung out to the ship's side, the shift amounts of the centre of the gravity of the ship become;

$$y = \frac{w}{\Delta} l \cos\alpha \sin\beta,$$

$$z = \frac{w}{\Delta}(l \sin\alpha + H)$$

and the heel angle θ is derived from $GZ = GM \sin\theta = y\cos\theta + z\sin\theta$

$$\tan\theta = \frac{l\cos\alpha\sin\beta}{\frac{\Delta}{w}GM - l\sin\alpha - H}$$

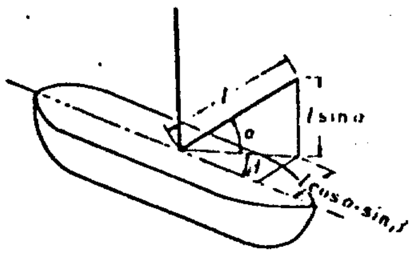


Fig. 28

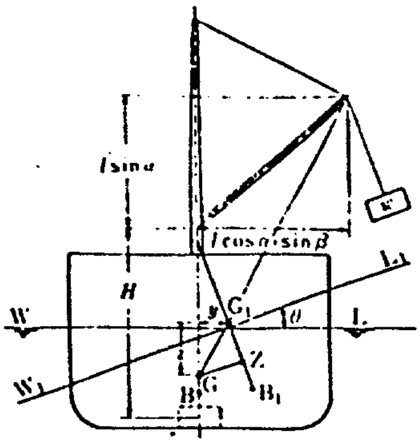


Fig. 29

4.1.4. Inclining Experiment

In order to determine the vertical centre of the gravity of the ship, weights of ballast w are shifted transversely y across the deck, as shown in Fig. 30, and the angle of inclination to the upright θ (normally between the range from 0.2 degree to 1.0 degree) is taken from the readings of the plumb-bob, U-tube or clinometre, then KG can be obtained by the following formulas:

$$GM = \frac{wy}{\Delta \tan \theta}, \quad \tan \theta \fallingdotseq s/l$$

$$KG = KM - GM$$

Generally, KM is obtained from Hydrostatic Curves of the particular vessel on her mean draught, but if the trim of the ship is rather big, KM should be corresponded to actual draught of the experiment, otherwise the vertical centre of the gravity of the ship might be misread.

In the case of tankers or ore carriers, the inclining experiment may be carried out by shifting water ballast through connected pipes transversely by gravity between the both wing tanks in port and starboard side instead of using the said weights of ballast.

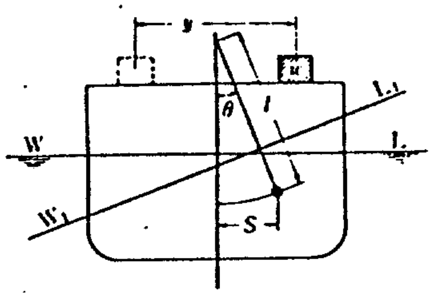


Fig. 30

4.2. Statical Stability at Large Angles of Inclination

4.2.1. Formulas of Righting Lever and Dynamical Stability

Referring to Fig. 31,

Righting lever $\quad GZ = \dfrac{v \times hh_1}{\nabla} - BG \sin \theta$

Dynamical stability $\quad = \Delta (B_1Z - BG) = \Delta \int_0^\theta GZ\, d\theta$

$$= \Delta \left\{ \frac{v(gh + g_1h_1)}{\nabla} - BG(1 - \cos \theta) \right\}$$

For a vertical wall-sided vessel

Righting lever $GZ = \left(GM + BM\frac{\tan^2\theta}{2}\right)\sin\theta$

Dynamical stability $= \Delta\left\{GM + \frac{BM}{2}\frac{(1-\cos\theta)}{\cos\theta}\right\}(1-\cos\theta)$

where,
- Δ = Displacement
- ∇ = Volume of displacement
- v = Wedge shaped volume
- g, g_1 = Centres of gravity of the wedges
- h, h_1 = Drawn perpendiculars to the new waterline W_1L_1 from the centres of gravity of the wedges g, g_1

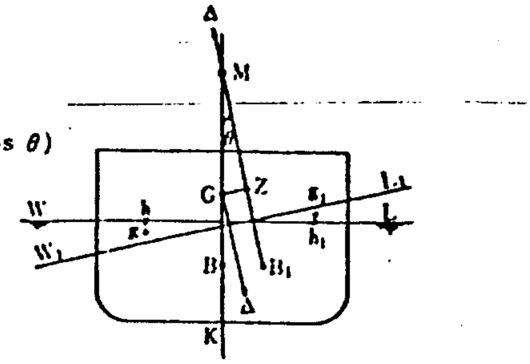


Fig. 31

4.2.2. Curves of Stability

We can obtain Fig. 32 by calculating righting levers and dynamical stabilities for various angles of inclination based on a constant displacement and a constant position for the centre of gravity.

In this figure,

- $\overline{ab}$ = Area oac x Δ,
- θ_R = Range of stability, Angle of vanishing stability
- GZ_{max} = Maximum righting lever
- θ_{max} = Angle of maximum stability

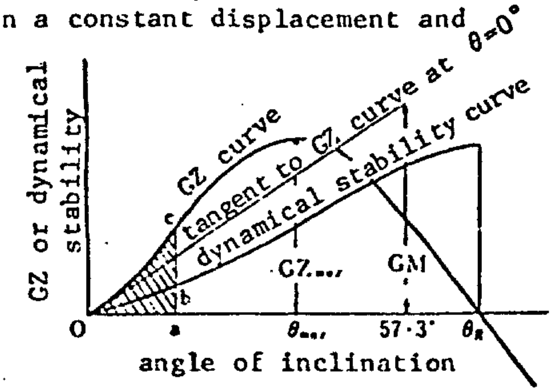


Fig. 32

* : Slope of stability curve at the origin

4.2.3. Cross Curves of Stability

Cross Curves of Stability is to be made by the calculations of $GZ = M/\Delta$ obtained by means of the Integrator and using Tchebycheff's Rule. A body plan is to be prepared, showing the shape of the sections at the distances from amidships required by the rule. Displacements Δ and moments about the centre line are converted by the multiplier of integrator from its area and moment readings on the various waterlines of required angles of inclination maintaining a constant position for the centre of gravity. In the case, buoyancy (or displacement) of the body plan under upper deck, superstructures and the structures on upper deck like the superstructures is to be counted in. But in case of producing the curves of stability, buoyancy of the structures beyond the flooding angle of sea water shall not be counted in. Therefore, it is convenient for designers to produce the curves of stability for both cases of including and excluding the structures on upper deck.

Note) The flooding angle of sea water is the angle of inclination when the waterline comes to the coaming height of the opening with closing device of which strength and the watertightness is not effective.

4.2.4. Approximation of Stability

The following formula for approximate estimation of the righting lever GZ for various angles of inclination is presented by KUWANO and SHIMADA.

$$GZ = F_1(\theta)\,a + F_2(\theta)\,b + F_3(\theta)\,BM + GM\sin\theta$$

where, a = Dynamical righting lever at 90 degrees of inclination + BC
b = Statical righting lever at 90 degrees of inclination + BC
(Refer to Fig. 33)

$F_1(\theta)$, $F_2(\theta)$, $F_3(\theta)$ are obtained from Table 36.
Approximate figures of a and b are obtained from Figs. 33 and 34.
f in these figs. means an effective freeboard considering the effects of sheer and camber of upper deck and

$$f = (D-d) + \frac{1}{7}(S_F + S_A) + 0.63H$$

where, S_F, S_A = Sheers on forward and aft perpendiculars
H = Camber on deck

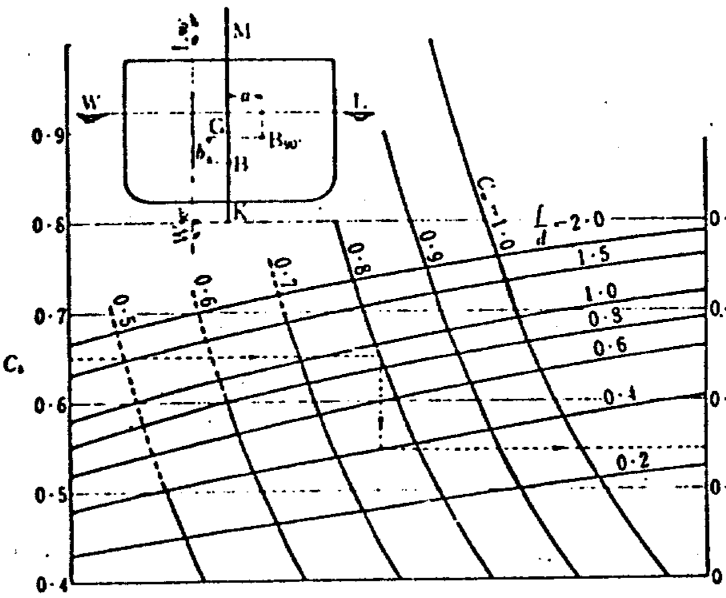


Fig. 33

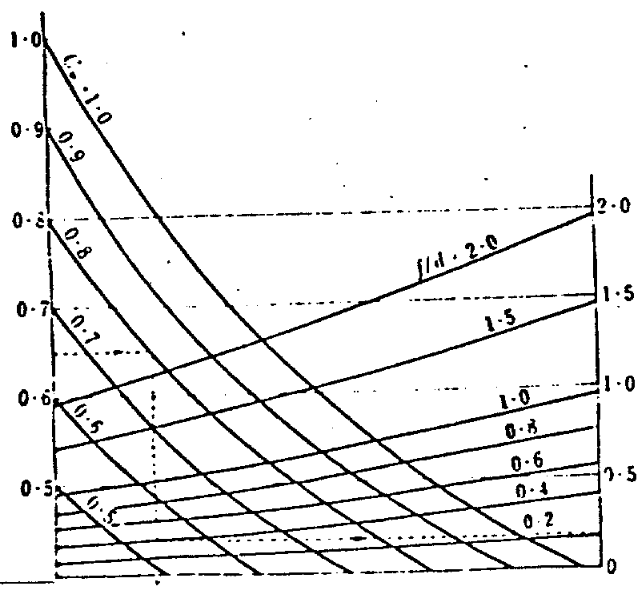
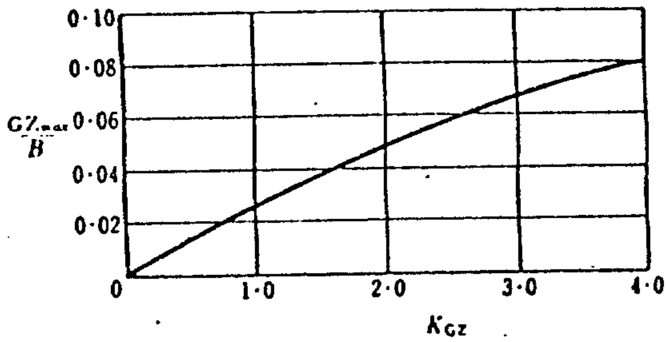


Fig. 34

Table 36

F \ θ	0°	15°	30°	45°	60°	75°	90°
$F_1(\theta)$	0	0	0·5458	1·2221	1·2835	0·7174	0
$F_2(\theta)$	0	0	−0·2190	−0·4012	−0·1967	0·3642	1·0000
$F_3(\theta)$	0	0·0093	−0·3148	−0·8248	−1·0980	−1·0877	−1·0000
$\sin\theta$	0	0·2588	0·5000	0·7071	0·8660	0·9659	1·0000

Maximum righting lever GZ_{max} is obtained from Fig. 35 and the same considering the effects of superstructures is proposed by WATANABE, KANOH and HARADA.



$$K_{GZ} = \frac{C_w}{C_b^2} \times \left(\frac{KG}{d}\right)^{-1} \times \left(\frac{f}{d}\right)^{3/2} \times \left(\frac{B}{d}\right)^2 \times \left(\frac{GM}{B}\right)^{1/2}$$

Fig. 35

4.2.5. Various Causes to Affect Stability

(1) Influence of forms of ship (Table 37)

Table 37

Forms \ Items	GM	BM	KB	θ_R	GZ_{max}	θ_{max}	Remarks
Increase of beam	Increa.	Increa.	–	Decrea.	Increa.	Decrea.	
Increase of draught	Decrea.	Decrea.	Increa.	Decrea.	Decrea.	–	Constant D, and lines
Increase of freeboard	Decrea.	–	–	Increa.	Increa.	Increa.	Constant under waterlines
Increase of sheer	Decrea.	–	–	Increa.	Increa.	Increa.	
Increase of flare	–	–	–	Increa.	Increa.	Increa.	
Increase of KG	Decrea.	–	–	Decrea.	Decrea.	Decrea.	Constant hull form

(2) Effect of wind

(a) Heeling lever by steady wind pressure

$$D_w = 0{\cdot}76\times10^{-4}\,V^{2}AH/\Delta \text{ (m)}$$

where, A = Longitudinal projected area of hull above waterline at upright condition (sq. m)

H = Vertical distance between the centre of A and the centre of longitudinal projected area of hull under waterline (m)

Δ = Displacement (t)

V = Steady wind velocity (m/sec)

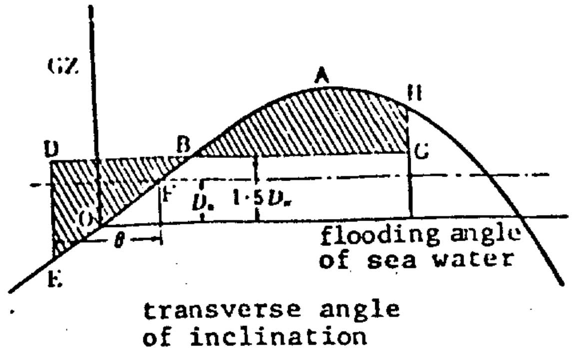


Fig. 36

(b) Heeling lever caused by gust

The Japanese Regulations for Ship's Stability assumes the velocity of gust $\sqrt{1{\cdot}5}$ times of the velocity of steady wind, therefore, the heeling lever caused by gust is assumed $1{\cdot}5D_w$. (Refer to Fig. 36)

4.3. Japanese Regulations for Ship's Stability (1956 - Rev. 1968)

(1) Stability of passenger boat (Art. 11 Clause 1)

To fulfill the following conditions at any time;

i) $GM>0$

ii) $$GZ_o \geqq \frac{1{\cdot}71\,AH+0{\cdot}214\sum\left(7-\frac{n}{a}\right)nb}{100\,\Delta} \text{ (m)}$$ (No. 3 Format)

where, GZ_o = Righting lever at marginal angle of inclination α (α fulfills $\tan\alpha = 0{\cdot}8\tan\beta$. β is the smallest of transverse angle of inclination when deck edge is immersed to waterline, 20 degrees or flooding angle of sea water.)

A = Longitudinal projected area above waterline at upright position (m^2)

H = Vertical distance between the centre of underwater projected area and the centre of A (m)

n = Numbers of passengers of each compartment

a = Floor area of each compartment (m^2)

b = Mean breadth of possible movement of passengers for each compartment (m)

Δ = Displacement (t)

But for the passenger boats engaged in smooth water area, it may be allowed to use the formula of $GZ_o = GM\tan\alpha$ (m)

(2) Stability of passenger boats of coastal and deep sea service (Art. 11 Clause 2)

In addition to the requirement mentioned in (1) above, it is requested to fulfill the following conditions in any time (No. 4 Format).

i) On the stability curves, area ABCH > Area BDE (Fig. 36)

where, D_w = Heeling lever by constant wind = kAH/Δ (m) (A, H and Δ are the same as above, k is a constant defined in Table 38.)

θ = Angle of rolling = $\sqrt{138 rs/N}$ (deg), $r = 0{\cdot}73 + 0{\cdot}6\frac{OG}{d}$,

OG = Vertical distance from the centre of gravity to waterline at upright condition (m) (But if the centre of gravity is located under water, the figure should have negative sign.)

d = Mean draught measured from the upper surface of keel for steel vessels and the lower edge of rabbet of keel for wooden vessels (m)

$s = p - qT$, T = Rolling period (sec), p and q are constants defined in Table 38. (But in cases of $s > 0{\cdot}1$ or $s < 0{\cdot}035$, $s = 0{\cdot}1$, or $s = 0{\cdot}035$ respectively.)

N = Decrement constant = 0.02 (for normal vessel having bilge keels) and figures defined by the Administration for other type of vessels.

Table 38

Cruising Range	Standard Wind Velocity m/s	k	p	q
Ocean	26	0.0514	0.151	0.0072
Coastal	19	0.0274	0.153	0.0100
Inshore	15	0.0171	0.155	0.0130

ii) $GZ_{max} \gtrsim$ [0.0215 B or 0.275 m, whichever is the smaller] (m)

where, B = Ship's breadth measured between the outsides of frames for steel vessels and the outsides of side plates for wooden vessels at the widest part (m).

(3) Stability criteria for fishery boats should be referred to Clause 17 item 2 and 3.

4.4. Stability Criteria for Passenger Ferry Boats (Japanese MOT Circular Ship Inspection No. 367, 1973)

As for the stability requirement for passenger ferry boats, the above 4.3. (1) and (2) should be applied with the following additional alternatives.

(1) It should be included that all the passengers are loaded on the uppermost passenger deck at normal condition (only applying Art. 11 Clause 1).

(2) $$GZ_a \gtrsim \frac{2{\cdot}74\,AH + 0{\cdot}214\sum(7 - \frac{n}{a})\,nb}{100\,\Delta}$$ (m) (No. 3 Format)

(3) Table 39 should be applied instead of Table 38. (No. 4 Format)

Table 39

Cruising Range	Standard Wind Velocity m/s	k	p	q
Coastal and above	26	0.0514	0.151	0.0072
Inshore	19	0.0274	0.153	0.0100

(4) Passenger ferry boats intended to cruise the coastal and above ranges should have an angle of inclination (θ) of not more than 20 degrees at fully loaded departure and arrival condition, but the boats with effective anti-rolling system (refer to Ship Inspection No. 481, 31 (6)) or restricted to inshore range may not follow this requirement.

4.5. IMCO's Resolutions about Stability (A. 167 (1968), A. 206 (1971))
IMCO adopted the following resolutions about the intact stability for the passenger ships, cargo ships, and lumber carriers with deck loading having their length under 100 m.

4.5.1. Stability Criteria for Passenger Ships and Cargo Ships

(1) Area A up to θ = 30 degrees of GZ curves of Fig. 37 should be $A \geqq 0.055$ (m - rad)

(2) Area A + B, up to whichever smaller angles of 40 degrees or flooding angle (θ_f) should be $A+B \geqq 0.09$ (m - rad)

(3) Area B, between θ = 30 degrees and whichever smaller angles of 40 degrees or θ_f should be $B \geqq 0.03$ (m - rad)

(4) $GZ \geqq 0.20$m at $\theta \geqq 30$ degrees

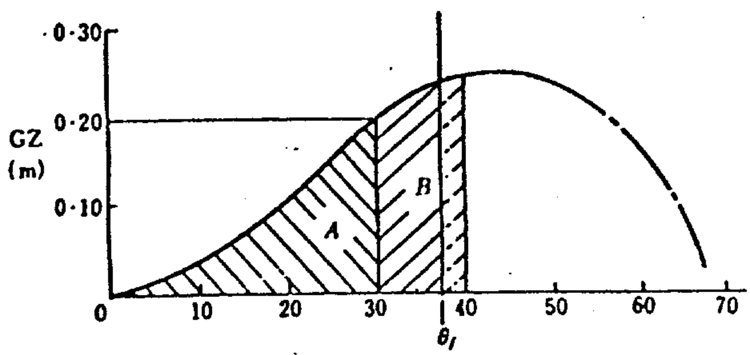


Fig. 37

(5) Angle of maximum stability should be $\theta_{max} \geqq 25$ degrees, preferably 30 degrees and over.

(6) $G_oM \geqq 0.15$m

4.5.2. Stability Standard for Lumber Carriers with Deck Loading

(1) Area A, up to 40 degrees or θ_f whichever is the smaller on GZ curve in Fig. 38 should be $A \geqq 0.08$ (m - rad)

(2) $GZ_{max} \geqq 0.25$m

(3) $G_oM > 0$ at any time in cruising condition.
$G_oM \geq 0 \cdot 10$ in departure condition.
In these cases, water absorption (10 percent in weight is to be increased at arrival condition) and icebound should be considered.

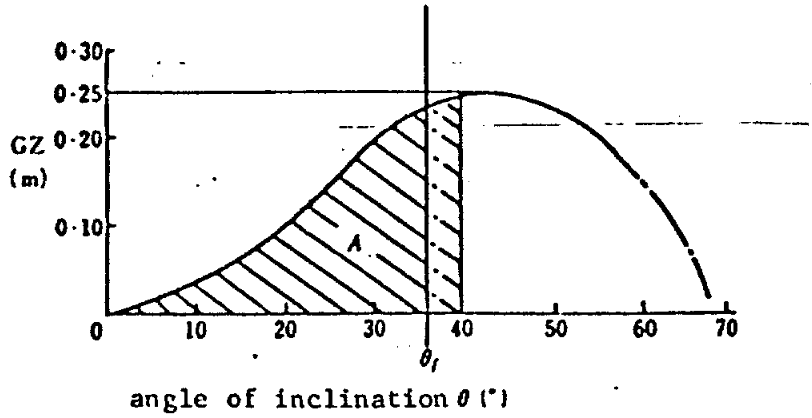


Fig. 38

(4) Range of on-deck cargo
Longitudinally it should be loaded between superstructures and transversely on full breadth.

(5) Influence of on-deck timber
When GZ curve is prepared, the buoyancy of timber may be included assuming the deck timber have a water absorption rate of 25%.

4.5.3. Additional Criteria for Passenger Ship

(1) Angle of inclination caused by a movement of passengers should be not more than 10 degrees. Shifting moment made by the passengers should be considered to the actual worst condition but it is not necessary to calculate on the rate of more than 4 persons/sq.m.

(2) Angle of inclination caused by ship's turning should be less than 10 degrees, however, heeling moment M_R caused by the turning should be calculated by following formula:

$$M_R = 0 \cdot 02 \frac{V_s^2}{L} \Delta (KG - \frac{d}{2})$$

where, V_s = Service speed (m/sec)
L = Length on loaded waterline (m)
Δ = Displacement (t)
d = Mean draught (m)
KG = Height from keel to the centre of gravity of the vessel (m)

4.6. Instant Judging Method of Stability of Smaller Vessels

(1) GZ_{max} should be located over the limited line in Fig. 39.

(2) When GZ_{max} is unknown, all of KG, GM, and f (freeboard) should be located in a better position than limited line in Fig. 40, 41 and 42 respectively.

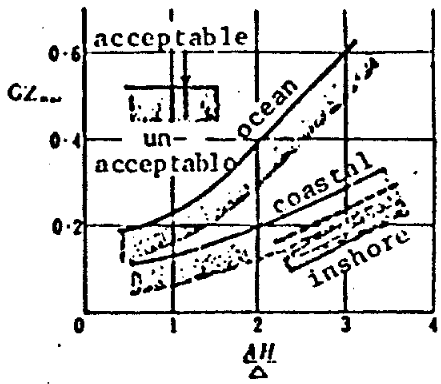


Fig. 39

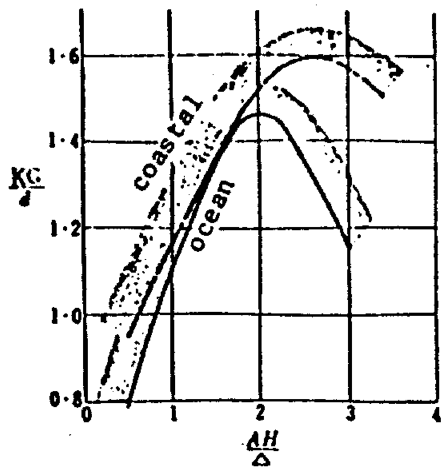


Fig. 40

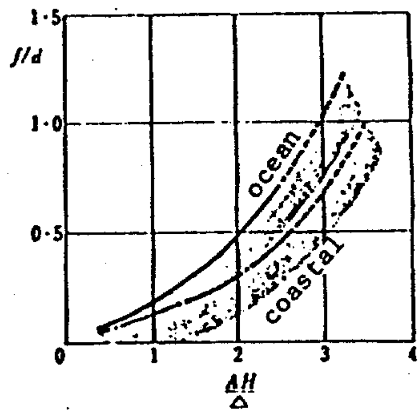


Fig. 41

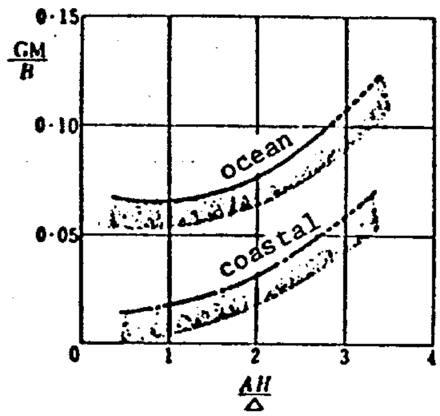


Fig. 42

4.7. Damaged Stability

Damaged Stability Regulations are settled for special vessels, ocean going passenger vessels, passenger ferry boats and tankers which LLC 1966 should be applied to. (Refer to 2.7, 3.1, 3.3 and 3.4)

5. TONNAGE ADMEASUREMENT

Some of the influential regulations on tonnage measurement (including canal regulations) are listed in the Table 40. In this Section 5, except otherwise referred to, the regulations and rules stipulated by Japanese Law of Tonnage Measurement of Ships, the Regulations of Tonnage Measurement of Ships and the Guideline for Tonnage Measurement of Ships are introduced.

Table 40 Influential Tonnage Regulations and the Applying Governments

Tonnage Regulations	Relevant Law, Regulation, etc.	Applying Government
Japanese Regulations	Law of Tonnage Measurement of Ships. Regulations of Tonnage Measurement of Ships (register length $\geq$ 20 m). Simplified Regulations of Tonnage Measurement of Ships (register length $<$ 20 m). Guideline for Tonnage Measurement of Ships.	Japan, South Vietnam*, Iran*, Singapore*
British Regulations	Merchant Shipping (Tonnage) Regulations. Tonnage Measurement of Ships (Instruction for the Guidance of Surveyors)	United Kingdom and the British Commonwealth of Nations, Republic of South Africa*, Greece*, India*, Hong Kong*, Taiwan*, Jugoslavia*, Brazil*, Singapore*, Pakistan*
Oslo Convention Regulations (International Regulations)	International Regulations for Tonnage Measurement of Ship	Cambodia, Central African Republic, Denmark, Federal Republic of Germany, Finland, France, Iceland, Israel, Norway, Poland, Gabonese Republic, Republic of Senegal, Sweden, Malagasy Democratic Republic, Netherlands, Republic of Ivory Coast (aboves are member governments of the Oslo Convention), Brazil*, Portugal*, Bulgaria*, Somali Democratic Republic*
United States Regulations	Regulations for the Measurement of Vessel	U.S.A., Panama*, Liberia*, Honduras*, Philippines*
Panama Canal Regulations	Panama Canal Tonnage Regulations	—
Suez Canal Regulations	Suez Canal Tonnage Regulations	—

Note) 1. * shows the government which has applied the captioned regulations or whose own regulations are, in principle, same as the captioned regulations.

2. For the detailed interpretation of above Japanese Regulations the "Detailed Interpretation on the Tonnage Measurement" (for ships not less than 20m in length) is stipulated and effective.

5.1. Definition of Terms for Tonnage Measurement

(1) Tonnage capacity
Inner capacity of a ship used for tonnage calculation. Unit in m^3 (Japan, International Regulations etc.) or ft^3 (British, U.S.A., International Regulations etc.) is used. To Suez and Panama Canal Regulations tonnage capacity calculated by the regulations of each registry government of a ship is applied.

(2) Tonnage
Tonnage capacity $(m^3) \times 0.353$, or
Tonnage capacity $(ft^3) \div 100$

(3) Upper deck, tonnage deck

(a) Upper deck is the uppermost complete deck. In a ship with a raised quarter, the assumed extended surface of the upper deck parallel to the raised quarter is taken as the upper deck.

(b) Tonnage deck shall be the upper deck in a ship with one or two complete decks, and the second lowest deck in a ship with three or more complete decks (Japan, U.S.A.). The upper deck and the second uppermost deck shall be taken as the tonnage deck in a ship having one complete deck and having two or more complete decks respectively (British, International Regulations, U.S. Dual Tonnage).

5.2. Gross Tonnage, GT

5.2.1. Spaces to be included in gross tonnage

(1) Spaces below the tonnage deck
(2) Between deck spaces above the tonnage deck
(3) Enclosed spaces on the upper deck

5.2.2. Spaces below the upper deck

(1) Spaces below the tonnage deck
Generally, the volume of spaces is calculated by use of Simpson's Rule.

(a) Bottom structures
Spaces below the floor plate of a single bottom ship and the double bottom spaces are exempted from inclusion in the gross tonnage. However, the height of the floor plate and the double bottom, except in the main engine room, should be within the standard height prescribed by the length of tonnage deck except for application of U.S. Regulations which have no such restriction. Double bottom spaces with height exceeding the standard height shall be taken as single bottom structures (British and International Regulations).
The exemption of following spaces should be carefully confirmed according to the Regulations to be applied.
Spaces of hopper shaped double bottom extended to the ship's side shell plate.
Spaces of double bottom of a ship with double hull.

Spaces of double bottom located between the longitudinal side bulkheads. In case of a ship with double bottom of longitudinal frame system and the American Bureau of shipping measures the tonnage on behalf of U.S. Government pursuant to the U.S. Regulations, the lowest division point of depth shall be top of the bottom longitudinal frames.

(b) Ceiling and sparring
Spaces outside the inner surface of continuous side ceiling or sparring with batten aperture of 30 cm and below or the spaces below the upper surface of the bottom ceiling are exempted from inclusion in the gross tonnage provided that total thickness of such ceiling and sparring together with the joist does not exceed 7.5 cm. British, U.S. and International Regulations allow the thickness or joist not to be included in that of the ceiling.

(c) Divisional measurement
Where there is a step exceeding 15 cm between the adjacent double bottoms or the double and the single bottoms, the ship length is divided into two parts at the stepped point and tonnage is measured separately for both sides of the stepped point. Divisional measurement is not applied to the single bottom structure nor to aft and fore peak tanks and the end space of the tunnel recess.
To measurement of under deck tonnage by Suez Canal Regulations, the divisional measurement is not applied.

(d) Addition to or deduction from under deck tonnage
The locally irregular spaces such as convex and concave of the double bottom for installation of engine bed for an internal combustion engine, bulbous bow, jut of the cruiser stern, convexed and concaved part of slipway of a whale factory ship are calculated independently and added to or deducted from the under deck tonnage.

(e) Rise of floor
In a tanker or an ore carrier etc., generally, the breadth of the horizontal part of the bottom, shall be taken as the breadth at the lowest division point of depth. However, some of the Regulations has special requirements on the minimum rise of floor and special attention should be paid to this fact (ex., According to the British Regulations the breadth at the lowest division point of depth is measured neglecting the rise of floor if such rise of floor is less than 1/120).

(2) Between deck spaces above the tonnage deck and under the upper deck
Tonnage measurement is done in a manner different from that for the under deck tonnage measurement, but basic rule applied is the same Simpson's Rule.

5.2.3. Enclosed Spaces on or above the Upper Deck

(1) Superstructures, deck houses etc.
All structures on or above the upper deck bounded by ship's hull, bulkheads, decks or covering plate except the "exempted spaces" mentioned in (3).

(2) Excess of hatchways
If the aggregate tonnage of all the hatchways on or above the upper deck exceeds 5/1000 of the gross tonnage, exclusive of the hatchways, the excess over 5/1000 is added to the tonnage of the enclosed spaces on or above the upper deck. Hatchways on or above the upper deck opened to the spaces mentioned in (3) are not taken as hatchways.

(3) Exempted spaces in the enclosed spaces on or above the upper deck (Table 41)

Generally, the exempted spaces are as follows except by Suez and Panama Canal Regulations.

(a) Engine room

Inner spaces of engine casings or decoration funnel not used for other purposes are exempted. However, the space in the engine room on the upper deck may be added to the gross tonnage, partially or in full, by the application of the ship's owner only in case the net tonnage is decreased. The summary of this addition is as follows:

i) In case the initial ratio of the actual tonnage to the gross tonnage (p.p. space/GT) is smaller than 0.13, the addition is allowed up to an extent that the p.p. space/GT after addition is slightly over 0.13.

ii) In case the initial p.p. space/GT is 0.13 and over, the addition is not allowed except that p.p. space/GT after addition exceeds 0.20.

iii) In case the p.p. space/GT after addition exceeds 0.20, all or a part of the spaces in the engine room may be added.

(b) Machinery spaces for miscellaneous machinery (other than the engine room)

"Miscellaneous machinery" means machinery used for steering, anchoring, mooring, auxiliary boilers and machinery independent from the main engine in their operation, factory machinery of a whale factory ship, deck machinery and accessories (control equipment) and so forth. Spaces for these miscellaneous machinery are exempted in whole if such spaces are clearly distinguished from other spaces or partially if not distinguished clearly and spaces occupied by the machinery are exempted.

(c) Wheel house

Spare wheel house, chart space in the wheel house are included in the wheel house. An independent chart room may be exempted by some Regulations (ex. British, International Regulations).

(d) Galley

(e) Entrance room

Spaces above the openings for stairways leading to the lower decks, protection spaces for the stairway openings and the spaces above the stairways leading to the upper decks. However the British and U.S. Regulations do not allow to exempt the spaces above the stairways leading to the upper decks.

(f) Cargo hold

Dry cargo hold spaces are exempted from enclosure in the gross tonnage, but the spaces, like expansion trunks for a cargo tank of a tanker, for bulk liquid or gas cargos such as oil or chemicals are taken as gross tonnage spaces.

(g) Stores for articles for ship

Deck stores, machinery stores, electric stores and the like.

(h) Workshop

Work shop in machinery part, carpenter's shop and the like.

(i) Fish treatment spaces

Spaces for processing fish.

Table 41 Treatment of Spaces (except open spaces) for Exemption and Deduction

G: To be included in GT, N: To be included in NT, —: Not to be included in Tonnages

Tonnage Regulations	Japan		Oslo Convention		British		U.S.		Panama Canal		Suez Canal	
Spaces	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck
Spaces under double bottom	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —	— *1 —
clean ballast tank, cofferdam (※1)	G —	G —	— —	G — *2	— —	G — *2	— —	— —	G —	G —	G N	G N
Other hull tanks	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
Cargo holds (except cargo oil tanks)	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Hatchways	G(1) N	G N	G(1) N	G N	G(1) N	G N	G(1) N	G N	G(1) N	G N	G(1) N	G N
Light & air spaces on bulkheads (except on engine casings)	— —	G N(1)	— —	G N(1)	— —	G N(1)	— —	G N(1)	— —	G N(1)	— —	G N(1)
Entrance rooms (above openings)	— —	G — *3	— —	G — *3	— —	G — *3	— —	G — *3	— —	G — *3	— —	G — *3
" (above stairways)	— —	G — *3	— —	G — *3	G — *3	G — *3	G — *3	G — *3	G — *3	G — *3	G — *3	G — *3
Passages (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for other use)	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
Captain's rooms (living r., bed r., office)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
Crew's rooms (living r., bed r.)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G — *15	G — *15
Supervisor's room, technician's room, worker's rooms (※2)	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
Owner's rooms	G N	G N	G N	G N	G N	G N	G*12 N	G N	G N	G N	G N	G N
Passengers' rooms	G N	G N	G N	G N	G N	G N	G*12 N	G N	G N	G N	G N	G N
Pilot's room	G N	G N	G N	G N	G N	G N	G N	G N	G —	G —	G N	G N
Spare rooms (for crew)	G —	G —	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
" (for others)	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
Chief officer's office, chief engineer's office	G —	G —	G —	G —	G —	G —	G — *14	G — *14	G —	G —	G —	G —
Other offices	G —	G —	G —	G —	G N	G N	G N	G N	G N	G N	G N	G N
Wheel house	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Chart room	G —	G —	— —	G —	— —	G —	G —	G —	G —	G —	G —	G N
Salon, mess room (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for passengers)	G N	G N	G N	G N	G N	G N	G*12 N	G N	G N	G N	G N	G N
" (for crew and passengers)	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G —	G —	G N	G N
Lounge, smoking room, recreation room (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for passengers)	G N	G N	G N	G N	G N	G N	G*12 N	G N	G N*16	G N*16	G N	G N
" (for crew & passengers)	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G N	G N
Pantry (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for passengers)	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
" (for crew & passengers)	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G N	G N
Galley, sink spaces (for crew only)	— —	G —	G —	G —	— —	G —	— —	G —	G —	G —	G —	G —
" (for passengers)	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
" (for crew & passengers)	— —	G — *4	— —	G — *4	— —	G — *4	— —	G — *4	G — *4	G — *4	G N	G N

Table 41 (continued)

Tonnage Regulations	Japan		Oslo Convention		British		U. S.		Panama Canal		Suez Canal	
Spaces	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck
Bath rooms, wash rooms (for crew only)	G —	G —	— —	G —	— —	G —	G —	G —	G —	G —	G —	G —
" (for passengers)	G N	G N	G N	G N	G N	G N	G*12 N	G N	G N	G N	G N	G N
" (for crew and passengers)	G — *4	G — *4	— *5 —	G — *4	— *5 —	G — *4	G — *4	G — *4	G — *1	G — *4	G N	G N
Hospital, clinic, dispensary (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for passengers)	G N	G N	G N	G N	G N	G N	G N	G N	G —	G —	G N	G N
" (for crew & passengers)	G — *4	G — *1	G — *4	G — *1	G — *4	G — *4	G — *4	G — *1	G —	G —	G N	G N
Lavatories except in private cabin (for crew only)	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —
" (for passengers)	— —	G N	G N	G N	G N	G N	— —	G N	G N	G N	G N	G N
" (for crew & passengers)	— —	G — *1	— *5 —	G — *1	— *5 —	G — *4	— —	G — *1	G — *1	G — *4	G N	G N
Laundry, drying room (for crew only)	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
" (for others)	G —	G — *4	G — *4	G — *4	G — *4	G — *4	G — *4	G — *1	G — *1	G — *4	G N	G N
Provision stores (for crew only)	G —	G —	G — *6	G — *6	G — *6	G — *6	G N	G N	G N	G N	G N	G N
" (for passengers)	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
" (for crew & passengers)	G — *4	G — *4	G — *7	G — *7	G — *7	G — *7	G N	G N	G N	G N	G N	G N
Mail room, parcel store	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Clothes lockers, dirty clothes locker	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —	G —
Linen locker	G —	G —	G —	G —	G —	G —	G N	G N	G N	G N	G N	G N
Seal locker	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N	G N
Boatswain's stores	— —	G — *2	— —	G — *2	— —	G — *2	— —	G — *2	G — *2	G — *2	G N	G N
Paint stores	— —	G — *2	— —	G — *2	— —	G — *2	— —	G — *2	G — *2	G — *2	G N	G N
Deck stores (except Boatswain's store)	— —	G N	— —	G —	— —	G —	— —	G N	G N	G N	G N	G N
Stores in machinery and electric parts	— —	G — *8	— —	G — *8	— —	G — *8	— —	G — *8	G N	G N	G N	G N
Carpenter's shop	— —	G N	— —	G N	— —	G N	— —	G N	G —	G —	G N	G N
Workshop in machinery part	— —	G — *8	— —	G — *8	— —	G — *8	— —	G — *8	G — *9	G — *9	G N	G N
Wireless (Radio) room	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —	G —	G N
Battery room	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Generator for wireless use, emergency generator	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Lighting equipment stores	— —	G — *2	— —	G —	— —	G — *2	— —	G — *2	G — *2	G — *2	G —	G N
Gyro compass	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Steering gear	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Windlass, mooring equipment	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Chain locker	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Ballast pumps	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G N
Cargo pumps	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Cargo and ballast pumps	— —	G N	— —	G — *2	— —	G N	— —	G N	G N	G N	G N	G N
Fuel oil transfer pumps	— —	G N	— —	G N	— —	G N	— —	G —	G —	G —	G N	G N

Table 41 (continued)

Tonnage Regulations	Japan		Oslo Convention		British		U. S.		Panama Canal		Suez Canal	
Spaces	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck	on or above upper deck	under upper deck
Fire pumps	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —
CO_2 bottle rooms for fire fighting	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —
Mechanical ventilator, air conditioner (for non-commercial use)	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —
" (for commercial use)	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Refrigerator (for non-commercial use)	— —	G —	— —	G —	— —	G —	— —	G —	G —	G —	G —	G —
" (for commercial use)	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Accessories of cargo winches	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Factory facilities (of whale factory ship etc.)	— —	G N	— —	G N	— —	G N	— —	G N	G N	G N	G N	G N
Engine room (under upper deck)		G — *10		G — *10		G — *10		G — *10		G — *10		G — *10
Engine room casings (first tier in superstructure)	— *11 —		— *11 —		— *11 —		— *11 —		G — *10		G — *10	
" (second tier and above in superstructure)	— *11 —		— *11 —		— *11 —		— *11 —		— —		G — *10	
" (first tier in deck house)	— *11 —		— *11 —		— *11 —		— *11 —		— —		G — *10	
" (second tier and above in deck house)	— *11 —		— *11 —		— *11 —		— *11 —		— —		— —	

Note. ※1. A cofferdam is exempted from inclusion in tonnage by Japanese Regulations and, by other regulations, treated as a ballast tank only when it is used for clean ballast tank.

※2. To be treated as crew if registered as licensed mariners.

G (1) Excess tonnage of hatchways, i.e. residual tonnage after subtracting 5/1000 of the gross tonnage of the ship excluding hatchways from the tonnage of the hatchways, is to be added to the gross tonnage.

N (1) Deduction of the spaces below the upper deck depends upon use thereof.

*1 Suez Canal Regulations require the drain tank for lubricating oil in the double bottom space be treated as a part of engine room and the tonnage thereof be included in CT.
*2 Maximum deduction is limited by CT.
*3 To be treated as passage.
*4 Generally, deducted in non-passenger ships and not deducted in passenger ships.
*5 Generally, exempted in non-passenger ships and not exempted in passenger ships.
*6 Limited by tonnage of the crew's room.
*7 Generally, *6 is applied to non-passenger ships, and not deducted in passenger ships.
*8 Maximum allowable volume in relation to CT may be included in the engine room.
*9 Maximum deduction is limited by tonnage of the engine room.
*10 Deduction to be calculated in accordance with the ratio of tonnage of the engine room and CT.
*11 To be treated as a part of engine room below the upper deck if included in CT.
*12 Passenger rooms and owner's rooms on the superstructure deck are exempted.
*13 Conditions for deduction of passages depends upon each Regulation.
*14 Chief engineer's office only is deducted.
*15 Some crew's rooms as pumpman's room or deck store keeper's room are not deducted.
*16 To be deducted in passenger ships.

(j) Lavatory

If lavatory equipment is provided in bath room or washroom, the spaces for lavatory use are taken as the lavatory. Some regulations treat washroom and bath room for the captain and the crew as lavatory (ex., British, International Regulations).

(k) Radio room

Radio room includes the apparatus for wireless communication. Some rules do not allow the exemption (ex., U.S. Regulations)

(l) Spaces for emergency, fire fighting and sanitary equipment

Spaces for gas generators for fire extinguishing or sterilizing, air conditioning unit, distiller for drinking water, telephone operating machine search light etc.

5.3. Net Tonnage, NT

Net tonnage is obtained by subtracting from the gross tonnage the tonnage of all deducted spaces. The summary deducted spaces are as follows. (Table 41)

(a) Mariners' daily rooms

Mariners are the captain and other crew registered in the Register Book of Mariner who are paid salary or other compensations for their labor. Mariners' daily rooms are captain's rooms, crew's living rooms, bed rooms, mess rooms, galleys, washrooms, bath rooms, lavatories, hospital, dispensary etc. and the attached passages or light and air spaces for these spaces. Provision stores are generally taken as mariners' daily rooms but some Regulations restrict the deduction (ex., British, International Regulations) or do not allow the deduction at all (ex., U.S. Regulations).

(b) Chart room

Some Regulations allow the deduction of the chart room (ex., British, International Regulations).

(c) Ballast tanks, cofferdams

Deduction depends on each Regulation (Table 42).

(d) Spaces for steering equipment, mooring equipment, windlass and their accessories

(e) Spaces for bilge pumps, ballast pumps and auxiliary machinery connected thereto and auxiliary boilers.

(f) Spaces for fire extinguish pumps, gas generators for fire fighting and sterilizing, distillers for drinking water, fire alarm equipment and emergency electric source for radio equipment.

(g) Boatswain's stores

Boatswain's stores are stores for deck articles, covers sheaves, ropes, accessories of life boats, life saving appliances. There exits a limit of deduction which varies depending on the Regulations. (Table 43)

Table 43 Deduction Limit for a Boatswain's Store (Japan)

Unit: m^3

Gross Volume V	Max. Deduction
$400 > V$	8
$1400 > V \geq 400$	$V \times 0{\cdot}02$
$2800 > V \geq 1400$	28
$V \geq 2800$	$V \times 0{\cdot}01 (\leq 213)$

Table 42 Comparison Table for Treatment of Ballast Tanks and Cofferdam

Regulations	Japan (J.G.)	International (Oslo Convention)	British	U. S. A.	Panama Canal	Suez Canal
Purpose	To be used only for ballasting. Fore & aft peak tanks may be used for loading fresh water exclusively or alternatively with sea water.	To be used only for ballasting. Fore & aft peak tanks to be treated same as J.G. (Including cofferdams)	Same as International Regulations	To be used only for ballasting (Including cofferdams)	Same as International Regulations	—
Pumping devices	To be equipped with pumping devices with appropriate capacity. Ballast pumps may be served also for bilge water discharging, fire extinguishing and general service.	Diameter of the pumping pipes to be 2-1/2" (64 mm) or over. To be independent of other pumping system.	Diameter of the pumping pipes to be normally 2-1/2" or over. To be independently used for ballast tank.	To be fitted with appropriate pipings and connected only to ballast tanks and independent of other pumping system.	To be served only for ballast tanks and independent of other pumping system.	—
Size of manhole	To be 0.46 m^2 or less (Openings to be equipped with direct closing device).	To be 4.91 ft^2 (0.46 m^2) or less.	To be 4.91 ft^2 (0.46 m^2) or less with max. diameter up to 30"(760 mm). Two manholes may be allowed at most.	Diameter to be 24" or less. Coaming with height 6" or less may be allowed except on the weather deck.	To be 4.91 ft^2 (0.456 m^2) or less, or the diameter to be 30" or less in case of a circular hole.	—
Restriction	If the total capacity of ballast tanks is abnormally large, the necessity of such large capacity shall be carefully studied from the view point of safety of the ship in connection with its purpose before approval.	19% of GT (including the exempted double bottom ballast tanks).	Same as International Regulations	Approval to be required in case of over 30% of GT.	No restriction	—
Treatment	Deduction	Exemption for the spaces above the upper deck. Deduction for other spaces.	Same as International Reguations	Exemption	Deduction	No exemption and no deduction

(h) Engine room

Deduction for engine room is decided by the p.p. space/GT as shown in Table 44. The actual tonnage of the engine room is obtained by subtracting from the whole tonnage of the engine room spaces (machinery room, boiler room, boiler room bulkheads, shaft tunnel, escape trunk etc.) the tonnage of the spaces for the undermentioned machinery or auxiliary boilers which are not used for propulsion of the ship. Suez Canal Regulations and Panama Canal Regulations have their own stipulation on the deduction of the engine room and auxiliary machinery which are quite different from other Regulations, for which special attention should be paid.

Table 44 Deduction for Engine Room

$P = \frac{\text{p.p. space}}{GT}$	Deduction	Remarks
$0{\cdot}13 \geq P$	$\text{p.p. space} \times \frac{32}{13}$	In no event the deduction shall exceed 55% of tonnage obtained by subtracting from GT the deduction tonnage other than for engine room.
$0{\cdot}20 > P > 0{\cdot}13$	$GT \times 0{\cdot}32$	
$P \geq 0{\cdot}20$	$\text{p.p. space} \times \frac{7}{4}$	

i) Boilers for exclusive use for heating the accommodations.
ii) Switchboard or distribution panel for electric generator etc. independent of the main engine and its auxiliary machinery.
iii) Refrigerators and their accessories.
iv) Distillers for drinking water, pressure tank for fresh or sea water.
v) Bilge pumps, ballast pumps, fire pumps etc..
vi) Cargo oil pumps and their drivers.
vii) Miscellaneous storage tanks (for fuel oil, boiler water, fresh water, lubricating oil etc.). Tanks involved in the circulating systems for the main engine are included in engine room.
viii) Fuel oil settling tanks provided that their capacity for fuel oil of up to two day use is included in engine room. The calculation of capacity for fuel oil of two day use depends on each Regulation (Table 45).
ix) Machinery stores, work shop, electric stores provided that capacity up to 0.75% of GT is included in engine room.
x) Other stores than above.

Table 45 Fuel Oil Consumption of Two Days (Japan) m^3

Reciprocating engine	IHP x 0.0200
Turbine engine	SHP x 0.0150
Diesel engine	BHP x 0.0104
Turbine electric engine	SHP (of propulsion motor) x 0.0160
Diesel electric engine	SHP (") x 0.0120

IHP, SHP, BHP: Maximum continuous output (PS) of main engine (propulsion motor)

5.4. Tonnage Marks

Most of the Regulations, except Canal Regulations, have become to apply "tonnage mark" system instead of so called "tonnage hatch" system to ships having two or more complete decks which has two systems as follows:

5.4.1. Method of Single Lower Tonnage with Regard to Full Load Line (Japan)

(1) Full load line

The designated level of statutory full load line should be lower than the level calculated on the basis that the "second deck" (the deck next below the uppermost complete deck) is the freeboard deck.

(2) Treatment of tonnage

Tonnage is calculated assuming the second deck the upper deck (lower tonnage) because the loadable capability of a ship in consideration of height of the full load line is approximately same as that of a conventional open shelter decker.

5.4.2. Optional Dual Tonnage Method by Tonnage Mark Table

(1) Dual tonnage method

In ships having two or more complete decks, both higher tonnage (= tonnage normally measured by placing tonnage mark) and lower tonnage (tonnage mentioned in 5.4.1) are registered by certificate of measurement.

(2) Identification of tonnage mark

The location of the tonnage mark is decided in accordance with the tonnage mark table. Namely, the distance from (molded line of) the second deck to the tonnage mark is measured based on the length of the second deck and the ratio of the length of the second deck to the depth of the second deck. The level thus determined is approximately of same height of the full (assigned) load line determined on the basis of the second deck being the freeboard deck.

(3) Treatment of dual tonnage

The assignment of the optional dual tonnage for the basis for application of laws or regulations or imposition of various duties depends upon the each Administration, however, a ship may be assigned dual tonnage as follows:

i) A higher tonnage applicable when the tonnage mark is submerged, viz. in condition of deeper draft than the level of the tonnage mark.

ii) A lower tonnage applicable when the tonnage mark is not submerged, viz. in condition of shallower draft than the level of the tonnage mark.

5.5. International Convention on Tonnage Measurement of Ships, 1969

By the year of 1978 or 1979, the captioned International Convention, instead of the conventional Regulations, is expected to come into force as the standard Regulations to be commonly used in the world. Japanese Government (J.G.) is preparing, as of October 1974, for ratification of the Convention together with stipulation of corresponding domestic laws and regulations. Hereunder are the summary of the Convention. It is notable that the contents of this handbook is subject to change at the time of stipulation of the Japanese domestic laws and regulations.

5.5.1. Application (Table 46) (Article 3, 4)

Table 46 Application

Navigation area		International voyages*1 (Not applicable to ships solely navigating the Great Lakes of North America and the River St. Lawrence, the Caspian Sea or the Plate, Parana and Urguay Rivers.)	
Length of ship		Not applicable to ships of less than 24 m (79 ft)*2	
Type of ship		Not applicable to ships of war.	
Time of application	New ships	When built	
	Existing ships	Within 12 years after effectuation of the Convention	When and if the owner requests so, (if not, as per below mentioned) or at the time of alterations or modification in large scale which the Administration deems to be a substantial variation in their existing gross tonnage.*3
		After above grace period	Applicable to all ships which shall be remeasured.

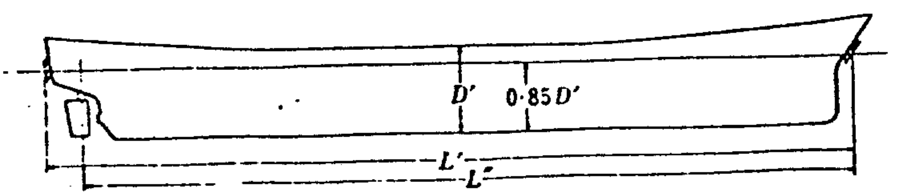
*1 May be applicable to ships not engaged in international voyages.

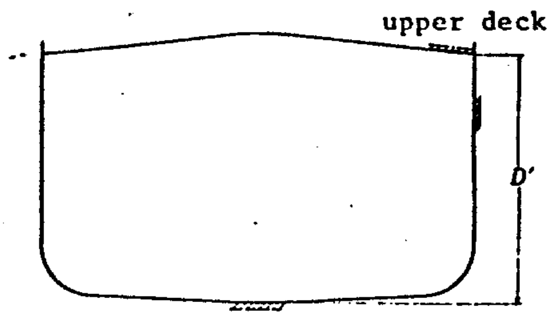
*2 The simplified Regulations for Tonnage Measurement of Ships to be applied to ships of less than 24 m in length.

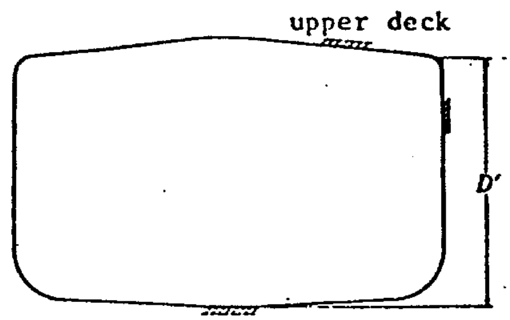
*3 Followings are the alterations or modifications in large scale.
- Elongation, shortening or deepening of ship's body.
- Extension, shortening, removal and addition of superstructures including deck houses.
- Modifications and new installation of hatchways.
- Change in assigned full load line.
- Modifications or replacement in the cargo holds or stores for ship articles.

5.5.2. Definitions of Terms (Table 47) (Article 2, Regulations 2, 4)

Table 47 Definitions of Terms

Term	Definition
Length	0.96 L' or L'' whichever is larger.  D' : the least molded depth

<table>
<tr><th>Term</th><th colspan="2">Definition</th></tr>
<tr><td>Breadth</td><td colspan="2">Maximum breadth of ship, measured amidships to the molded line of the frame.</td></tr>
<tr><td>Molded depth</td><td colspan="2">Ships with normal form


Ships with round gunwale


(For reference, definitions of the molded depth for wood and composite ships or ships having a lower part of the midship section of a hollow character are also given.)</td></tr>
<tr><td rowspan="4">Molded draft</td><td>Ships to which LLC is applied</td><td>Assigned summer load line (except timber load line)</td></tr>
<tr><td>Passenger ships engaged in international voyages</td><td>The deepest subdivision load line by SOLAS or other international agreements</td></tr>
<tr><td>Ships for which the load line or permissible draft is assigned by Japanese Regulations though LLC is not applicable</td><td>Assigned summer load line or maximum permissible draft by J.G.</td></tr>
<tr><td>Other ships than above</td><td>75% of the molded depth at midship</td></tr>
<tr><td>Upper deck</td><td colspan="2">The uppermost complete deck exposed to weather and sea, which has permanent means of weathertight closing of all openings in the weather part thereof and below which all openings in the side of the ship are fitted with permanent means of watertight closing. In a ship having a stepped upper deck, the lowest line of the exposed deck and the continuation of that line parallel to the upper part of the deck is taken as the upper deck.</td></tr>
</table>

5.5.3. Gross Tonnage, GT (Regulation 3)

The gross tonnage (GT) of a ship shall be determined by the following formula:

$$GT = K_1 V$$

Where, V = Total volume of all enclosed spaces of the ship in cubic meters

$K_1 = 0.2 + 0.02 \log_{10} V$

(1) Enclosed spaces (Regulation 2)
All those spaces which are bounded by the ship's hull, by fixed or portable partitions or bulkheads, by decks or coverings other than permanent or movable awnings.
Treatment for the weather parts is as follows:

(a) Funnels, skylights, fan house, entrance rooms, companion's hatch etc. are included in enclosed spaces.

(b) Ventilators, cargo oil pipes, electric cable trunks, masts, derrick posts etc. are neglected in tonnage measurement.

(c) Deck cranes and the like are not taken as a part of the ship's body.

(d) Small tanks, miscellaneous store boxes etc. which are fixed to the ship's body are included in enclosed spaces except those of volume of less than 1 m^3 which are neglected in tonnage measurement.

(2) Excluded spaces (Regulation 2)
The spaces referred to in following (a) - (e) are called excluded spaces and are not included in the volume of enclosed spaces, except that any such space which fulfils at least one of the following three conditions (i)(ii)(iii) are treated as an enclosed space.

(i) the space is fitted with shelves or other means for securing cargo or stores.
(ii) the openings are fitted with any means of closure (steel doors, steel grid doors, temporary wooden plate cover for tonnage openings etc. are taken as means of closure).
(iii) the construction provides any possibility of such openings being closed.

(a) A space within an erection opposite an end opening extending from deck to deck except for a curtain plate of a depth not exceeding by more than 25 millimeters (one inch) the depth of the adjoining deck beams, such opening having a breadth equal to or greater than 90 per cent of the breadth of the deck at the line of the opening of the space. The treatment of the spaces to be excluded under this provision is as follows:

i) A space between the actual end opening and a line drawn parallel to the line or face of the opening at a distance from the opening equal to one half of the width of the deck (B') at the line of the opening shall be excluded from the volume of enclosed spaces provided that the breadth of the opening at a distance $\frac{1}{2}B'$ from the end opening is equal to or greater than $0.9\ B'$. (Fig. 43 (1))

ii) Should the width of the space because of any arrangement except by convergence of the outside plating, become less than 90 per cent of the breadth of the deck, only the space between the line of the opening and a parallel line drawn through the point where the athwartships width of the space becomes equal to, or less than, 90 per cent of the breadth of the deck shall be excluded from the volume of the enclosed spaces. (Fig. 43 (2), (3), (4))

iii) Where an interval which is completely open except for bulwarks or open rails separates any two spaces, the exclusion of one or both of which is permitted under sub-paragraphs (a)(i) and/or (a)(ii), such exclusion shall not apply if the separation between the two spaces is less than the least half breadth of the deck in way of the separation. (Fig. 43 (5), (6))

(b) A space under an overhead deck covering open to the sea and weather, having no other connexion on the exposed sides with the body of the ship than the stanchions necessary for its support. In such a space, open rails or a bulwark and curtain plate may be fitted or stanchions fitted at the ship's side, provided that the distance between the top of the rails or the bulwark and the curtain plate is not less than 0.75 meters (2.5 feet) or one-third of the height of the space, whichever is the greater. (Fig. 43 (7))

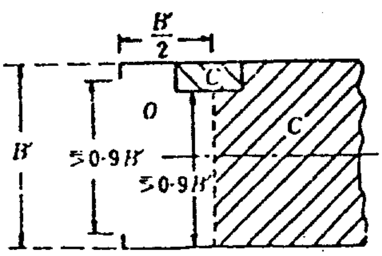
(c) A space in a side-to-side erection directly in way of opposite side openings not less in height than 0.75 meters (2.5 feet) or one-third of the height of the erection, whichever is the greater. If the opening in such an erection is provided on one side only, the space to be excluded from the volume of enclosed spaces shall be limited inboard from the opening to a maximum of one-half of the breadth of the deck in way of the opening. (Fig. 43 (8))

(d) A space in an erection immediately below an uncovered opening in the deck overhead, provided that such an opening is exposed to the weather and the space excluded from enclosed spaces is limited to the area of the opening. (Fig. 43 (9))

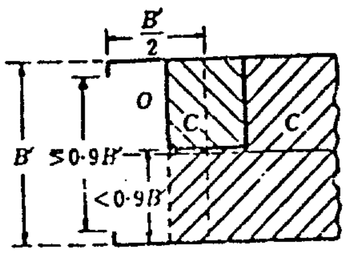
(e) A recess in the boundary bulkhead of an erection which is exposed to the weather and the opening of which extends from deck to deck without means of closing, provided that the interior width is not greater than the width at the entrance and its extension into the erection is not greater than twice the width of its entrance. (Fig. 43 (10))

Note) In Fig. 43 (1) - (10), the following abbreviation is applied:

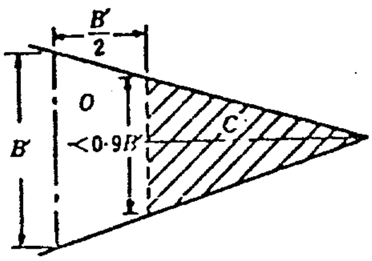
O = Excluded space, *C* = Enclosed space
I = Space to be taken as an enclosed space
Hatched part = Space to included in enclosed spaces
B' = Breadth of the deck in way of the opening. In ships with rounded gunwales the breadth is measured as indicated in Fig. 43 (11).



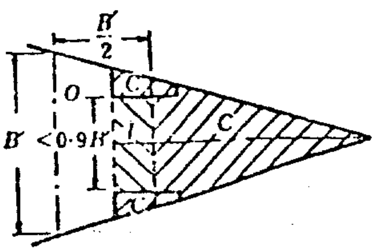
(1) Excluded space



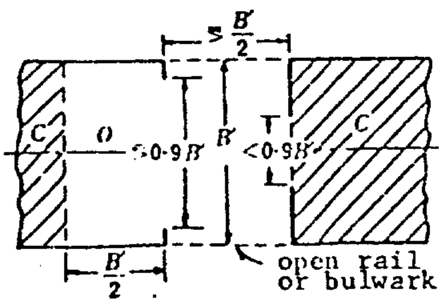
(2) Excluded space



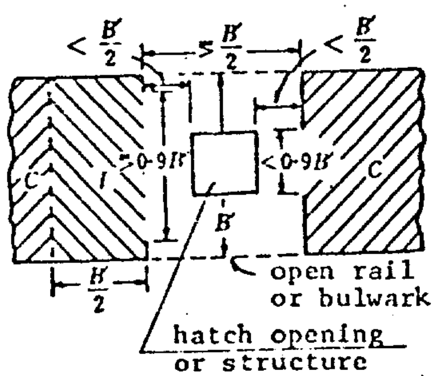
(3) Excluded space



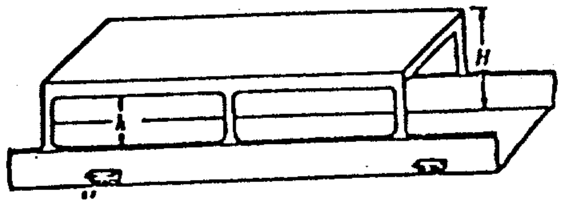
(4) Excluded space



(5) Excluded space

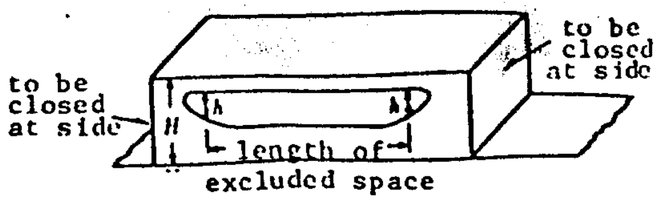


(6) Excluded space



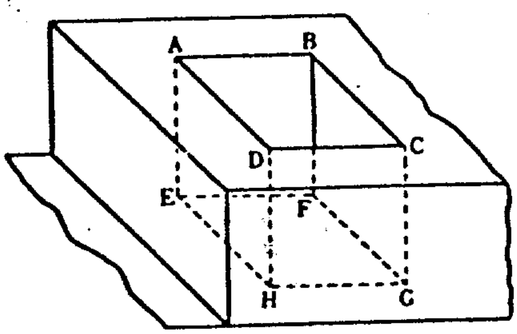
h to be not less than H/3 or 0.75m (2.5ft) whichever is the greater

(7) Excluded space



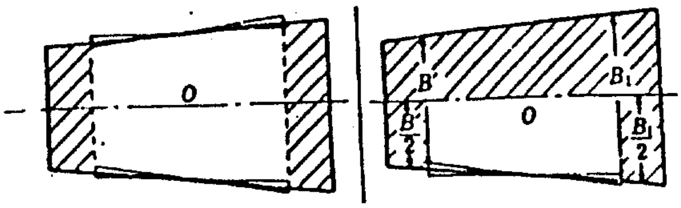
h to be not less than H/3 or 0.75m whichever is the greater

(8) Excluded space



ABCD is the opening on deck.
ABCDEFGH is excluded from closed space.

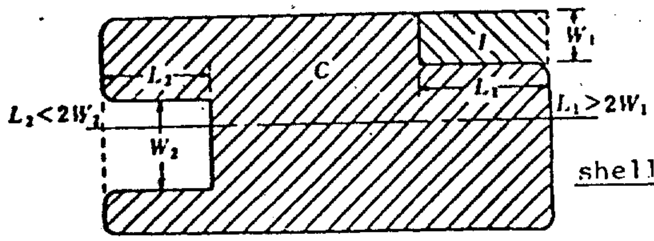
(9) Excluded space



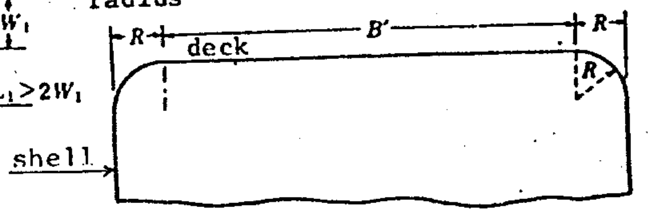
symmetrical side openings at each side

opening at one side

(8) Excluded space



(10) Excluded space



(11) B' of the ship with round gunwale

Fig. 43

5.5.4. Net Tonnage, NT (Regulation 4)

The net tonnage of a ship is determined by the following formula:

$$NT = K_1 V_c \left(\frac{4d}{3D}\right)^2 + K_2 \left(N_1 + \frac{N_2}{10}\right)$$

where, $\left(\frac{4d}{3D}\right) \leq 1$, $K_1 V_c \left(\frac{4d}{3D}\right)^2 \geq 0{\cdot}25GT$, $NT \geq 0{\cdot}30GT$

and where, V_c = Total volume of cargo spaces (m³)

$K_1 = 0{\cdot}2 + 0{\cdot}02 \log_{10} V_c$ $\qquad K_2 = 1{\cdot}25 \frac{GT + 10\,000}{10\,000}$

D = Molded depth amidships

d = Molded draft amidships

N_1 = Number of passengers in cabin with not more than 8 berths

N_2 = Number of other passengers

$N_1 + N_2$ = Total number of passengers the ship is permitted to carry as indicated in the ship's passenger certificate; when $N_1 + N_2$ is less than 13, N_1 and N_2 shall be taken as zero.

(1) Cargo spaces (Regulation 2)
Cargo spaces to be included in the computation of net tonnage are enclosed spaces appropriated for the transport of cargo which is to be discharged from the ship, provided that such spaces have been included in the computation of gross tonnage. Such cargo spaces shall be certified by permanent marking with the letters CC (Cargo Compartment) to be so positioned that they are readily visible and not to be less than 100 mm (4 inches) in height.
The volume of the cargo spaces is measured in following manners:

(a) Trunks, bilge well and permanent ballast are excluded. Small trunks like a ventilation trunk are neglected to be included in cargo spaces.

(b) Hatchways are included in cargo spaces.

(c) The thermal insulation is neglected and the volume is measured within the ship's shell plate or steel bulkheads.

(d) Slop tanks are included in cargo spaces.

(e) Clean ballast tanks are not included in cargo spaces, but emergency ballast tanks with piping system through which cargo oil could be transferred thereinto shall be taken as cargo spaces provided that the piping system meets the requirements therefor.

(f) Ore-oil-ballast tanks used for loading oil and ballast alternatively within a considerably short period are included in cargo spaces.

(g) In ships designed for multipurpose but exclusively used for one purpose for a certain period. the space not used for that purpose are excluded from cargo spaces provided that measures to secure the non-use of the spaces are provided. In this case, remeasurement is required with change of purpose and, if the net tonnage decreases as the result of the remeasurement, a new International Tonnage Certificate incorporating the net tonnage so determined shall not be issued until 12 months have elapsed from the date of issuance of the current certificate.

(h) In ships with single bottom, except for carrying liquid cargos, the spaces below the floor plates are not included in cargo spaces.

(2) Passenger (Regulation 2)
A passenger is every person other than:

(a) The master and the members of the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship (ex. shipowners, charterers, pilots, stevedores, public officials etc. Persons in the spare rooms are not taken as passengers unless they are included in the certified number of passenger.); and

(b) A child under one year of age.

5.5.5. Calculation and Example of Calculation

(1) Calculation of volumes (Regulation 6)
All volumes included in the calculation of gross and net tonnages shall be measured, irrespective of the fitting of insulation or the like, to the inner side of the shell or structural boundary plating.
Volumes of appendages shall be included in the total volume (propeller bossing, skeg etc. are calculated as appendages but rudder, propeller, stabilizer fin etc. are not).

Volumes of spaces open to the sea may be excluded from the total volume (sea chests, tunnel for side thruster, anchor recess, slipway of a whaler etc. are open to the sea but hawse pipe, rudder trunk, bait well are not). Appendages and open spaces one-third of total of whose maximum length, maximum breadth and maximum height is equal to or less than 1.67 m are neglected in tonnage measurement.

(2) Calculation system
In Japan, the Ministry of Transport (MOT) has developed a computing program by electronic computer based on the Regulations of this Convention which will be available for use in MOT or authorized shipyards. For manual calculation too the procedure shall be authorized by MOT. For reference, for measurement of under deck volumes, the offset data prepared by a shipyard may be used.

(3) Example of calculation
An example of calculation is shown in Fig. 44.

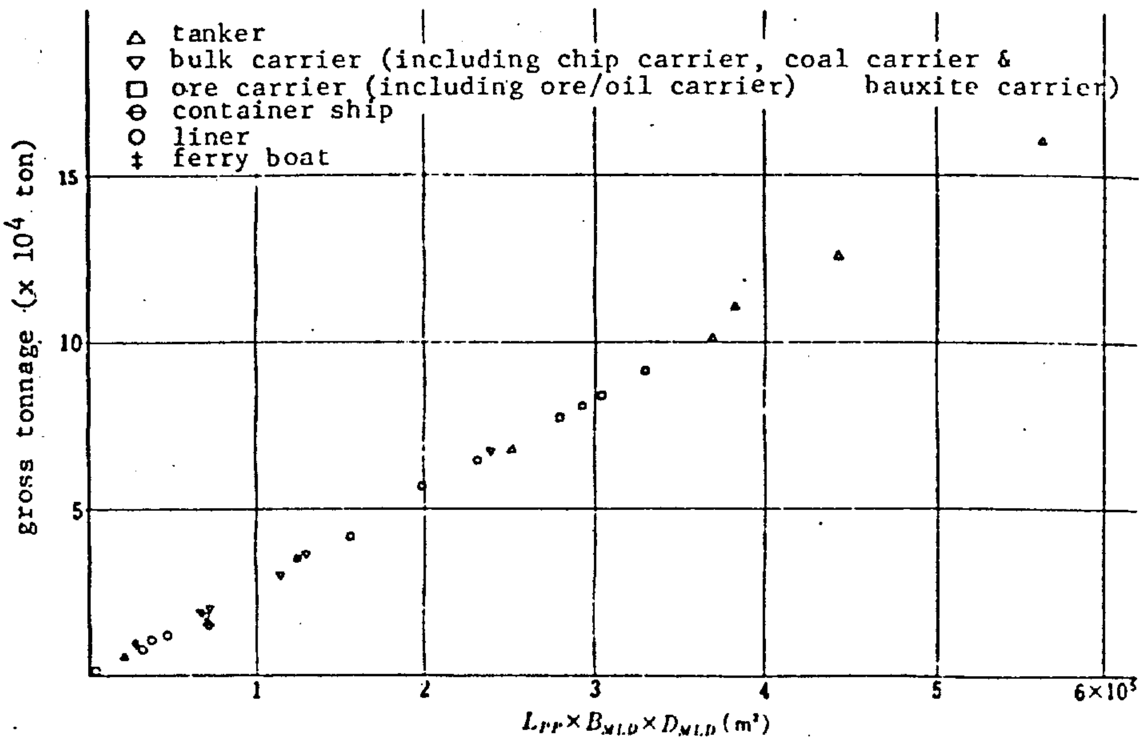


Fig. 44 Gross Tonnage Calculation based on International Convention Tonnage Measurement of Ships, 1969

6. RESISTANCE AND PROPULSION

6.1. Symbols and Coefficients

6.1.1. Symbols and Abbreviations

Symbol & Abbreviation	ITTC	Description
A_0	A_0	Disk area of propeller
A_D	A_D	Developed area of propeller blades
A_E	A_E	Expanded area of propeller outside boss
A_P	A_P	Projected area of propeller blades outside boss
a_E	a_E	Expanded-area ratio A_E/A_0
a_P	a_P	Projected-area ratio A_P/A_0
B_P	B_P	Output coefficient $N(\mathrm{DHP})^{0.5}/V_A^{2.5}$
B_U	B_U	Thrust coefficient $N(\mathrm{THP})^{0.5}/V_A^{2.5}$
BHP	P_B	Brake horsepower
C_{adm}		Admiralty constant $\Delta^{2/3}V_s^3/\mathrm{HP}$
C_B	C_B, δ	Block coefficient $= C_b$
C_M	C_M, β	Midship section coefficient $= C_{\mathrm{m}}$
C_P	C_P, ϕ	Prismatic coefficient $= C_p$
C_S		Wetted surface area coefficient $S/\sqrt{\nabla L}$
C_T	C_T	Total resistance coefficient $R_T/(\frac{1}{2}\rho S V^2)$ (Suffix F, R, W, V follow to R_T)
C_V	C_{VP}, ϕ_V	Vertical prismatic coefficient $= C_{pv}$
C_W	C_{WP}, α	Waterplane area coefficient
©	©	$\dfrac{1000\left(\frac{R}{\Delta}\right)}{Ⓚ^2} = 427 \cdot 1 \dfrac{\mathrm{EHP}}{\Delta^{2/3}V_s^3}$
D	D	Diameter of propeller
d_H	d	Diameter of propeller boss
DHP	P_D	Delivered horsepower
e	P_V	Vapor pressure of water (kg/m²)
EHP	P_E	Effective horsepower
F_n	F_n	Froude Number $V/\sqrt{Lg}$
F_{nv}	F_{nr}	$V/\sqrt{\nabla^{1/3}g}$
I		Depth of shaft centre (m)
i_E	i_E	Entrance angle of water line (deg.)
J	J	Advance coefficient of propeller $V_A/(nD)$
k	k	Form factor
K_Q	K_Q	Torque coefficient of propeller $Q/(\rho n^2 D^5)$
K_{QA}		K_Q/J^2
$K_{QA'}$		K_Q/J^3
K_{QN}		K_Q/J^5

Symbol & Abbreviation	ITTC	Description
K_T	K_T	Thrust coefficient of propeller $T/(\rho n^2 D^4)$
K_{TB}		K_T/J^2
K_{TA}		K_T/J^4
Ⓚ	Ⓚ	$V\Big/\sqrt{\frac{g}{2\pi}\frac{\nabla^{1/3}}{2}}$
Ⓛ	Ⓛ	$V\Big/\sqrt{\frac{g}{2\pi}\frac{L}{2}}$
l_{cb}		($\otimes$B/L)×100(%) (+: Aftward from midship) (-: Forward from midship)
Ⓜ	Ⓜ	Length displacement ratio $L/\nabla^{1/3}$
N		Revolutions per minute
n		Revolutions per second
P	P	Pitch of propeller (m)
Ⓟ		$V\Big/\sqrt{\frac{g}{2\pi}C_P L}$
p		Pitch ratio P/D
Q	Q	Torque (kg.m)
R	R	Resistance (kg)
R_F	R_F	Frictional resistance (kg)
R_n	R_n	Reynolds Number VL/ν
R_R	R_R	Residual resistance (kg)
R_T	R_T	Total resistance (kg)
R_W	R_W	Wave-making resistance (kg)
	R_V	Viscosity resistance (kg)
r_T	$C_{T\nabla}$	Total resistance coefficient $R_T/(\frac{1}{2}\rho\nabla^{2/3}V^2)$ (Subscripts F,R,W refer to "frictional", "residual" and "wave-making" etc.)
r_T'		Total resistance coefficient $R_T/(\rho\nabla^{2/3}V^2)$ (Subscripts F,R,W refer to "frictional", "residual" and "wave-making" etc.)
S	S	Wetted surface area
Ⓢ	Ⓢ	Wetted surface area coefficient $S/\nabla^{2/3}$
s_A	s_A	Apparent slip ratio $\frac{nP-V}{nP}$
s_R	s_R	Real slip ratio $\frac{nP-V_A}{nP}=1-\frac{J}{p}$
SHP	P_S	Shaft horsepower
T	T	Thrust (kg)
t	t	Thrust deduction factor $1-\frac{R}{T}$

Symbol & Abbreviation	ITTC	Description
THP	P_T	Thrust horsepower $-U$
V	V	Speed
V_A	V_A	Advance speed of propeller
V_K		Speed (kt)
V_{KA}		Advance speed of propeller (kt)
w	w	Wake factor $1-\frac{V_A}{V}$
w_Q	w_Q	Wake factor (calculated by K_Q)
w_T	w_T	Wake factor (calculated by K_T)
Z	Z	Number of propeller blades
α		Scale ratio (model ship length/ship length)
	λ	Scale ratio (ship length/model ship length)
δ	δ	Taylor's advance ratio ND/V_{KA}
Δ	Δ	Displacement $W(t), \rho g \nabla \times 10^{-3}(t)$
∇	∇	Volume of displacement (m^3)
η_B	η_B	Propeller efficiency (behind the hull)
η_H	η_H	Hull efficiency $(1-t)/(1-w)$
η_O	η_O	Propeller efficiency (open water)
η_P	η_D	Propulsive efficiency EHP/DHP
η_R	η_R	Relative rotative efficiency η_B/η_O
η_T	η_S	Transmission efficiency DHP/(SHP or BHP)
μ	μ	Coefficient of viscosity ($kg \cdot sec/m^2$)
ν	ν	Coefficient of kinetic viscosity μ/ρ (m^2/sec)
ρ	ρ	Mass density ($kg\ sec^2/m^4$)
γ	γ	Specific gravity (non-dimensional)
σ	σ	Cavitation Number $(p-e)/(\frac{1}{2}\rho V^2)$ p : Static water pressure including atmospheric pressure

6.1.2. Relations among Coefficients (A symbol with mark ' on the right shoulder denotes one in English Unit)

(1) Coefficients about dimensions of ship

(a) Displacement-length ratio

i) $\dfrac{\Delta}{\left(\frac{L}{10}\right)^3} = 3.588\times10^{-2}\times\dfrac{\Delta'}{\left(\frac{L'}{100}\right)^3} = \dfrac{10^3}{\left(\frac{L}{\Delta^{1/3}}\right)^3} = 1.025\times10^3\times C_v = \dfrac{1.025\times10^3}{\text{Ⓜ}^3}$

ii) $\dfrac{\Delta'}{\left(\frac{L'}{100}\right)^3} = 2.788\times10\times\dfrac{\Delta}{\left(\frac{L}{10}\right)^3} = \dfrac{10^6}{\left(\frac{L'}{\Delta'^{1/3}}\right)^3} = 2.857\times10^4\times C_v = \dfrac{2.857\times10^4}{\text{Ⓜ}^3}$

(b) Length-displacement ratio

i) $\dfrac{L}{\Delta^{1/3}} = 3.032\times10^{-1}\times\dfrac{L'}{\Delta'^{1/3}} = 10^1\times\left\{\dfrac{\Delta}{\left(\frac{L}{10}\right)^3}\right\}^{-1/3} = \dfrac{9.918\times10^{-1}}{C_v^{1/3}} = 9.918\times10^{-1}\times\text{Ⓜ}$

ii) $\dfrac{L'}{\Delta'^{1/3}} = 3.298\times\dfrac{L}{\Delta^{1/3}} = 10^2\times\left\{\dfrac{\Delta'}{\left(\frac{L'}{100}\right)^3}\right\}^{-1/3} = \dfrac{3.271}{C_v^{1/3}} = 3.271\times\text{Ⓜ}$

(c) Coefficient of displacement volume

$C_v = \dfrac{\nabla}{L^3} = \dfrac{1}{\text{Ⓜ}^3} = 9.756\times10^{-4}\times\dfrac{\Delta}{\left(\frac{L}{10}\right)^3} = 3.5\times10^{-5}\times\dfrac{\Delta'}{\left(\frac{L'}{100}\right)^3}$

$= \dfrac{9.756\times10^{-1}}{\left(\frac{L}{\Delta^{1/3}}\right)^3} = \dfrac{35}{\left(\frac{L'}{\Delta'^{1/3}}\right)^3}$

(d) Length-displacement volume ratio

$\text{Ⓜ} = \dfrac{L}{\nabla^{1/3}} = \dfrac{1}{C_v^{1/3}} = 1.008\times\left\{\dfrac{\Delta}{\left(\frac{L}{10}\right)^3}\right\}^{-1/3} = 3.057\times10\times\left\{\dfrac{\Delta'}{\left(\frac{L'}{100}\right)^3}\right\}^{-1/3} = 1.008\times\dfrac{L}{\Delta^{1/3}}$

$= 3.057\times10^{-1}\times\dfrac{L'}{\Delta'^{1/3}}$

(2) Coefficients for wetted surface area

(a) $\text{Ⓢ} = \dfrac{S}{\nabla^{2/3}}$ (b) $C_s = \dfrac{S}{\sqrt{\nabla L}} = \dfrac{\text{Ⓢ}}{\text{Ⓜ}^{1/2}}$

(3) Coefficients for speed (refer to Table 48)

(a) Froude Number $F_n = \dfrac{V}{\sqrt{Lg}}$

(b) Speed-length ratio $\dfrac{V_k}{\sqrt{L}}, \dfrac{V_k'}{\sqrt{L'}}$ (Refer to Chapter I, 1.2.2 (2)(d))

(c) $F_{nv} = \dfrac{V}{\sqrt{\nabla^{1/3}g}} = \text{Ⓜ}^{1/2}\cdot F_n = \dfrac{\text{Ⓚ}}{\sqrt{4\pi}}$

(d) $\text{Ⓚ} = \dfrac{V}{\sqrt{\frac{g}{2\pi}\cdot\frac{\nabla^{1/3}}{2}}} = \sqrt{4\pi}\,F_{nv} = \sqrt{4\pi}\,\text{Ⓜ}^{1/2}F_n = \text{Ⓜ}^{1/2}\text{Ⓛ}$

(e) $\text{Ⓛ} = \dfrac{V}{\sqrt{\frac{g}{2\pi}\cdot\frac{L}{2}}} = \sqrt{4\pi}\,F_n = \dfrac{\text{Ⓚ}}{\text{Ⓜ}^{1/2}} = \sqrt{4\pi}\,\dfrac{F_{nv}}{\text{Ⓜ}^{1/2}}$

(f) $\textcircled{P} = \dfrac{V}{\sqrt{\dfrac{g}{2\pi} C_p L}} = \sqrt{\dfrac{2\pi}{C_p}}\, F_n = \dfrac{\textcircled{L}}{\sqrt{2 C_p}}$

(g) Reynolds number $R_n = \dfrac{VL}{\nu} = \sqrt{g}\,\dfrac{L^{3/2}}{\nu} F_n$

Table 48

n	$\sqrt{n}$	$1/\sqrt{n}$
$g = 9.806\,65$ m/sec^2	$\sqrt{g} = 3.132$	$1/\sqrt{g} = 0.319\,3$
$g' = 32.174\,0$ ft/sec^2	$\sqrt{g'} = 5.672$	$1/\sqrt{g'} = 0.176\,3$
$4\pi = 12.566\,4$	$\sqrt{4\pi} = 3.545$	$1/\sqrt{4\pi} = 0.282\,1$
$2\pi = 6.283\,2$	$\sqrt{2\pi} = 2.507$	$1/\sqrt{2\pi} = 0.398\,9$
$\pi = 3.141\,6$	$\sqrt{\pi} = 1.772$	$1/\sqrt{\pi} = 0.564\,2$

(4) Coefficients for resistance

(a) $C = \dfrac{R}{\dfrac{1}{2}\rho S V^2} = \dfrac{R}{0.132\,32 \times \rho S V_k^2} = \dfrac{R'}{1.426\,2 \times \rho' S' V_k'^2}$

(b) $r = \dfrac{R}{\dfrac{1}{2}\rho \nabla^{2/3} V^2}$ (c) $r' = \dfrac{R}{\rho \nabla^{2/3} V^2}$

where $r = 2r' = \textcircled{S}\, C$

(d) $\textcircled{C} = \dfrac{\dfrac{R}{\Delta}}{\textcircled{K}^2} = \dfrac{1000}{8\pi}\textcircled{S}\, C = \dfrac{1000}{8\pi}\, r = \dfrac{1000}{4\pi}\, r' \fallingdotseq 427.1 \dfrac{\text{EHP}}{\Delta^{2/3} V_k^3}$

(e) $\dfrac{R}{\Delta} = \textcircled{C}\textcircled{K}^2 = 500 \times F_n^2 \textcircled{M}\textcircled{S}\, C = 500 \times F_n^2 \textcircled{M}\, r = 1000 \times F_n^2 \textcircled{M}\, r' = \dfrac{1}{2.240} \times \dfrac{R'}{\Delta'}$

(5) Horsepower (refer to Chapter I, 1.2.2 (2)(n))

(a) Effective horse power (EHP)

i) $\text{EHP (PS)} = \dfrac{RV}{75} = 6.859 \times 10^{-3} \times R V_k = 6.859 \times 10^{-3} \times \Delta V_k \dfrac{R}{\Delta}$

$= 9.496 \times 10^{-2} \times S V_k^3 C$
$= 9.496 \times 10^{-2} \times \nabla^{2/3} V_k^3 r$ $\Big\}$ $(\rho = 104.62\,\text{kg}\cdot\text{sec}^2/\text{m}^4)$

$= \dfrac{\Delta^{2/3} V^3 r}{1.4576}$

ii) $\text{EHP}'\text{(HP)} = \dfrac{R'V'}{550} = 3.071 \times 10^{-3} \times R' V_k' = 3.071 \times 10^{-3} \times \Delta' V_k' \dfrac{R'}{\Delta'}$

$= 8.717 \times 10^{-3} \times S' V_k'^3 C$ $(\rho = 1.9905\ \text{lb}\cdot\text{sec}^2/\text{ft}^4)$

(b) Delivered horse power (DHP)

i) $\text{DHP (PS)} = \dfrac{2\pi n Q}{75} = \eta_r \times (\text{BHP 又は SHP}) = \dfrac{\text{EHP}}{\eta_r}$

ii) $\text{DHP}'\text{(HP)} = \dfrac{2\pi n Q'}{550}$

(c) Thrust horse power (THP)

i) $\text{THP (PS)} = U = \frac{TV_A}{75} = \frac{1-w}{1-t}\text{EHP} = \eta_R\eta_o\text{DHP}$

ii) $\text{THP}'\text{(HP)} = U' = \frac{T'V_A'}{550}$

6.2. Estimation of Hull Resistance and Effective Horse Power

6.2.1. General

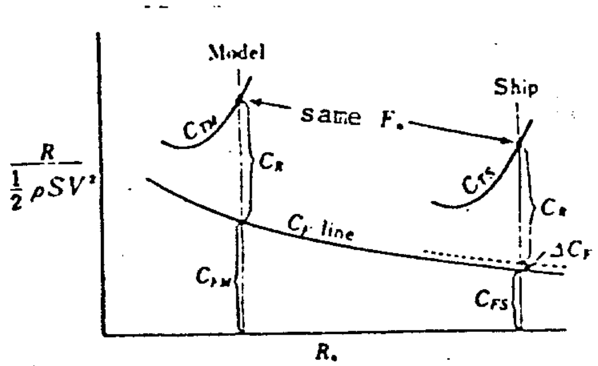
There are two (2) methods for estimating hull resistance and effective horse power, the one is a method of estimating and calculating the total resistance and effective horse power by separating the total resistance into some components to be calculated respectively and composing the components, and the other is a method to estimate effective horse power directly. The former is further categorized into a method of estimating the resistance by charts derived from a series of model tests, a method by resistance tests using model ship and a method to estimate the resistance of the ship from the results of model tests for similar vessels. The latter, the direct estimation method of effective horse power, is a simple and practical method if the data of suitable similar vessels are available. But, in general it is a custom to apply the former estimation method as outlined in the followings.

Froude proposed that total resistance is divided into two independent components, the one is a function of Reynolds Number ($R_n = VL/\nu$) and the other is a function of Froude Number ($F_n = V/\sqrt{Lg}$) as shown in the following formula:

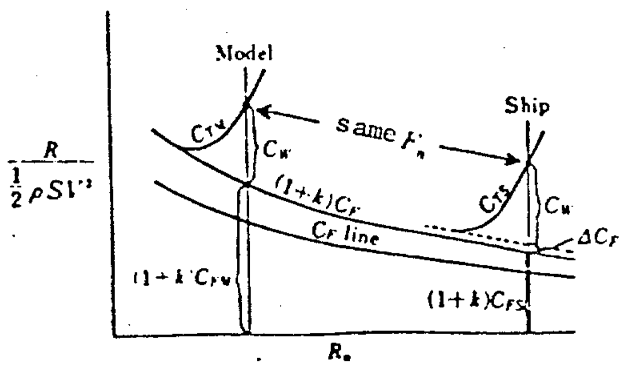
$$C_T = f_1(R_n, r_1, r_2, \cdots\cdots) + f_2(F_n, r_1, r_2, \cdots\cdots)$$

where $r_1, r_2, \cdots\cdots$; are parameters which represent ship's form.

According to this proposal, for the two ships with a similar geometrical forms (for example, actual ship and model ship), the effects of $r_1, r_2, \cdots\cdots$ are eliminated and the values of f_1 become equal at the same R_n and the values of f_2 become equal at the same F_n in accordance with the dynamical Law of Comparison. There are two methods of dividing resistance into two components corresponding to the above f_1 and f_2, namely, the two dimensional extrapolation method of taking frictional resistance coefficient for f_1 and residual resistance coefficient for f_2 and the three dimensional extrapolation method of taking viscosity resistance coefficient for f_1 and wave making resistance coefficient for f_2. (Refer to Fig. 45)



(a) Two-dimensional extrapolation method.



(b) Three-dimensional extrapolation method

Fig. 45 Extrapolation methods

Actually, it is impossible to make R_n and F_n equal at the same time for two ships of similar form but different sizes, and consequently, the values of f_t are calculated as mentioned below and the values of f_t for each ship are compared at the same F_n or the values of a vessel for which f_t is known (for example, model ship) are extended to the vessel in question, (i.e. actual vessel). Resistance calculations for an actual vessel will be done by the following procedures.

Two dimensional extrapolation method $C_{ts} = (C_{fs} + \Delta C_f) + C_r$

Three dimensional extrapolation method $C_{ts} = \{(1+k)C_{fs} + \Delta C_f\} + C_w$

where C_{fs} is the frictional resistance coefficient of the actual vessel and it is normal to deal with $(1+k)$ as a constant value which is decided only by the ship's form and have no relation to the values of R_n or F_n. Applicable values are decided by the model tests or the estimation formulas. C_r or C_w is also decided by the model tests or the estimation methods. ΔC_f is introduced originally as a correction factor for the roughness of the hull surface and some trials have been made to obtain it theoretically, but at present, it is used as a kind of correction factor for errors between the model ship and actual ship and practical value for it is estimated from the actual experiences. When C_{ts} is thus obtained, the effective horse power is calculated by the following formula:

$$R_{ts} = C_{ts} \times \frac{1}{2}\rho_s S_s V_s^2 \qquad \mathrm{EHP} = \frac{1}{75} R_{ts} \cdot V_s$$

6.2.2. Estimation Method by Composing the Hull Resistance Components

(1) Estimation method of resistance components by using charts or approximate formulas

(a) Estimation of frictional resistance.

Frictional resistance of a ship is calculated assuming that it is equal to the frictional resistance of a smooth plank of same length and area (so called equivalent plate)

i) Calculation formulas for frictional resistance

R.E. Froude's formula

$$R_f = \gamma\lambda\{1 + 0.0043(15-t)\} S V^{1.825} = 0.2973\gamma\lambda\{1 + 0.0043(15-t)\} S V_k^{1.825}$$

where, R_f = Frictional resistance (kg)
γ = Specific gravity of fluid
$\lambda = 0.1392 + 0.258/(2.68 + L)$
S = Wetted surface area (m²)
V_k = Speed (kt)
t = Temperature of fluid normally 15 deg. C in actual ships

Schoenherr's formula (Table 49)

$$R_f = C_f \frac{1}{2}\rho S V^2; \quad \frac{0.242}{\sqrt{C_f}} = \log_{10}(R_n C_f)$$

or approximately

$$C_f = 0.463(\log_{10} R_n)^{-2.6}; \quad (R_n = 10^6 \sim 10^9)$$

Hughes' formula

$$R_f = C_f \frac{1}{2}\rho S V^2; \quad C_f = 0.066(-2.03 + \log_{10} R_n)^{-2}$$

Table 49 Schoenherr's Frictional Resistance Coefficient

$C_f \times 10^3$ Sea water at 15 degrees C, Coefficient of kinetic viscosity $\nu = 1{\cdot}18831 \times 10^{-6}$ m²/sec

V_K	V	*L* m																							
kt	m/sec	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	380	400	420	440	460	480	500
7	3·60	2·017	1·908	1·836	1·782	1·740	1·706	1·677	1·652	1·630	1·611	1·593	1·577	1·562	1·549	1·537	1·526	1·515	1·505	1·496	1·487	1·478	1·470	1·463	1·456
8	4·12	1·981	1·874	1·804	1·751	1·710	1·677	1·668	1·624	1·603	1·584	1·567	1·551	1·537	1·524	1·511	1·500	1·490	1·480	1·470	1·462	1·454	1·447	1·439	1·432
9	4·63	1·948	1·845	1·775	1·724	1·684	1·652	1·624	1·601	1·579	1·561	1·544	1·528	1·515	1·502	1·490	1·479	1·469	1·459	1·450	1·442	1·434	1·432	1·419	1·412
10	5·14	1·921	1·819	1·751	1·701	1·662	1·630	1·603	1·579	1·559	1·541	1·524	1·509	1·496	1·482	1·470	1·461	1·450	1·441	1·433	1·424	1·416	1·409	1·401	1·395
11	5·66	1·897	1·796	1·729	1·681	1·642	1·611	1·584	1·561	1·541	1·522	1·506	1·491	1·478	1·465	1·454	1·444	1·435	1·425	1·416	1·408	1·400	1·393	1·386	1·379
12	6·17	1·874	1·775	1·710	1·662	1·624	1·593	1·567	1·544	1·524	1·506	1·490	1·476	1·463	1·450	1·440	1·429	1·419	1·410	1·402	1·394	1·386	1·379	1·372	1·365
13	6·69	1·854	1·756	1·693	1·645	1·608	1·577	1·551	1·528	1·509	1·491	1·476	1·462	1·448	1·437	1·426	1·415	1·406	1·397	1·388	1·381	1·373	1·366	1·359	1·353
14	7·20	1·836	1·740	1·677	1·630	1·593	1·562	1·537	1·515	1·496	1·478	1·463	1·448	1·436	1·424	1·413	1·403	1·394	1·385	1·377	1·369	1·361	1·354	1·347	1·341
15	7·72	1·819	1·724	1·662	1·616	1·579	1·549	1·524	1·502	1·482	1·465	1·450	1·437	1·424	1·412	1·402	1·391	1·382	1·373	1·365	1·357	1·350	1·343	1·336	1·330
16	8·23	1·804	1·710	1·648	1·603	1·567	1·537	1·511	1·490	1·470	1·455	1·440	1·426	1·413	1·402	1·391	1·381	1·372	1·363	1·355	1·347	1·340	1·333	1·327	1·320
17	8·74	1·789	1·697	1·635	1·590	1·555	1·526	1·500	1·479	1·461	1·444	1·429	1·415	1·403	1·391	1·381	1·371	1·362	1·352	1·346	1·338	1·330	1·324	1·317	1·311
18	9·26	1·775	1·684	1·624	1·579	1·544	1·515	1·490	1·469	1·450	1·435	1·419	1·406	1·394	1·382	1·372	1·362	1·352	1·345	1·337	1·329	1·322	1·315	1·309	1·302
19	9·77	1·763	1·673	1·614	1·568	1·534	1·505	1·480	1·459	1·441	1·425	1·410	1·397	1·385	1·373	1·363	1·353	1·345	1·336	1·328	1·321	1·314	1·307	1·300	1·294
20	10·29	1·751	1·662	1·603	1·559	1·524	1·496	1·470	1·450	1·433	1·416	1·402	1·388	1·377	1·365	1·355	1·346	1·337	1·328	1·321	1·313	1·306	1·299	1·293	1·287
21	10·80	1·740	1·652	1·593	1·549	1·515	1·486	1·463	1·442	1·424	1·408	1·394	1·381	1·368	1·357	1·347	1·338	1·329	1·321	1·313	1·306	1·299	1·292	1·285	1·280
22	11·32	1·729	1·642	1·584	1·541	1·506	1·478	1·455	1·435	1·416	1·400	1·386	1·372	1·361	1·350	1·340	1·331	1·322	1·314	1·306	1·299	1·292	1·285	1·279	1·273
23	11·83	1·719	1·633	1·575	1·532	1·498	1·470	1·447	1·427	1·409	1·393	1·379	1·366	1·354	1·343	1·333	1·323	1·316	1·307	1·300	1·292	1·285	1·279	1·272	1·267
24	12·35	1·170	1·624	1·567	1·524	1·490	1·463	1·440	1·419	1·402	1·386	1·372	1·359	1·347	1·337	1·327	1·318	1·308	1·300	1·293	1·286	1·279	1·272	1·266	1·260
25	12·86	1·701	1·616	1·558	1·517	1·482	1·456	1·432	1·412	1·395	1·379	1·365	1·353	1·341	1·330	1·320	1·311	1·302	1·294	1·287	1·280	1·273	1·267	1·261	1·255
26	13·38	1·693	1·607	1·551	1·509	1·476	1·448	1·426	1·405	1·388	1·373	1·359	1·346	1·335	1·324	1·314	1·305	1·297	1·289	1·281	1·274	1·267	1·261	1·255	1·249
27	13·89	1·684	1·600	1·544	1·502	1·469	1·442	1·419	1·400	1·382	1·367	1·353	1·340	1·329	1·318	1·309	1·300	1·291	1·283	1·276	1·269	1·262	1·256	1·250	1·244
28	14·40	1·677	1·593	1·537	1·496	1·463	1·435	1·413	1·394	1·376	1·361	1·347	1·335	1·324	1·313	1·303	1·298	1·286	1·278	1·270	1·263	1·257	1·251	1·244	1·239
29	14·92	1·669	1·586	1·530	1·489	1·456	1·429	1·407	1·388	1·371	1·356	1·342	1·330	1·318	1·308	1·298	1·289	1·281	1·273	1·265	1·258	1·252	1·245	1·240	1·234
30	15·43	1·652	1·579	1·524	1·482	1·450	1·424	1·401	1·382	1·365	1·350	1·336	1·324	1·313	1·303	1·233	1·284	1·276	1·268	1·261	1·254	1·247	1·241	1·235	1·229

Prandtl-Schlichting's formula

$$R_f = C_f \frac{1}{2}\rho S V^2,\quad C_f = 0.455(\log_{10} R_n)^{-2.58}$$

ITTC 1957 model ship correlation line

$$R_f = C_f \frac{1}{2}\rho S V^2,\quad C_f = 0.075(\log_{10} R_n - 2)^{-2}$$

ii) Estimation of wetted surface area

Wetted surface area below the load water line, an integration of the girth length along the projected ship's length, is applied. No correction for obliquity of the waterline is made. Approximate formulas for the wetted surface are as follows, and those of the appendages, to be obtained by separate calculation, are added to the wetted surface area of the hull.

Denny's formula $\quad S = (1.7^* d + C_B B)L = 1.7^* dL + \nabla/d$

* It is recommended to adopt following values instead of 1.7 for the ships of larger full hull form with normal bow:

Full load condition	1.81
Half load condition	1.76
Ballast condition	1.75

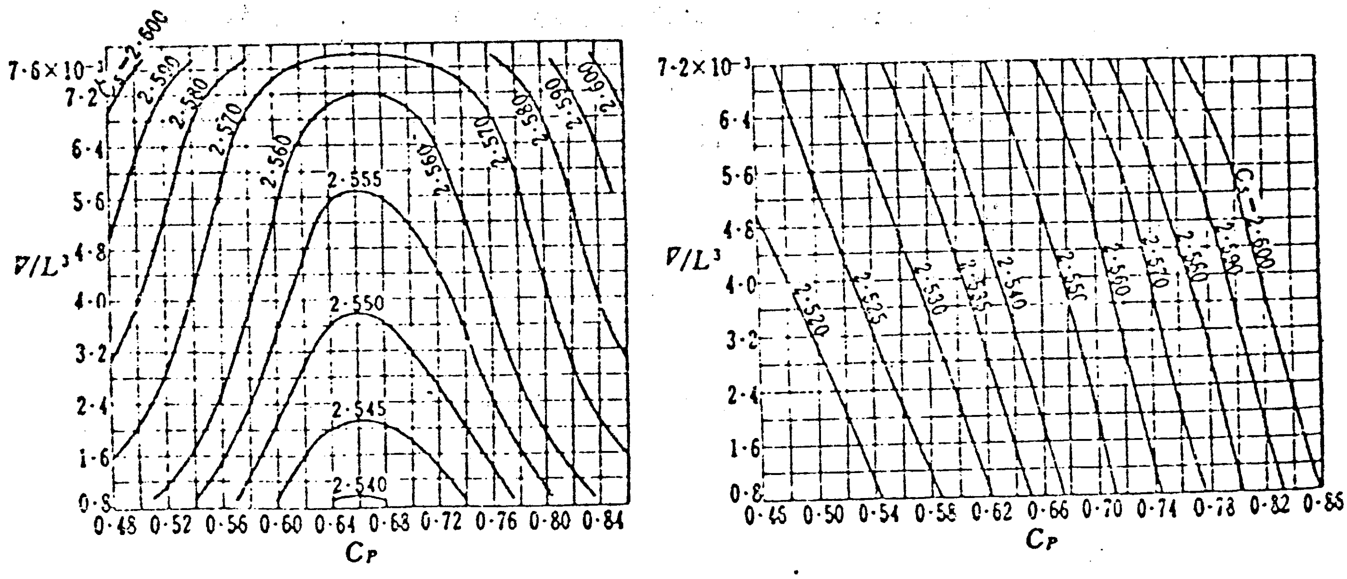
Olsen's formula $\quad S = LB\{1.22(d/B) + 0.46\}(C_B + 0.765)$

Froude's formula $\quad S = \nabla^{2/3}\{3.4 + (L/2\cdot\nabla^{1/3})\}$

Taylor Basin formula $\quad S = C_s\sqrt{\nabla L}$,

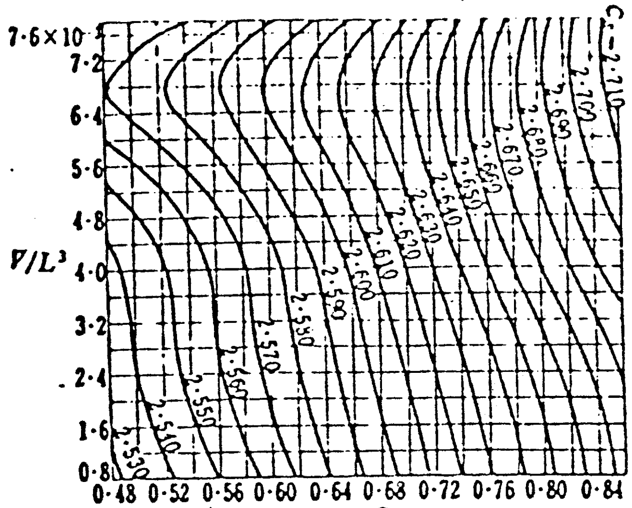
C_s ; refer to Fig. 46 (a), (b), (c)

In addition to the above, there are proposal charts for calculating wetted surface area such as SR 45, Series 60 etc.



(a) C_s ($B/d = 2.25$) (b) C_s ($B/d = 3.00$)

Fig. 46 Wetted surface area coefficient



(c) C_s $(B/d=3\cdot75)$

Fig. 46 Wetted surface area coefficient

(b) Estimation of residual resistance

i) Yamagata's charts

After careful analysis of the results of many model tests, Dr. Yamagata proposed the following formulas and charts shown in Figs. 47, 48 and 49. In the case of using these charts, careful attention shall be paid to the fact that these charts are apt to give rather bigger resistances than read ones for large vessels because Froude's formula is applied to the calculation of frictional resistance.

$$R_R = r_R \frac{1}{2} \rho \nabla^{2/3} V^2,$$

$$r_R = k_r \{r_{R0} + (\Delta r_R)_{B/L} + (\Delta r_R)_{B/d}\}$$

where, k_r = 1 for single screw ship and 1.10 - 1.20 for twin screw ship

r_{R0} = Residual resistance coefficient for standard hull form

$(\Delta r_R)_{B/L}$ and $(\Delta r_R)_{B/d}$ are the correction amounts to the residual resistance coefficient when B/L and B/d are differnet from those of standard hull form.

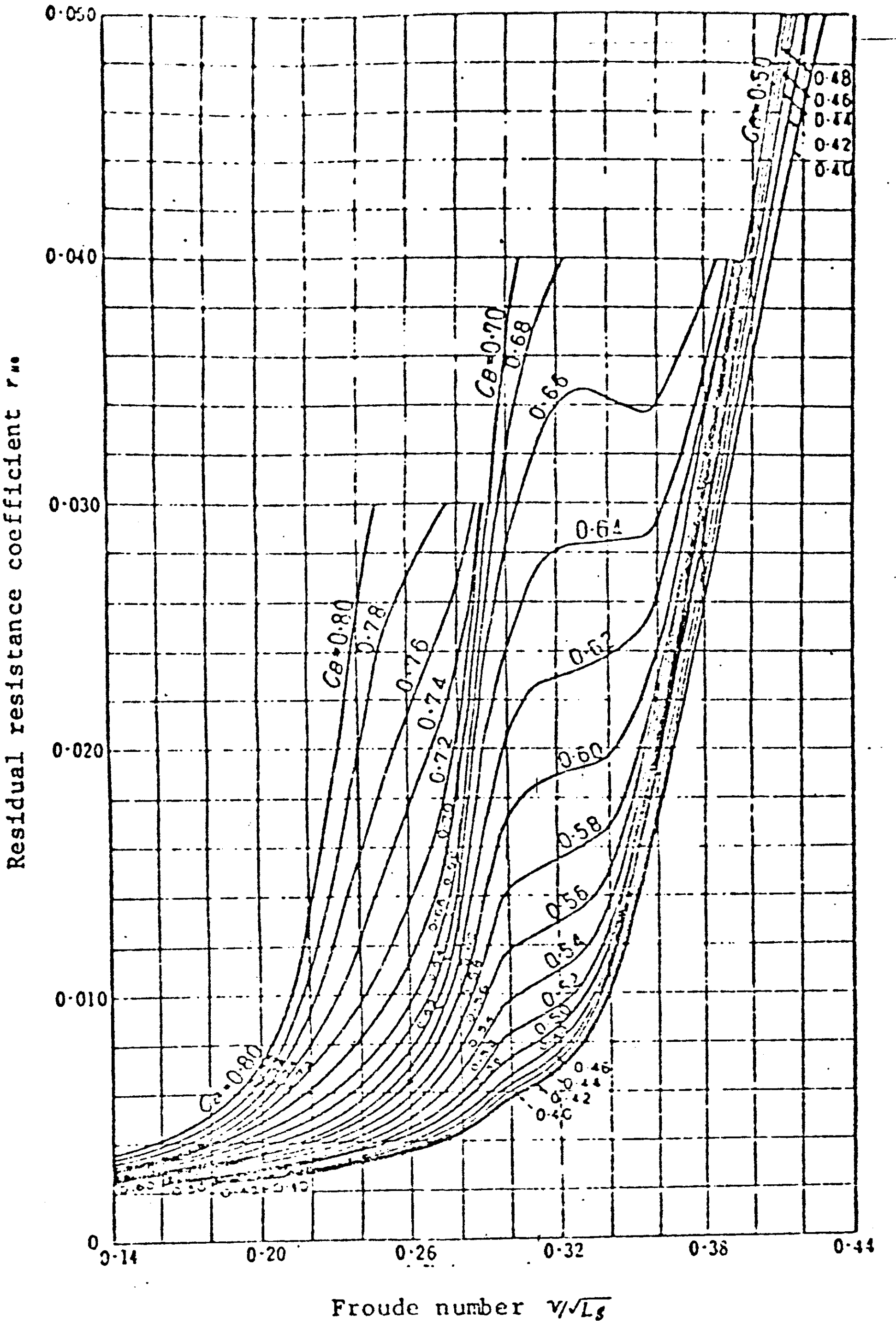


Fig. 47 Residual resistance coefficient for standard hull form (Yamagata chart)

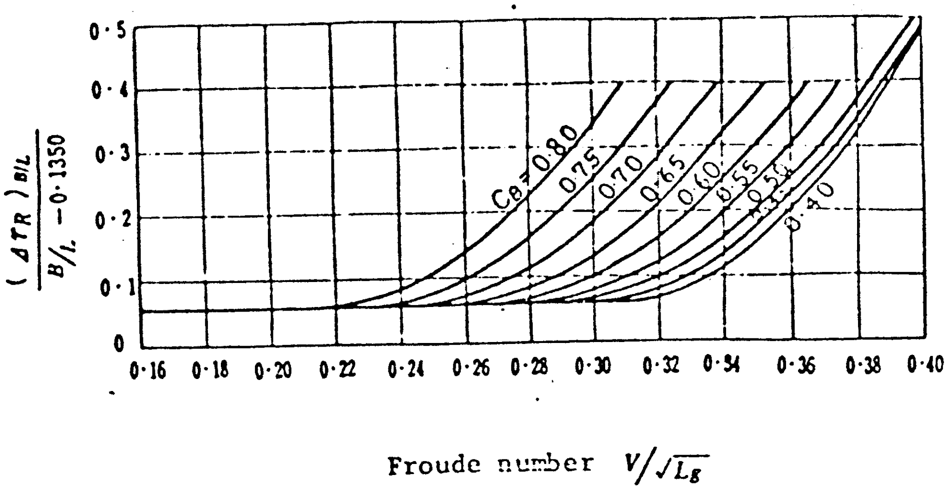


Fig. 48 Correction due to different B/L (Yamagata chart)

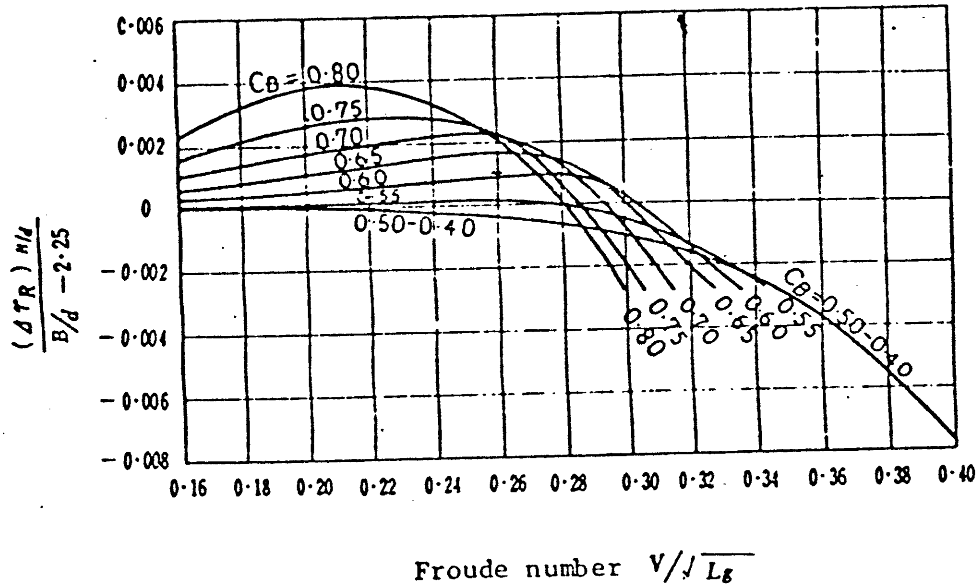


Fig. 49 Correction due to different B/d (Yamagata chart)

ii) Taylor Basin charts

These are the results of reanalysis based on the Schoenherr's frictional resistance formula of results of a series of model tests conducted by D.W. Taylor

$$R_t = C_t \frac{1}{2} \rho S V^2, \qquad C_t = f\left(\frac{\nabla}{L^3},\ C_p,\ \frac{B}{d},\ \frac{V}{\sqrt{Lg}}\right), \qquad L = \text{Water line length}.$$

and the charts are given against C_p varying from 0.48 to 0.86 in the case of B/d of 2.25, 3.00 and 3.75. The readings from these charts are tabulated in Table 50 (a), (b) and (c). It is recommended to use this method paying attention to the facts that the C_v of the model ships was rather smaller than that of the normal merchant vessels and constant l_{cb} (at the center of water line length) was applied.

Table 50 (a) Residual Resistance Coefficient C_R (by Taylor Basin Chart)

$B/d = 2{\cdot}25$

C_P	∇/L^3	$V/\sqrt{Lg}$ 0·16	0·18	0·20	0·22	0·24	0·26	0·28	0·30	0·32	0·34	0·36
	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
0·50	1·0	0·20	0·20	0·20	0·20	0·20	0·20	0·20	0·24	0·40	0·67	1·01
	2·0	0·26	0·27	0·28	0·29	0·32	0·37	0·40	0·43	0·70	1·25	2·00
	3·0	0·31	0·31	0·33	0·36	0·43	0·50	0·54	0·61	0·98	1·76	2·92
	4·0	0·35	0·36	0·37	0·42	0·52	0·59	0·63	0·77	1·23	2·30	
	5·0	0·41	0·42	0·44	0·49	0·60	0·70	0·75	0·93	1·51	2·90	
	6·0	0·46	0·47	0·49	0·55	0·68	0·83	0·87				
	7·0	0·52	0·53	0·56	0·65	0·80	0·99	1·05				
0·55	1·0	0·22	0·22	0·22	0·22	0·22	0·23	0·25	0·27	0·32	0·49	0·74
	2·0	0·27	0·27	0·28	0·28	0·30	0·38	0·46	0·53	0·65	1·00	1·57
	3·0	0·32	0·32	0·33	0·35	0·40	0·49	0·62	0·78	1·00	1·42	2·25
	4·0	0·38	0·38	0·38	0·42	0·48	0·60	0·77	0·99	1·25	1·84	2·94
	5·0	0·44	0·44	0·44	0·47	0·55	0·68	0·87	1·11	1·46	2·12	
	6·0	0·49	0·50	0·50	0·54	0·63	0·77	0·97	1·17	1·51	2·32	
	7·0	0·55	0·55	0·56	0·62	0·72	0·89	1·10				
0·60	1·0	0·23	0·23	0·23	0·23	0·25	0·28	0·37	0·45	0·46	0·52	0·68
	2·0	0·28	0·28	0·28	0·30	0·37	0·50	0·74	1·02	1·03	1·12	1·48
	3·0	0·34	0·34	0·34	0·38	0·47	0·66	1·03	1·45	1·55	1·65	2·18
	4·0	0·38	0·38	0·40	0·46	0·56	0·80	1·32	1·85	2·00	2·15	2·85
	5·0	0·45	0·45	0·47	0·53	0·64	0·90	1·49	2·18	2·41	2·61	3·47
	6·0	0·50	0·50	0·52	0·60	0·71	1·01	1·66				
	7·0	0·55	0·56	0·59	0·68	0·80	1·10	1·82				
0·65	1·0	0·23	0·23	0·23	0·23	0·28	0·40	0·59	0·76	0·78	0·78	0·86
	2·0	0·28	0·28	0·29	0·34	0·47	0·68	1·05	1·62	1·67	1·60	1·81
	3·0	0·34	0·34	0·35	0·45	0·63	0·90	1·48	2·31	2·47	2·41	2·67
	4·0	0·40	0·40	0·42	0·54	0·73	1·04	1·85	2·95	3·23	3·20	3·52
	5·0	0·46	0·47	0·49	0·63	0·82	1·18	2·22	3·55	4·02	4·07	4·42
	6·0	0·52	0·52	0·57	0·72	0·90	1·29	2·46				
	7·0	0·57	0·57	0·64	0·80	0·97	1·38	2·67				
0·70	1·0	0·23	0·23	0·23	0·28	0·40	0·59	0·81	1·13	1·23	1·16	1·14
	2·0	0·30	0·30	0·32	0·47	0·71	0·97	1·46	2·31	2·47	2·36	2·30
	3·0	0·36	0·36	0·42	0·60	0·87	1·22	1·97	3·26	3·77	3·60	3·66
	4·0	0·40	0·42	0·51	0·70	1·01	1·43	2·48	4·28	5·02	4·89	4·90
	5·0	0·46	0·49	0·59	0·81	1·10	1·56	2·89				
	6·0	0·52	0·56	0·68	0·90	1·20	1·68	3·21				
	7·0	0·59	0·64	0·77	0·96	1·28	1·82	3·51				
0·75	1·0	0·24	0·26	0·32	0·47	0·70	0·90	1·12	1·61	1·66	1·55	1·50
	2·0	0·31	0·36	0·47	0·74	1·14	1·42	1·86	2·98	3·29	3·23	3·06
	3·0	0·37	0·44	0·61	0·96	1·38	1·82	2·41	4·29	5·12	5·16	4·82
	4·0	0·44	0·52	0·73	1·10	1·52	2·02	3·10				
	5·0	0·50	0·59	0·83	1·24	1·64	2·16					
	6·0	0·57	0·67	0·91	1·34	1·76	2·31					
	7·0	0·62	0·73	0·98	1·41							
0·80	1·0	0·32	0·45	0·62	0·91	1·30	1·45	1·70	2·21	2·17	2·06	1·96
	2·0	0·38	0·53	0·80	1·29	1·94	2·32	2·63	3·76	4·36	4·40	4·21
	3·0	0·43	0·60	0·97	1·58	2·29	3·01		5·39	6·63	6·85	6·49
	4·0	0·49	0·68	1·12	1·80	2·55	3·42					
	5·0	0·56	0·76	1·22	1·95	2·75						
	6·0	0·63	0·83	1·31	2·10							
	7·0	0·69	0·90	1·40	2·24							
0·85	1·0	0·51	0·91	1·38	1·89	2·36	2·26	2·79				
	2·0	0·60	0·99	1·54	2·26	3·20						
	3·0	0·66	1·06	1·70	2·57							
	4·0	0·73	1·15	1·85	2·77							
	5·0	0·81	1·22	1·98	2·98							
	6·0	0·93	1·33	2·10	3·17							
	7·0	1·14	1·56	2·37	3·48							

Table 50 (b) Residual Resistance Coefficient C_R (by Taylor Basin Chart)

$B/d = 3{\cdot}00$

C_p	∇/L^3	$V/\sqrt{Lg}$										
		0·16	0·18	0·20	0·22	0·24	0·26	0·28	0·30	0·32	0·34	0·36
	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
0·50	1·0	0·25	0·25	0·25	0·26	0·33	0·38	0·37	0·43	0·60	0·85	1·14
	2·0	0·30	0·30	0·30	0·37	0·52	0·61	0·60	0·63	0·90	1·36	2·03
	3·0	0·35	0·35	0·36	0·44	0·63	0·74	0·77	0·84	1·17	1·91	3·04
	4·0	0·43	0·43	0·43	0·51	0·73	0·86	0·88	1·02	1·49	2·54	
	5·0	0·48	0·48	0·50	0·61	0·82	0·96	0·97	1·19	1·86		
	6·0	0·54	0·54	0·59	0·73	0·96	1·11	1·10	1·39	2·20		
	7·0	0·61	0·62	0·67	0·88	1·24	1·41	1·38				
0·55	1·0	0·28	0·28	0·29	0·31	0·42	0·51	0·54	0·58	0·63	0·86	0·97
	2·0	0·34	0·34	0·34	0·38	0·53	0·67	0·72	0·66	0·90	1·20	1·73
	3·0	0·40	0·40	0·40	0·47	0·62	0·75	0·83	0·94	1·16	1·61	2·51
	4·0	0·44	0·44	0·45	0·53	0·64	0·78	0·92	1·07	1·35	1·95	3·23
	5·0	0·50	0·50	0·52	0·60	0·72	0·82	0·97	1·21	1·60	2·31	
	6·0	0·57	0·57	0·60	0·70	0·82	0·91	1·04	1·35	1·86		
	7·0	0·63	0·63	0·69	0·85	1·01	1·10	1·19				
0·60	1·0	0·30	0·30	0·30	0·35	0·45	0·56	0·64	0·70	0·74	0·80	0·91
	2·0	0·37	0·38	0·38	0·44	0·58	0·75	0·97	1·17	1·29	1·46	1·75
	3·0	0·42	0·42	0·43	0·50	0·65	0·87	1·20	1·56	1·74	2·01	2·58
	4·0	0·47	0·47	0·49	0·57	0·71	0·93	1·30	1·89	2·18	2·51	3·22
	5·0	0·54	0·54	0·57	0·63	0·77	0·99	1·42	2·20	2·63	3·01	
	6·0	0·60	0·61	0·64	0·73	0·85	1·04	1·63	2·45			
	7·0	0·65	0·66	0·74	0·89	1·01	1·20	1·80				
0·65	1·0	0·33	0·33	0·34	0·36	0·41	0·55	0·74	0·88	0·95	0·97	0·98
	2·0	0·38	0·38	0·39	0·49	0·63	0·85	1·25	1·75	1·93	2·00	2·15
	3·0	0·44	0·44	0·48	0·62	0·77	1·07	1·62	2·43	2·79	2·88	3·19
	4·0	0·52	0·52	0·56	0·70	0·86	1·19	1·93	3·02	3·55	3·73	4·12
	5·0	0·56	0·57	0·63	0·80	0·92	1·26	2·15	3·52	4·28	4·53	
	6·0	0·62	0·63	0·72	0·90	1·00	1·33	2·38				
	7·0	0·72	0·73	0·82	0·98	1·08	1·46	2·65				
0·70	1·0											
	2·0	0·42	0·42	0·48	0·64	0·82	1·08	1·58	2·41	2·70	2·70	2·72
	3·0	0·48	0·49	0·58	0·81	1·10	1·40	2·15	3·40	3·97	4·10	4·20
	4·0	0·55	0·56	0·68	0·95	1·24	1·60	2·57	4·22	5·15	5·47	5·64
	5·0	0·61	0·63	0·78	1·04	1·33	1·73	2·89				
	6·0	0·68	0·72	0·87	1·10	1·40	1·85	3·13				
	7·0	0·75	0·82	0·96	1·16	1·52	1·98	3·42				
0·75	1·0											
	2·0	0·45	0·47	0·62	0·90	1·28	1·57	1·97	3·09	3·63	3·56	3·45
	3·0	0·52	0·56	0·76	1·11	1·69	2·06	2·65	4·35	5·38	5·46	
	4·0	0·59	0·65	0·86	1·31	1·92	2·46	3·22				
	5·0	0·65	0·74	0·97	1·38	2·05	2·73					
	6·0	0·72	0·82	1·06	1·45	2·15	2·85					
	7·0	0·80	0·92	1·12	1·50	2·26	2·97					
0·80	1·0											
	2·0	0·47	0·65	0·93	1·39	2·04	2·61	3·03	4·15	4·96	4·90	4·63
	3·0	0·65	0·86	1·14	1·65	2·59	3·48					
	4·0	0·72	0·93	1·25	1·77	2·81						
	5·0	0·77	0·99	1·30	1·85	2·92						
	6·0	0·82	1·03	1·33	1·91	3·05						
	7·0	0·87	1·07	1·38	1·98	3·14						

Table 50 (c) Residual Resistance Coefficient C_r (by Taylor Basin Chart)

$B/d = 3{\cdot}75$

C_r	∇/L^3	$V/\sqrt{Lg}$										
		0·16	0·18	0·20	0·22	0·24	0·26	0·28	0·30	0·32	0·34	0·36
	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
0·50	1·0	0·33	0·33	0·33	0·36	0·43	0·48	0·46	0·45	0·58	0·81	1·13
	2·0	0·38	0·38	0·40	0·45	0·55	0·63	0·64	0·65	0·86	1·35	2·09
	3·0	0·46	0·46	0·48	0·55	0·67	0·78	0·83	0·90	1·21	1·94	3·11
	4·0	0·52	0·53	0·56	0·68	0·83	0·96	1·02	1·16	1·61	2·64	4·34
	5·0	0·58	0·58	0·61	0·74	0·96	1·14	1·19	1·43	2·10	3·39	
	6·0	0·66	0·67	0·71	0·84	1·12	1·33	1·39	1·66	2·54		
	7·0	0·73	0·74	0·78	0·94	1·27	1·53	1·60				
0·55	1·0	0·38	0·38	0·38	0·38	0·42	0·46	0·45	0·46	0·55	0·61	0·77
	2·0	0·44	0·45	0·45	0·47	0·53	0·63	0·69	0·64	0·88	1·11	1·68
	3·0	0·50	0·50	0·52	0·58	0·66	0·76	0·86	1·03	1·17	1·65	2·48
	4·0	0·55	0·56	0·59	0·66	0·79	0·87	1·04	1·26	1·51	2·16	3·28
	5·0	0·64	0·63	0·68	0·75	0·86	0·98	1·19	1·50	1·87	2·70	
	6·0	0·72	0·72	0·75	0·83	0·97	1·08	1·30	1·63	2·14		
	7·0	0·78	0·79	0·83	0·94	1·12	1·18	1·36				
0·60	1·0	0·42	0·42	0·42	0·42	0·45	0·49	0·56	0·61	0·70	0·76	0·83
	2·0	0·48	0·49	0·50	0·51	0·56	0·71	0·91	1·12	1·30	1·49	1·83
	3·0	0·54	0·55	0·56	0·59	0·66	0·87	1·15	1·50	1·79	2·10	2·61
	4·0	0·61	0·61	0·63	0·70	0·77	0·95	1·38	1·84	2·25	2·70	3·41
	5·0	0·68	0·70	0·72	0·80	0·87	1·07	1·58	2·20	2·69	3·20	4·03
	6·0	0·75	0·76	0·80	0·90	0·96	1·21	1·78	2·51			
	7·0	0·82	0·84	0·90	1·00	1·10	1·34	1·88				
0·65	1·0	0·44	0·45	0·45	0·48	0·52	0·58	0·71	0·88	0·99	1·00	1·05
	2·0	0·52	0·52	0·53	0·59	0·65	0·82	1·23	1·72	1·95	2·07	2·26
	3·0	0·58	0·58	0·60	0·69	0·79	1·06	1·64	2·38	2·77	3·05	3·40
	4·0	0·64	0·65	0·70	0·81	0·90	1·23	1·96	2·87	3·45	3·81	4·28
	5·0	0·72	0·72	0·79	0·91	1·03	1·40	2·24	3·45	4·15	4·60	
	6·0	0·78	0·80	0·87	1·00	1·16	1·55	2·49				
	7·0	0·84	0·87	0·97	1·10	1·26	1·68	2·88				
0·70	1·0											
	2·0	0·58	0·58	0·61	0·73	0·91	1·15	1·67	2·41	2·70	2·78	2·85
	3·0	0·64	0·64	0·70	0·88	1·12	1·43	2·21	3·37	3·98	4·29	4·40
	4·0	0·71	0·71	0·79	0·98	1·26	1·65	2·62	4·05	4·97	5·36	5·69
	5·0	0·77	0·77	0·87	1·08	1·36	1·83	2·98				
	6·0	0·83	0·83	0·96	1·20	1·48	2·00	3·21				
	7·0	0·90	0·91	1·05	1·30	1·58	2·08	3·39				
0·75	1·0											
	2·0	0·63	0·65	0·76	1·02	1·36	1·71	2·19	3·12	3·61	3·63	3·61
	3·0	0·68	0·71	0·83	1·14	1·60	2·10	2·81	4·32	5·28	5·63	
	4·0	0·75	0·79	0·92	1·26	1·76	2·34	3·41				
	5·0	0·82	0·86	1·00	1·36	1·89	2·51					
	6·0	0·88	0·89	1·08	1·46	1·99	2·62					
	7·0	0·94	0·96	1·16	2·06	2·09	2·72					
0·80	1·0											
	2·0	0·66	0·76	1·04	1·54	2·17	2·61	3·08	3·99	4·68	4·80	4·79
	3·0	0·73	0·84	1·14	1·67	2·51	3·22					
	4·0	0·80	0·91	1·23	1·77	2·69						
	5·0	0·86	0·97	1·28	1·87	2·77						
	6·0	0·92	1·05	1·37	1·97	2·90						
	7·0	0·98	1·13	1·46	2·10	3·10						
0·85	1·0											
	2·0	0·78	1·01	1·58	2·41	3·29						
	3·0	0·82	1·07	1·67	2·55							
	4·0	0·88	1·13	1·77	2·68							
	5·0	0·98	1·24	1·90	2·81							
	6·0	1·10	1·39	2·16	3·08							
	7·0	1·40	1·74	2·50								

iii) SR 45 charts

SR 45 charts are the results of the analysis of a series of model test data for high speed cargo boats conducted by SR 45 based on ITTC 1957 model ship correlation line.

$$R_R = r_R \frac{1}{2} \rho \nabla^{2/3} V^2, \quad r_R = r_{R0} k_1 k_2, \quad r_{R0} = f\left(\frac{V}{\sqrt{g L_{DWL}}} \cdot \frac{B}{d_{FWL}} \cdot \frac{L}{B}\right)$$

where r_{R0} is residual resistance coefficient for hull form of C_B = 0.625 and l_{cb} = 1.3%, k_1 and k_2 are the correction factors for C_B and l_{cb} respectively when they are different from the standard figures for the hull form of L/B = 7.00, B/d_{FWL} = 2.40, L_{DWL} is the water line length at full load draught, and d_{FWL} is the full load draft. The readings of charts of r_{R0}, k_1 and k_2 on the full load condition, half load condition (70 percent of full load displacement with 1 percent trim by the stern) and light load condition (45 percent of full load displacement with 2% trim by the stern) are shown in Table 51 (a), (b), (c), Table 52 (a), (b), (c) and Table 53 (a), (b), (c). In relation to the charts of SR 45, the Ship Research Institute of Japanese Ministry of Transport (SRI) presented the charts of r_{R0} for the hull form of C_B=0·575 and l_{cb}=1·9% using the similar method. The readings of these charts are listed in Table 54, 55 and 56.

iv) SRI charts for large full vessel with normal bow

SRI charts are the results of the analysis of a series of model test data for large tankers conducted by SRI based on Schoenherr's frictional resistance formula.

$$R_R = r_R' \rho \nabla^{2/3}, \qquad r_R' = f\left(\frac{L}{B} \cdot C_B \cdot \frac{B}{d_{FWL}} \cdot \frac{V}{\sqrt{g L_{DWL}}}\right)$$

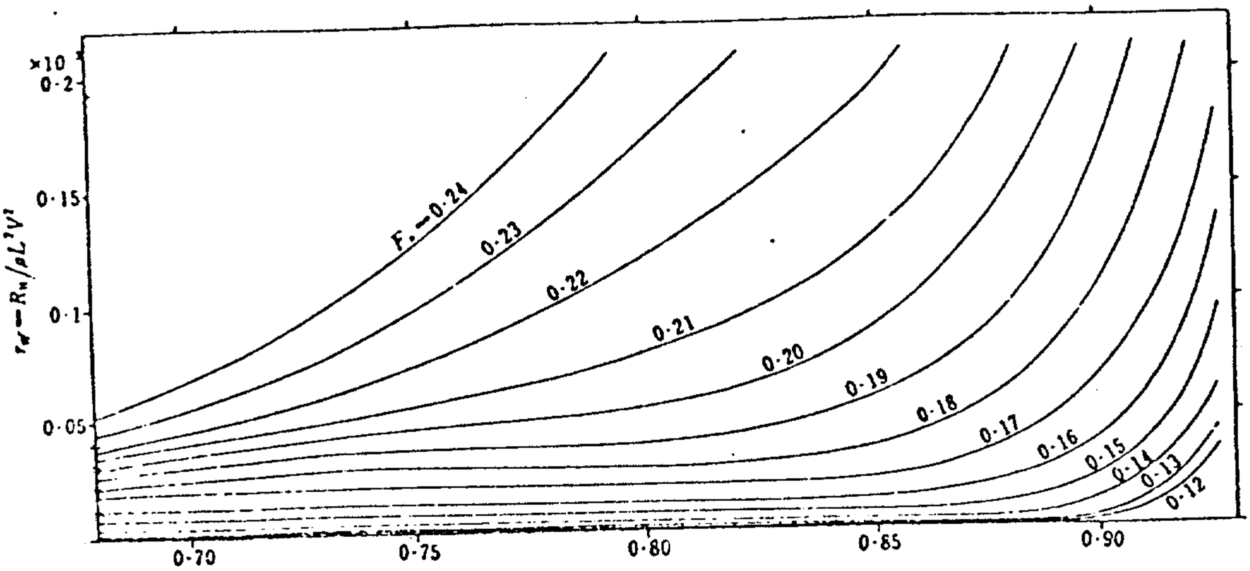
And the charts for the hull forms of B/d = 2.46 and 2.76 are presented on the full load condition, half load condition (65% of full load displacement with 1% trim by the stern) and ballast condition (44% of full load displacement with 2% trim by the stern). The readings of these charts are shown in Table 57, 58 and 59.

v) Others

In addition to the above, there are Todd charts and Lap charts which are applicable to the single screw merchant vessel hull form. Todd's charts are results of analysis and mathematical fairing by usage of electronic computer of the model test data about 45 ships based on Schoenherr's frictional resistance formula and are given against range of C_B = 0.60 - 0.80, L/B = 5.5 - 8.5, B/d = 2.5 - 3.5. Lap charts are the results of analysis of the various model test data using Schoenherr's frictional resistance formula and the charts for each l_{cb} of the hull form of B/d = 2.4 are made taking the speed length ratio as a base and C_P (0·60~0·80) as a parameter.

(c) Estimation of wave-making resistance

Estimation chart of wave-making resistance for large vessel (with normal bow) is shown in Fig. 50. This is the results of the re-analysis of the data of SRI tanker series, L/B, C_B and l_{cb} series of SR 41 and SR 61 and Todd's series 60 based on Schoenherr's frictional resistance formula.



C_{PF} Prismatic coefficient of forward half of the hull

Fig. 50 Wave-making resistance coefficient for ships with normal bow

Table 51 (a) Residual Resistance Coefficient r_{R0} (at Full Load Condition) (by SR 45 Charts)

$\frac{V}{\sqrt{gL_{DWL}}}$	$\frac{B}{d_{Full}}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$
0·20	2·0	5·52	4·93	4·42	3·92
	2·2	5·25	4·59	4·21	4·03
	2·4	5·13	4·52	4·17	4·02
	2·6	5·15	4·71	4·31	3·90
	2·8	5·32	5·16	4·62	3·66
0·22	2·0	5·82	4·81	4·14	4·17
	2·2	5·77	5·07	4·44	4·22
	2·4	5·75	5·25	4·62	4·21
	2·6	5·77	5·35	4·69	4·15
	2·8	5·84	5·37	4·65	4·04
0·24	2·0	6·23	4·92	4·28	4·44
	2·2	6·05	5·17	4·58	4·42
	2·4	5·99	5·37	4·80	4·41
	2·6	6·04	5·52	4·93	4·40
	2·8	6·19	5·63	4·98	4·40
0·25	2·0	7·00	6·02	5·75	5·11
	2·2	7·02	5·98	5·70	5·12
	2·4	6·95	6·01	5·75	5·10
	2·6	6·80	6·12	5·89	5·04
	2·8	6·58	6·32	6·13	4·95
0·26	2·0	9·50	8·41	7·81	6·66
	2·2	9·53	8·29	7·74	6·81
	2·4	9·28	8·15	7·66	6·80
	2·6	3·76	7·99	7·64	6·64
	2·8	7·97	7·81	7·61	6·32
0·27	2·0	14·51	12·56	11·81	10·64
	2·2	13·84	12·27	11·61	10·26
	2·4	13·04	11·85	11·32	9·85
	2·6	12·11	11·31	10·95	9·42
	2·8	11·04	10·66	10·50	8·97
0·28	2·0	20·04	17·18	16·16	15·43
	2·2	18·53	16·71	15·85	14·39
	2·4	17·30	16·04	15·28	13·47
	2·6	16·36	15·18	14·46	12·66
	2·8	15·71	14·12	13·38	11·97
0·29	2·0	24·21	21·46	19·46	18·59
	2·2	22·12	20·52	18·85	17·47
	2·4	20·59	19·50	17·99	16·41
	2·6	19·91	18·39	16·88	15·42
	2·8	19·19	17·19	15·51	14·50
0·30	2·0	27·23	24·76	22·35	21·52
	2·2	24·86	23·31	21·14	19·85
	2·4	23·20	22·02	19·95	18·48
	2·6	22·24	20·90	18·79	17·40
	2·8	21·99	19·94	17·65	16·61

Table 51 (b) Correction Factor k_1 (at Full Load Condition) for C_B (at Full Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$ \ C_B	0·55	0·56	0·57	0·58	0·59	0·60	0·61	0·62	0·63	0·64	0·65
0·20	0·98	0·99	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·02	1·04
0·22	1·05	1·03	1·01	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
0·24	1·12	1·11	1·09	1·08	1·06	1·05	1·02	1·01	1·00	1·01	1·05
0·25	1·05	1·04	1·02	1·01	0·99	0·98	0·98	0·99	1·01	1·04	1·09
0·26	0·85	0·84	0·83	0·83	0·83	0·84	0·89	0·96	1·02	1·07	1·13
0·27	0·65	0·65	0·66	0·68	0·70	0·75	0·84	0·95	1·04	1·12	1·19
0·28	0·54	0·56	0·59	0·63	0·68	0·74	0·84	0·95	1·05	1·11	1·18
0·29	0·50	0·53	0·56	0·61	0·67	0·74	0·84	0·95	1·05	1·13	1·22
0·30	0·48	0·51	0·55	0·60	0·65	0·73	0·83	0·94	1·03	1·15	1·26

Table 51 (c) Correction Factor k_2 (at Full Load Condition) for l_{cb} (at Full Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$ \ l_{cb} %	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0	2·2	2·4	2·6
0·20	1·12	1·07	1·03	1·01	0·99	0·98	0·96	0·99	1·01	1·04	—
0·22	1·06	1·04	1·02	1·01	0·99	0·98	0·98	0·99	1·04	1·10	—
0·24	1·07	1·05	1·03	1·01	0·99	0·98	0·98	1·00	1·04	1·11	—
0·25	1·11	1·06	1·03	1·01	0·99	0·98	0·98	0·99	1·03	1·09	—
0·26	1·18	1·12	1·05	1·02	0·98	0·95	0·95	0·96	0·98	1·01	1·08
0·27	1·16	1·11	1·06	1·02	0·97	0·94	0·92	0·93	0·95	0·99	1·05
0·28	1·09	1·06	1·04	1·01	0·98	0·96	0·94	0·94	0·95	0·98	1·04
0·29	1·07	1·05	1·03	1·01	0·99	0·97	0·97	0·96	0·97	0·96	1·02
0·30	1·06	1·04	1·02	1·00	0·99	0·98	0·98	0·98	0·98	0·98	0·99

Table 52 (a) Residual Resistance Coefficient r_{R0} (at Half Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$	$B/d_{F.ll}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0	$V/\sqrt{gL_{DWL}}$	$B/d_{F.ll}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		$\times10^{-3}$	$\times10^{-3}$	$\times10^{-3}$	$\times10^{-3}$			$\times10^{-3}$	$\times10^{-3}$	$\times10^{-3}$	$\times10^{-3}$
0·20	2·0	5·67	4·47	3·60	4·30	0·28	2·0	17·98	16·76	15·15	14·24
	2·2	5·42	5·05	4·28	4·36		2·2	16·43	15·36	13·77	12·76
	2·4	5·38	5·30	4·52	4·28		2·4	15·30	14·20	12·62	11·65
	2·6	5·54	5·22	4·31	4·06		2·6	14·59	13·27	11·69	10·92
	2·8	5·91	4·80	3·65	3·70		2·8	14·31	12·58	10·97	10·57
0·22	2·0	6·16	4·85	4·14	4·81	0·30	2·0	21·49	19·90	18·08	16·74
	2·2	5·58	5·14	4·49	4·42		2·2	20·64	18·55	16·64	15·64
	2·4	5·42	5·30	4·62	4·17		2·4	19·61	17·39	15·47	14·57
	2·6	5·66	5·34	4·55	4·03		2·6	18·40	16·43	14·56	13·52
	2·8	6·32	5·27	4·26	4·09		2·8	17·01	15·66	13·91	12·49
0·24	2·0	6·43	5·25	5·10	5·17	0·32	2·0	22·12	20·20	18·57	16·83
	2·2	6·20	5·39	5·11	4·53		2·2	21·20	19·03	17·43	15·99
	2·4	6·12	5·55	5·19	4·22		2·4	20·36	18·05	16·43	15·10
	2·6	6·18	5·72	5·34	4·23		2·6	19·60	17·27	15·58	14·15
	2·8	6·39	5·90	5·56	4·55		2·8	18·92	16·68	14·89	13·14
0·26	2·0	9·55	7·96	7·41	7·35	0·34	2·0	23·26	20·96	19·01	17·76
	2·2	9·26	8·23	7·68	7·02		2·2	22·66	20·45	18·45	17·03
	2·4	8·99	8·25	7·68	6·72		2·4	22·00	19·83	17·79	16·25
	2·6	8·75	8·01	7·43	6·45		2·6	21·27	19·10	17·03	15·42
	2·8	8·54	7·51	6·92	6·22		2·8	20·47	18·27	16·17	14·55

Table 52 (b) Correction Factor k_1 (at Half Load Condition) for C_B (at Full Load Condition) (by SR 45 Charts)

C_B / $V/\sqrt{gL_{DWL}}$	0·55	0·56	0·57	0·58	0·59	0·60	0·61	0·62	0·63	0·64	0·55
0·20	0·96	0·95	0·95	0·94	0·93	0·93	0·95	0·98	1·01	1·04	1·06
0·22	1·00	1·00	1·00	1·00	1·00	1·00	1·00	0·99	1·00	1·02	1·05
0·24	0·99	0·99	1·00	1·00	1·00	0·99	0·99	0·99	1·01	1·03	1·07
0·26	0·78	0·79	0·81	0·84	0·86	0·89	0·92	0·97	1·03	1·09	1·16
0·28	0·52	0·56	0·60	0·64	0·69	0·76	0·84	0·94	1·04	1·12	1·20
0·30	0·48	0·51	0·55	0·60	0·66	0·73	0·83	0·93	1·06	1·17	1·28
0·32	0·54	0·57	0·60	0·64	0·69	0·76	0·84	0·94	1·05	1·18	1·30

Table 52 (c) Correction Factor k_2 (at Half Load Condition) for l_{cb} (at Full Load Condition) (by SR 45 Charts)

l_{cb} % / $V/\sqrt{gL_{DWL}}$	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0	2·2	2·4	2·6
0·20	1·02	1·01	1·00	1·00	0·99	1·00	1·01	1·02	1·05	1·11	1·19
0·22	1·05	1·03	1·01	1·00	0·99	1·00	1·01	1·03	1·07	1·13	1·23
0·24	1·08	1·05	1·02	1·00	0·99	1·01	1·02	1·06	1·11	1·18	1·27
0·26	1·15	1·07	1·02	1·00	0·99	1·01	1·03	1·07	1·11	1·16	1·22
0·28	1·06	1·03	1·01	1·00	0·99	1·00	1·01	1·02	1·02	1·03	1·03
0·30	1·04	1·02	1·01	1·00	0·99	1·00	1·00	1·00	1·00	1·01	1·01
0·32	1·05	1·03	1·01	1·00	0·99	1·00	1·01	1·01	1·02	1·03	1·04
0·34	1·07	1·04	1·01	1·00	0·99	1·00	1·01	1·02	1·04	1·05	1·07

Table 53 (a) Residual Resistance Coefficient r_{R0} (at Light Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$	$B/d_{F\cdot H}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0	$V/\sqrt{gL_{DWL}}$	$B/d_{F\cdot H}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		×10⁻³	×10⁻³	×10⁻³	×10⁻³			×10⁻³	×10⁻³	×10⁻³	×10⁻³
	2·0	5·62	5·25	5·21	4·99		2·0	16·67	15·81	14·82	12·58
	2·2	6·14	5·62	5·67	5·76		2·2	16·29	14·70	13·82	12·53
0·20	2·4	6·58	6·00	6·00	6·05	0·30	2·4	15·77	14·00	13·18	12·18
	2·6	6·95	6·40	6·21	5·87		2·6	15·09	13·72	12·91	11·55
	2·8	7·25	6·81	6·30	5·21		2·8	14·27	13·85	13·01	10·62
	2·0	6·30	5·70	5·39	5·25		2·0	18·46	16·93	15·54	13·79
	2·2	6·65	5·99	5·76	5·83		2·2	18·16	16·16	14·85	13·75
0·22	2·4	6·92	6·28	6·01	6·01	0·32	2·4	17·70	15·57	14·30	13·39
	2·6	7·12	6·56	6·16	5·80		2·6	17·09	15·18	13·88	12·70
	2·8	7·24	6·84	6·19	5·20		2·8	16·32	14·97	13·59	11·68
	2·0	7·34	5·96	5·03	5·73		2·0	22·24	20·15	17·96	16·41
	2·2	7·45	6·77	5·97	6·16		2·2	21·41	19·46	17·54	16·39
0·24	2·4	7·53	7·19	6·40	6·25	0·34	2·4	20·75	18·85	17·01	15·97
	2·6	7·58	7·23	6·34	6·00		2·6	20·27	18·33	16·38	15·15
	2·8	7·61	6·88	5·78	5·41		2·8	19·95	17·89	15·64	13·93
	2·0	9·39	7·90	6·96	7·69		2·0	31·03	28·19	24·57	21·07
	2·2	9·56	8·81	7·86	7·82		2·2	29·10	26·35	23·37	21·04
0·26	2·4	9·65	9·20	8·21	7·80	0·36	2·4	27·70	24·83	22·10	20·41
	2·6	9·67	9·07	8·02	7·64		2·6	26·83	23·62	20·77	19·17
	2·8	9·61	8·42	7·29	7·34		2·8	26·50	22·73	19·37	17·32
	2·0	13·48	13·23	12·53	11·15						
	2·2	13·73	12·58	11·71	10·86						
0·28	2·4	13·62	12·15	11·20	10·53						
	2·6	13·16	11·93	10·99	10·11						
	2·8	12·35	11·92	11·09	9·61						

Table 53 (b) Correction Factor k_1 (at Light Load Condition) for C_B (at Full Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$ \ C_B	0·55	0·56	0·57	0·58	0·59	0·60	0·61	0·62	0·63	0·64	0·65
0·20	1·07	1·10	1·12	1·11	1·08	1·04	1·01	0·99	1·01	1·06	1·18
0·22	1·00	1·05	1·07	1·08	1·07	1·04	1·01	0·99	1·00	1·03	1·08
0·24	0·96	1·01	1·04	1·05	1·04	1·02	1·01	0·99	1·00	1·03	1·08
0·26	0·82	0·89	0·95	0·98	0·98	0·97	0·97	0·98	1·02	1·07	1·14
0·28	0·68	0·74	0·78	0·83	0·87	0·90	0·94	0·98	1·02	1·08	1·16
0·30	0·65	0·68	0·71	0·75	0·80	0·84	0·90	0·96	1·03	1·11	1·20
0·32	0·73	0·76	0·78	0·81	0·84	0·87	0·92	0·96	1·02	1·09	1·18
0·34	0·88	0·88	0·89	0·90	0·91	0·92	0·95	0·98	1·01	1·07	1·15
0·36	0·91	0·91	0·91	0·91	0·92	0·93	0·95	0·98	1·01	1·05	1·11

Table 53 (c) Correction Factor k_2 (at Light Load Condition) for l_{cb} (at Full Load Condition) (by SR 45 Charts)

$V/\sqrt{gL_{DWL}}$ \ l_{cb} %	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0	2·2	2·4	2·6
0·20	1·09	1·04	1·01	1·00	1·00	1·03	1·08	1·12	1·15	1·18	1·21
0·22	1·06	1·03	1·01	1·00	1·00	1·03	1·08	1·12	1·15	1·18	1·21
0·24	1·09	1·04	1·01	1·00	1·01	1·04	1·10	1·14	1·17	1·19	1·22
0·26	1·10	1·05	1·02	1·00	1·01	1·05	1·10	1·15	1·19	1·22	1·25
0·28	1·08	1·04	1·01	1·00	1·00	1·03	1·07	1·11	1·15	1·19	1·22
0·30	1·04	1·02	1·01	1·00	1·00	1·02	1·05	1·09	1·12	1·15	1·17
0·32	1·06	1·03	1·01	1·00	1·01	1·03	1·06	1·10	1·14	1·16	1·18
0·34	1·08	1·04	1·01	1·00	1·01	1·04	1·09	1·13	1·17	1·20	1·23

Table 54 Residual Resistance Coefficient r_{R0} (at Full Load Condition) (by SRI Charts for High Speed Cargo Ships)

$V/\sqrt{gL_{DWL}}$	B/d_{Full}	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0	$V/\sqrt{gL_{DWL}}$	B/d_{Full}	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		×10⁻³	×10⁻³	×10⁻³	×10⁻³			×10⁻³	×10⁻³	×10⁻³	×10⁻³
0·20	2·0	5·61	3·96	4·37	4·65	0·27	2·0	8·30	8·25	8·62	7·68
	2·2	5·70	4·23	4·44	4·15		2·2	9·02	7·90	7·83	7·08
	2·4	5·76	4·62	4·74	3·94		2·4	9·28	7·82	7·56	6·76
	2·6	5·78	5·12	5·27	4·04		2·6	9·06	8·02	7·82	6·73
	2·8	5·77	5·74	6·03	4·44		2·8	8·38	8·49	8·61	6·98
0·22	2·0	5·51	5·28	5·69	4·86	0·28	2·0	10·33	10·53	10·65	9·48
	2·2	6·16	5·16	5·25	4·54		2·2	11·01	10·07	9·69	8·65
	2·4	6·42	5·24	5·18	4·38		2·4	11·16	9·78	9·20	8·20
	2·6	6·20	5·51	5·49	4·39		2·6	10·77	9·65	9·17	8·12
	2·8	5·80	5·98	6·19	4·57		2·8	9·85	9·67	9·60	8·41
0·24	2·0	5·96	5·72	5·94	5·40	0·29	2·0	12·56	12·38	12·23	10·92
	2·2	6·72	5·78	5·61	5·00		2·2	12·81	11·86	11·42	10·28
	2·4	6·93	5·88	5·56	4·80		2·4	12·76	11·50	10·92	9·82
	2·6	6·74	6·03	5·78	4·79		2·6	12·42	11·30	10·14	9·54
	2·8	6·01	6·22	6·28	4·98		2·8	11·79	11·26	10·87	9·43
0·25	2·0	6·48	6·08	6·21	5·81	0·30	2·0	13·63	13·54	13·56	12·34
	2·2	7·07	6·10	5·87	5·33		2·2	14·17	13·03	12·63	11·64
	2·4	7·28	6·20	5·82	5·10		2·4	14·24	12·70	12·08	11·04
	2·6	7·11	6·38	6·05	5·12		2·6	13·84	12·56	11·91	10·54
	2·8	6·56	6·64	6·60	5·39		2·8	12·16	12·61	12·11	10·13
0·26	2·0	7·31	6·79	6·79	6·51						
	2·2	7·72	6·66	6·46	5·96						
	2·4	7·89	6·72	6·42	5·72						
	2·6	7·80	6·97	6·70	5·75						
	2·8	7·49	7·40	7·34	6·05						

Table 55 Residual Resistance Coefficient r_{R0} (at Half Load Condition) (by SRI Charts for High Speed Cargo Ships)

$\frac{V}{\sqrt{gL_{DWL}}}$	$\frac{B}{d_{Full}}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0	$\frac{V}{\sqrt{gL_{DWL}}}$	$\frac{B}{d_{Full}}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		×10⁻³	×10⁻³	×10⁻³	×10⁻³			×10⁻³	×10⁻³	×10⁻³	×10⁻³
0·20	2·0	4·97	3·93	4·21	4·07	0·28	2·0	9·79	9·43	9·37	8·59
	2·2	5·24	4·49	4·67	4·04		2·2	9·92	9·02	8·60	7·67
	2·4	5·36	4·82	4·94	3·98		2·4	9·84	8·82	8·26	7·16
	2·6	5·34	4·92	5·02	3·89		2·6	9·55	8·83	8·33	7·05
	2·8	5·18	4·79	4·90	3·78		2·8	9·04	9·06	8·82	7·33
0·22	2·0	5·14	4·95	5·18	4·51	0·30	2·0	10·96	11·28	11·11	9·65
	2·2	5·70	5·12	5·06	4·21		2·2	11·22	10·44	9·88	8·73
	2·4	5·94	5·24	5·06	4·08		2·4	11·24	10·05	9·32	8·22
	2·6	5·85	5·32	5·18	4·12		2·6	11·03	10·14	9·44	8·12
	2·8	5·43	5·35	5·42	4·33		2·8	10·59	10·69	10·24	8·43
0·24	2·0	5·87	6·10	6·66	5·26	0·32	2·0	12·11	12·10	11·90	10·07
	2·2	6·44	5·73	5·94	4·79		2·2	12·64	11·48	11·00	9·64
	2·4	6·66	5·62	5·68	4·54		2·4	12·78	11·24	10·60	9·30
	2·6	6·52	5·78	5·87	4·50		2·6	12·19	11·38	10·76	9·07
	2·8	6·03	6·21	6·52	4·67		2·8	11·79	11·91	11·47	8·94
0·26	2·0	7·36	7·10	7·53	6·34	0·33	2·0	13·96	13·50	13·20	11·16
	2·2	7·77	6·86	7·02	5·94		2·2	14·36	12·76	13·20	10·68
	2·4	7·90	6·80	6·82	5·66		2·4	14·38	12·43	11·77	10·29
	2·6	7·76	6·92	6·93	5·51		2·6	13·95	12·53	11·88	10·00
	2·8	7·34	7·21	7·36	5·48		2·8	13·16	13·02	12·47	9·80

Table 56 Residual Resistance Coefficient r_{R0} (at Light Load Condition) (by SRI Charts for High Speed Cargo Ships)

$\frac{V}{\sqrt{gL_{DWL}}}$	$\frac{B}{d_{Full}}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0	$\frac{V}{\sqrt{gL_{DWL}}}$	$\frac{B}{d_{Full}}$	L/B 6·5	L/B 7·0	L/B 7·5	L/B 8·0
		×10⁻³	×10⁻³	×10⁻³	×10⁻³			×10⁻³	×10⁻³	×10⁻³	×10⁻³
0·20	2·0	6·23	5·70	5·73	4·62	0·28	2·0	9·71	9·64	9·43	8·64
	2·2	6·34	5·60	5·90	4·86		2·2	10·30	9·44	8·91	8·28
	2·4	6·46	6·02	6·15	5·04		2·4	10·42	9·38	8·74	8·06
	2·6	6·58	6·37	6·46	5·15		2·6	10·08	9·48	8·92	7·98
	2·8	6·75	6·82	6·88	5·20		2·8	9·28	9·72	9·46	8·05
0·22	2·0	7·02	6·36	6·57	5·75	0·30	2·0	11·29	10·75	10·11	9·34
	2·2	7·02	6·32	6·45	5·51		2·2	11·45	10·50	9·73	9·12
	2·4	7·02	6·46	6·54	5·38		2·4	11·40	10·44	9·64	8·96
	2·6	7·03	6·78	6·84	5·35		2·6	11·13	10·57	9·83	8·88
	2·8	7·05	7·27	7·36	5·43		2·8	10·65	10·88	10·20	8·86
0·24	2·0	7·88	7·16	7·25	6·75	0·32	2·0	13·74	12·43	11·32	10·77
	2·2	7·93	7·12	7·06	6·36		2·2	13·63	12·41	11·36	10·75
	2·4	7·88	7·20	7·08	6·10		2·4	13·38	12·36	11·34	10·60
	2·6	7·72	7·41	7·30	5·97		2·6	13·04	12·29	11·27	10·37
	2·8	7·45	7·74	7·72	5·98		2·8	12·56	12·19	11·15	9·75
0·26	2·0	8·78	8·24	8·23	7·68	0·34	2·0	18·59	17·91	16·16	14·17
	2·2	9·16	8·21	7·99	7·42		2·2	18·71	17·06	15·29	14·22
	2·4	9·18	8·24	7·94	7·20		2·4	18·30	16·40	14·66	13·90
	2·6	8·83	8·32	8·08	7·03		2·6	17·35	15·93	14·27	13·22
	2·8	8·12	8·45	8·41	6·90		2·8	15·87	15·64	14·13	12·17

Table 57 Residual Resistance Coefficient

$r_R' = \frac{R_R}{\rho \nabla^{2/3} V^2}$ (at Full Load Condition)

(by SRI Charts for Large Full Ships)

$\frac{V}{\sqrt{g L_{DWL}}}$	L/B \ C_B	$B/d_{Full} = 2{\cdot}46$				$B/d_{Full} = 2{\cdot}76$				L/B / C_B	$\frac{V}{\sqrt{g L_{DWL}}}$
		6·2	6·6	7·0	7·4	6·2	6·6	7·0	7·4		
		$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$		
0·14	0·78	3·07	2·71	2·52	2·44	3·07	2·77	2·63	2·57	0·78	0·14
	0·80	3·61	3·20	2·90	2·79	3·71	3·36	3·20	3·17	0·80	
	0·82	3·93	3·52	3·23	3·02	4·11	3·75	3·60	3·59	0·82	
	0·84	4·75	4·40	4·08	3·95	4·70	4·52	4·45	4·44	0·84	
0·16	0·78	3·15	2·82	2·59	2·52	3·20	2·83	2·73	2·69	0·78	0·16
	0·80	3·71	3·30	3·02	2·89	3·82	3·45	3·30	3·25	0·80	
	0·82	4·08	3·64	3·34	3·17	4·28	3·90	3·76	3·73	0·82	
	0·84	5·13	4·66	4·34	4·10	4·90	4·72	4·65	4·64	0·84	
0·17	0·78	3·27	2·96	2·73	2·64	3·30	3·01	2·92	2·89	0·78	0·17
	0·80	3·90	3·50	3·17	3·09	4·00	3·63	3·48	3·45	0·80	
	0·82	4·33	3·86	3·56	3·43	4·54	4·18	4·03	4·00	0·82	
	0·84	5·60	5·02	4·72	4·52	5·25	5·13	5·12	5·12	0·84	
0·18	0·78	3·54	3·23	2·99	2·92	3·56	3·29	3·16	3·13	0·78	0·18
	0·80	4·20	3·77	3·50	3·42	4·28	3·94	3·79	3·76	0·80	
	0·82	4·83	4·35	4·03	3·91	4·98	4·65	4·50	4·50	0·82	
	0·84	6·30	5·74	5·40	5·26	5·90	5·90	5·90	5·90	0·84	
0·19	0·78	3·96	3·63	3·41	3·35	3·97	3·68	3·62	3·62	0·78	0·19
	0·80	4·67	4·23	3·98	3·89	4·74	4·42	4·28	4·27	0·80	
	0·82	5·61	5·15	4·85	4·74	5·84	5·44	5·27	5·26	0·82	
	0·84	7·60	7·00	6·64	6·48	7·40	7·22	7·20	7·20	0·84	
0·20	0·78	4·59	4·22	4·05	3·99	4·55	4·33	4·23	4·24	0·78	0·20
	0·80	5·25	4·85	4·60	4·56	5·35	5·03	4·93	4·93	0·80	
	0·82	6·50	6·10	5·84	5·75	6·70	6·40	6·24	6·23	0·82	
	0·84	9·20	8·70	8·35	8·20	9·10	9·00	9·00	9·00	0·84	
0·21	0·78	5·55	5·19	4·99	4·94	5·54	5·25	5·15	5·15	0·78	0·21
	0·80	6·21	5·81	5·58	5·53	6·26	6·03	5·93	5·93	0·80	
	0·82	7·55	7·15	6·25	6·88	7·67	7·50	7·40	7·40	0·82	
	0·84	10·50	10·10	9·80	9·60	10·60	10·40	10·40	10·40	0·84	
0·22	0·78	6·98	6·61	6·42	6·34	6·97	6·67	6·58	6·58	0·78	0·22
	0·80	7·73	7·33	7·07	7·00	7·85	7·52	7·45	7·45	0·80	
	0·82	9·00	8·58	8·32	8·30	9·25	8·86	8·83	8·83	0·82	
	0·84	12·00	11·53	11·25	11·10	12·10	12·00	12·00	12·00	0·84	

Table 58 Residual Resistance Coefficient

$r_R' = \frac{R_R}{\rho \nabla^{2/3} V^2}$ (at Half Load Condition)

(by SRI Charts for Large Full Ships)

$\frac{V}{\sqrt{gL_{DWL}}}$	C_P \ L/B	$B/d_{Full}=2·46$: 6·2	$B/d_{Full}=2·46$: 6·6	$B/d_{Full}=2·46$: 7·0	$B/d_{Full}=2·46$: 7·4	$B/d_{Full}=2·76$: 6·2	$B/d_{Full}=2·76$: 6·6	$B/d_{Full}=2·76$: 7·0	$B/d_{Full}=2·76$: 7·4	L/B / C_B	$\frac{V}{\sqrt{gL_{DWL}}}$
		$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$	$\times 10^{-3}$		
0·14	0·78	3·67	3·30	3·05	2·94	3·70	3·35	3·20	3·17	0·78	0·14
	0·80	4·28	3·79	3·46	3·33	4·40	3·97	3·78	3·76	0·80	
	0·82	4·90	4·38	4·00	3·84	5·08	4·63	4·42	4·37	0·82	
	0·84	5·85	5·48	5·07	4·83	6·20	5·72	5·52	5·50	0·84	
0·16	0·78	3·94	3·63	3·35	3·22	4·01	3·68	3·52	3·50	0·78	0·16
	0·80	4·61	4·15	3·79	3·65	4·72	4·32	4·13	4·10	0·80	
	0·82	5·20	4·70	4·33	4·13	5·45	4·95	4·71	4·68	0·82	
	0·84	6·40	5·84	5·35	5·10	6·60	6·08	5·85	5·82	0·84	
0·18	0·78	4·46	4·07	3·82	3·74	4·48	4·16	4·04	4·03	0·78	0·18
	0·80	5·18	4·75	4·46	4·35	5·31	4·93	4·78	4·77	0·80	
	0·82	6·17	5·50	5·16	4·98	6·26	5·76	5·54	5·54	0·82	
	0·84	7·35	6·88	6·40	6·17	7·60	7·25	7·08	7·00	0·84	
0·19	0·78	4·86	4·52	4·24	4·13	4·86	4·56	4·43	4·42	0·78	0·19
	0·80	5·70	5·27	4·96	4·84	5·86	5·47	5·29	5·27	0·80	
	0·82	6·82	6·26	5·86	5·76	7·05	6·48	6·26	6·26	0·82	
	0·84	8·60	7·95	7·45	7·27	8·80	8·30	8·20	8·20	0·84	
0·20	0·78	5·48	5·06	4·80	4·69	5·50	5·16	5·00	4·95	0·78	0·20
	0·80	6·41	5·91	5·62	5·51	6·57	6·13	5·92	5·90	0·80	
	0·82	7·72	7·18	6·82	6·70	7·95	7·48	7·22	7·20	0·82	
	0·84	10·00	9·50	9·00	8·80	10·20	9·90	9·70	9·70	0·84	
0·21	0·78	6·31	5·87	5·62	5·52	6·35	5·98	5·83	5·80	0·78	0·21
	0·80	7·32	6·80	6·50	6·40	7·48	7·04	6·84	6·83	0·80	
	0·82	8·75	8·20	7·84	7·72	9·10	8·60	8·35	8·35	0·82	
	0·84	11·30	10·75	10·30	10·20	13·50	11·10	11·00	11·00	0·84	
0·22	0·78	7·46	7·00	6·72	6·62	7·50	7·10	6·90	6·90	0·78	0·22
	0·80	8·56	8·10	7·78	7·68	8·84	8·42	8·24	8·22	0·80	
	0·82	10·20	9·70	9·35	9·20	10·55	10·05	9·95	9·95	0·82	
	0·84	13·00	12·50	12·20	12·00	13·10	12·70	12·60	12·60	0·84	

Table 59 Residual Resistance Coefficient

$$r_R' = \frac{R_R}{\rho \nabla^{2/3} V^2}$$ (at Light Load Condition)

(by SRI Charts for Large Full Ships)

$\frac{V}{\sqrt{gL_{DWL}}}$	C_B \ L/B	$B/d_{Full}=2\cdot46$ 6·2	6·6	7·0	7·4	$B/d_{Full}=2\cdot76$ 6·2	6·6	7·0	7·4	L/B / C_B	$\frac{V}{\sqrt{gL_{DWL}}}$
		×10⁻³	×10⁻³	×10⁻³	×10⁻³	×10⁻³	×10⁻³	×10⁻³	×10⁻³		
0·14	0·78	4·50	3·98	3·64	3·51	4·69	4·22	4·01	3·95	0·78	0·14
	0·80	5·10	4·49	4·13	3·95	5·29	4·83	4·62	4·54	0·80	
	0·82	5·75	5·14	4·73	4·50	6·90	5·56	5·34	5·27	0·82	
	0·84	6·55	5·82	5·40	5·11	6·90	6·40	6·18	6·11	0·84	
0·16	0·78	4·78	4·27	3·88	3·73	4·90	4·46	4·24	4·17	0·78	0·16
	0·80	5·52	4·93	4·50	4·30	5·70	5·25	5·02	4·97	0·80	
	0·82	6·34	5·68	5·22	5·00	6·70	6·20	5·96	5·92	0·82	
	0·84	7·30	6·63	6·16	5·97	7·70	7·24	7·03	6·95	0·84	
0·18	0·78	5·23	4·66	4·25	4·09	5·37	4·90	4·67	4·53	0·78	0·18
	0·80	6·37	5·70	5·23	5·03	6·63	6·10	5·85	5·78	0·80	
	0·82	7·36	6·72	6·25	6·01	7·83	7·30	7·04	7·00	0·82	
	0·84	8·50	7·97	7·59	7·45	8·95	8·55	8·43	8·43	0·84	
0·19	0·78	5·56	5·02	4·57	4·44	5·70	5·26	5·01	4·93	0·78	0·19
	0·80	6·94	6·26	5·75	5·56	7·28	6·70	6·40	6·33	0·80	
	0·82	8·10	7·46	6·95	6·73	8·65	8·08	7·76	7·70	0·82	
	0·84	9·50	8·98	8·61	8·45	9·90	9·62	9·50	9·50	0·34	
0·20	0·78	6·10	5·45	5·05	4·85	6·20	5·75	5·43	5·34	0·78	0·20
	0·80	7·60	6·87	6·35	6·18	8·05	7·43	7·05	6·97	0·80	
	0·82	9·10	8·35	7·89	7·68	9·60	9·00	8·78	8·53	0·82	
	0·84	10·80	10·33	10·00	9·87	11·10	10·90	10·80	10·30	0·84	
0·21	0·78	6·80	6·10	5·66	5·36	6·90	6·37	6·07	6·00	0·78	0·21
	0·80	8·55	7·77	7·23	6·96	9·00	8·38	8·00	7·90	0·80	
	0·82	10·20	9·55	9·04	8·80	10·87	10·28	9·92	9·83	0·82	
	0·84	12·25	11·85	11·60	10·55	12·65	12·55	12·50	12·50	0·84	
0·22	0·76	7·85	7·05	6·42	6·10	8·00	7·35	6·93	6·80	0·78	0·22
	0·80	9·80	9·00	8·38	8·05	10·30	9·56	9·13	8·95	0·80	
	0·82	11·80	11·10	10·53	10·27	12·45	11·81	11·45	11·35	0·82	
	0·84	14·10	13·80	13·60	13·55	14·55	14·50	14·50	14·50	0·84	

(d) Estimation of form factor

i) Sasajima-Tanaka's formula
Following formula was proposed for large full vessels in connection with Schoenherr's frictional resistance formula.

$$k=\sqrt{\frac{\nabla}{L^3}}\,(2\cdot 2C_b+\frac{P}{C_b})$$

$$r=(\frac{B}{L})/\{1\cdot 3(1-C_b)-3\cdot 1l_{cb}\}$$

where, P is derived from Fig. 51 using the above r .

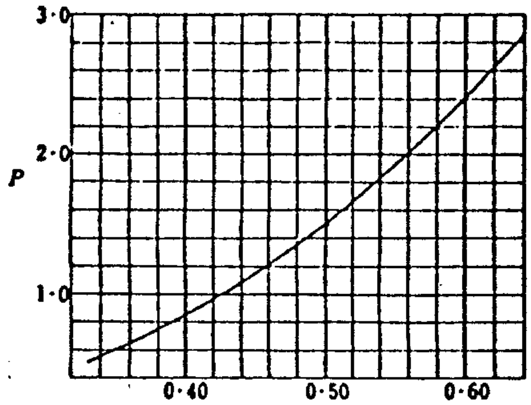


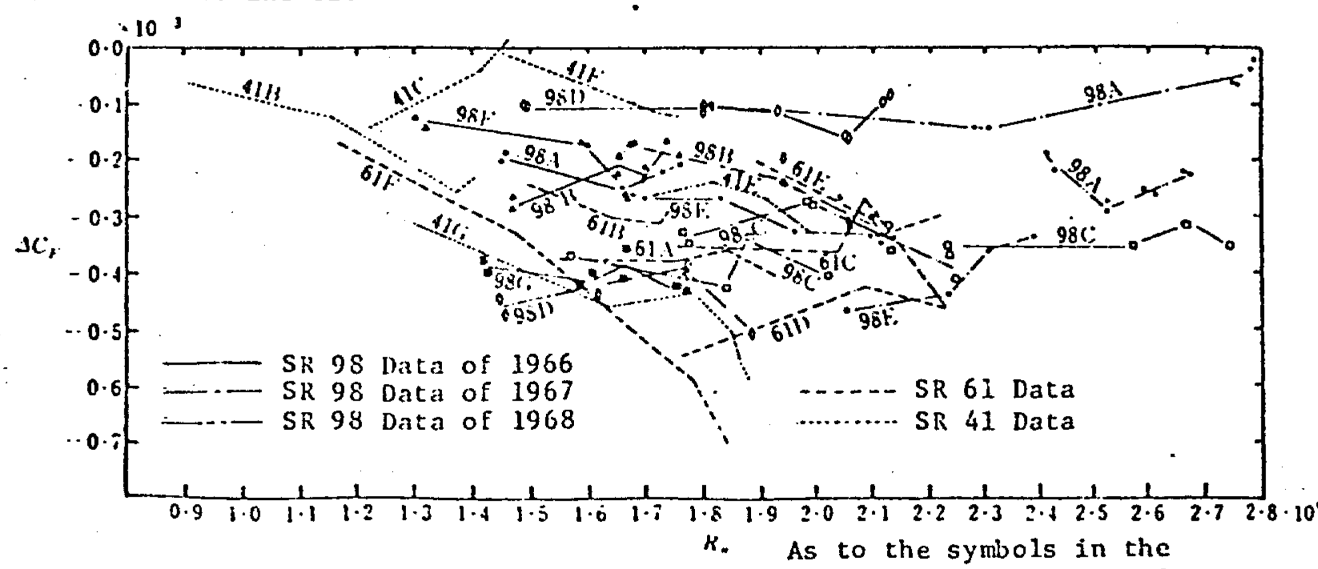
Fig. 51 Relation chart of P and r

ii) Tagano's formula
This was proposed from the results of analysis of the data obtained by SR 41, SR 61, SR 107 and the Mitsubishi Model Basin, and is the estimation formula in connection with Schoenherr's frictional resistance formula.

$$k=-0\cdot 087+8\cdot 91\frac{C_w}{\frac{L}{B}\sqrt{\frac{B}{d}}C_b}\cdot\frac{B}{L_r}$$

where, L_r is the length of the quadratic curve when the prismatic curve of the aft half body is assumed to be composed of a quadratic curve and a horizontal line for the parallel part under the condition of constant displacement.

(e) Estimation of roughness correction factor ΔC_f
The proper value shall be estimated from the actual values derived from the analysis of sea trial. One example of the actual values is shown on Fig. 52 which are the results of analysis made by the two dimensional extrapolation method using the Schoenherr's formula. The standard values used by SRI and The Shipbuilding Research Centre of Japan are also shown in Tables 60 and 61.



As to the symbols in the figure, refer to Table 81

Fig. 52 ΔC_f , examples of results of analysis

Table 60 Standard Values of ΔC_F (Two dimensional extrapolation method; Schoenherr)

Ship's Length m	$\Delta C_F \times 10^3$
100 and less	+0.4
100 - 130	+0.3
130 - 150	+0.2
150 - 170	+0.1
170 - 190	0
190 - 210	-0.1
210 - 230	-0.2
230 - 250	-0.3
250 and more	-0.4

Table 61 Standard Values of ΔC_F (Three dimensional extrapolation method; Schoenherr)

Ship's Length (m)	$\Delta C_F \times 10^3$	
	Full Load	Ballasted
125 and less	0.4	0.4
125 - 250	Linear Interpolation	
250 and more	0.15	0.25

Note) 1. ΔC_F for small vessel shall be dealt with separately.
2. Ballasted condition to have the 40-60% displacement of full load condition.

(2) Estimation method of resistance components by the towing test of model ship

Total resistance coefficient C_T corresponding to F_n and R_n are obtained from the total resistance and speed measured by towing test. According to the analysis of the above C_T by two dimensional extrapolation method, residual resistance coefficients C_R and r_R are obtained corresponding to F_n, and by three dimensional extrapolation method, wave making resistance coefficient C_W are obtained corresponding to form factor k and F_n. Several methods are proposed to determine the said k, but it is usual to assume $1+k=C_{TM}/C_{FM}$ at slow speed range where the wave making resistance seems negligible as shown on Fig. 53.

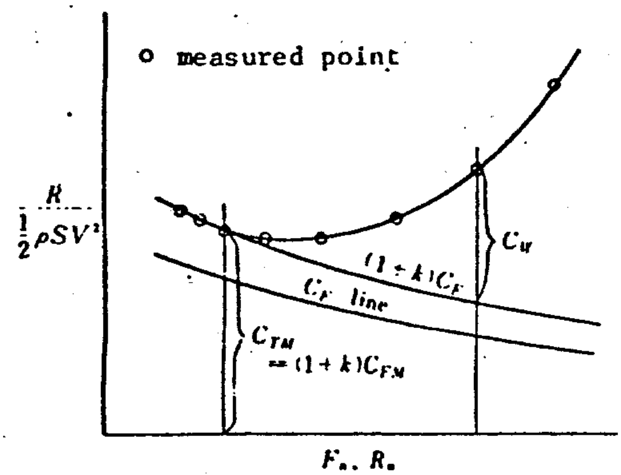


Fig. 53 Deriving method of $1+k$

(3) Estimation method of each resistance component when the results of towing tank test of similar vessels are available

The resistance components of the vessel and the similar vessel (r_R or k, C_W) are estimated by the same estimation charts or the estimation formulas and then the estimated values for the vessel are obtained by multiplying the ratio between the estimated values for each vessel to the measured value of the similar vessel.

6.2.3. Direct Estimation Method of Effective Horsepower

(1) Method to apply Ⓒ of similar vessel or other coefficients

When two hull forms are similar, the effective horsepower for one vessel is directly estimated from the value of the other vessel, assuming Ⓒ or C_1 $(=\Delta^{2/3} \times V^3/EHP)$ equal corresponding to the same F_n.

(2) Chart method

Ayre chart is a typical example. This method is simple but the accuracy is not so good.

6.2.4. Other Components of Resistance

(1) Appendage resistance
Approximate resistance increase due to bossing and bilge keel are listed in Table 62.
Resistance of the shaft bracket (kg) is given by the following formula.

$$R = 0.3 l^2 V^2$$

l = Breadth of the arm (m)

Table 62 Resistance Increase due to Appendages (%)

	Cargo ship & cargo/passenger ship		High speed passenger ship
	Single screw	Twin screw	
Bossing	0	2.5	4.0
Bilge keel	3	2.5	2.5

(2) Air resistance
Some percent of increase in resistance shall be taken into account according to the size of the superstructures. Refer to 7.3.3 when the calculation is to be taken.

(3) Resistance increase due to fouling
The frictional resistance increases when the hull surface becomes rough due to foulings caused by peeling-off of paint, rusting or adhered sea organisms such as sea weed. It is a rather complex matter how the fouling of the bottom is generated after the ship sails out of the dock and experiences show the different results depending on the characteristics of the paint, location of port and seasons. One example of data is shown in Fig. 54.

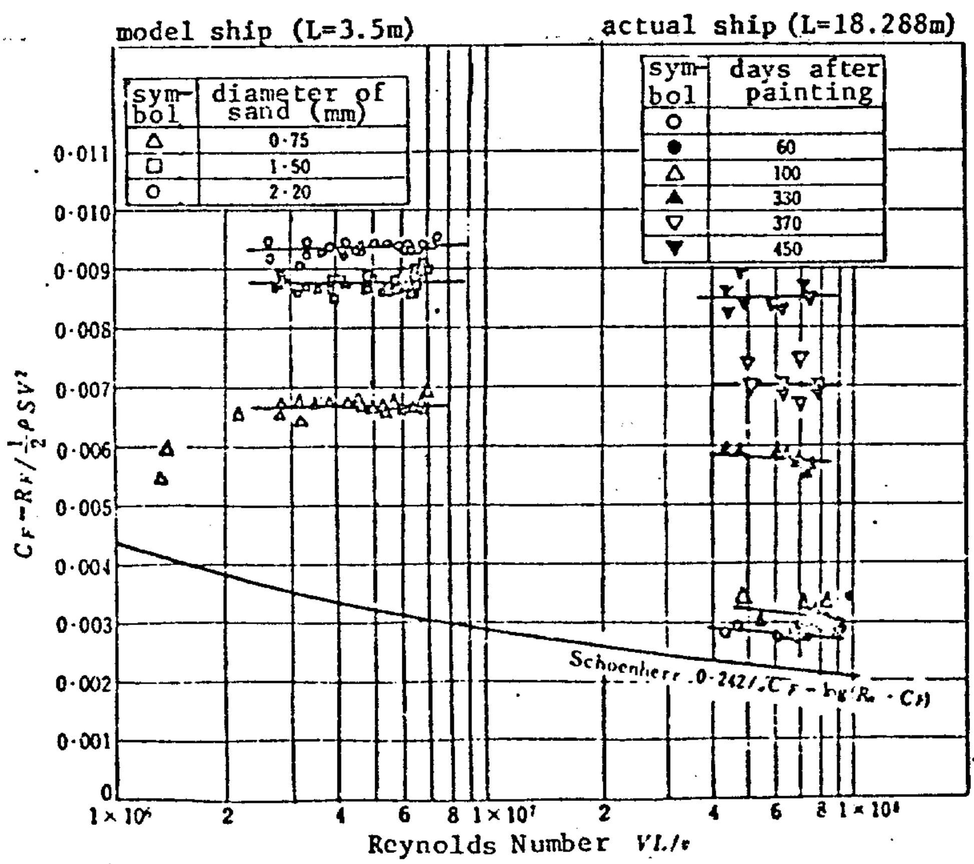


Fig. 54 Increased frictional resistance due to fouling of bottom

(4) Shallow water effect

In general, the resistance when the water depth is not sufficient is different from that in the water with enough depth as shown on Fig. 55. The minimum water depth (h) not affecting the resistance of the ship is shown as follows:

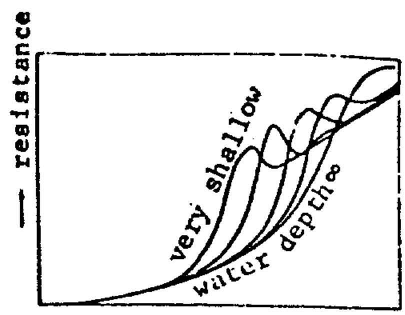


Fig. 55 Shallow water effect

Taylor $h > 10d$ or
$h > 10d\,(V'/\sqrt{L'})$ at $V'/\sqrt{L'} < 0.9$
for ships of $C_b < 0.65$

Baker Cargo ship $h > 7d$
High speed liner $h > 10d$

Kinoshita For the wave-making resistance $h/d > 30V/\sqrt{gL}$

Sudo Increase ratio α of frictional resistance
$\alpha(\%) = 191.4(\sqrt{A_M}/h - 0.32)^2 + 16.57(\sqrt{A_M}/h - 0.32)$

Lackenby When $A_M/h^2 > 0.05$, assuming decrease in ship speed V
$$\delta V/V = 0.1242\left(\frac{A_M}{h^2} - 0.05\right) + 1 - \{\tanh(gh/V^2)\}^{1/2}$$

Proposal for sea trial for VLCC and ITTC Trial Code
$$h > 3\sqrt{Bd} \quad \text{and} \quad h > 2.75V^2/g$$

where, A_M = Sectional area of midship

Other than the above we have the charts of Sjostrom (Naval Engineers Journal, 79 (1967), 271).

(5) Others

As for resistance increase by wind and wave, 7.3.3 and 7.3.4 are to be referred to.

6.3. Propeller

6.3.1. Definition of Terms (Refer to Fig. 56)

Z = Number of blades, D = Diameter of propeller, P = Pitch, Pitch ratio $p = P/D$, Blade thickness ratio t = Blade thickness at centre line/D, Boss ratio b = Boss diameter d_B/D, Expanded area ratio $a_E = A_E/A_0$, Projected area ratio $a_P = A_P/A_0$ (where, A_E, A_P = All blade expanded area and projected area except boss part, A_0 = Propeller disc area = $\pi D^2/4$, $a_P/a_E \fallingdotseq 1.067 - 0.229p$), Average blade breadth ratio = Average blade breadth $l_m/D = \pi a_E/\{2Z(1-b)\}$, Maximum blade breadth ratio = Maximum blade breadth l_{max}/D.

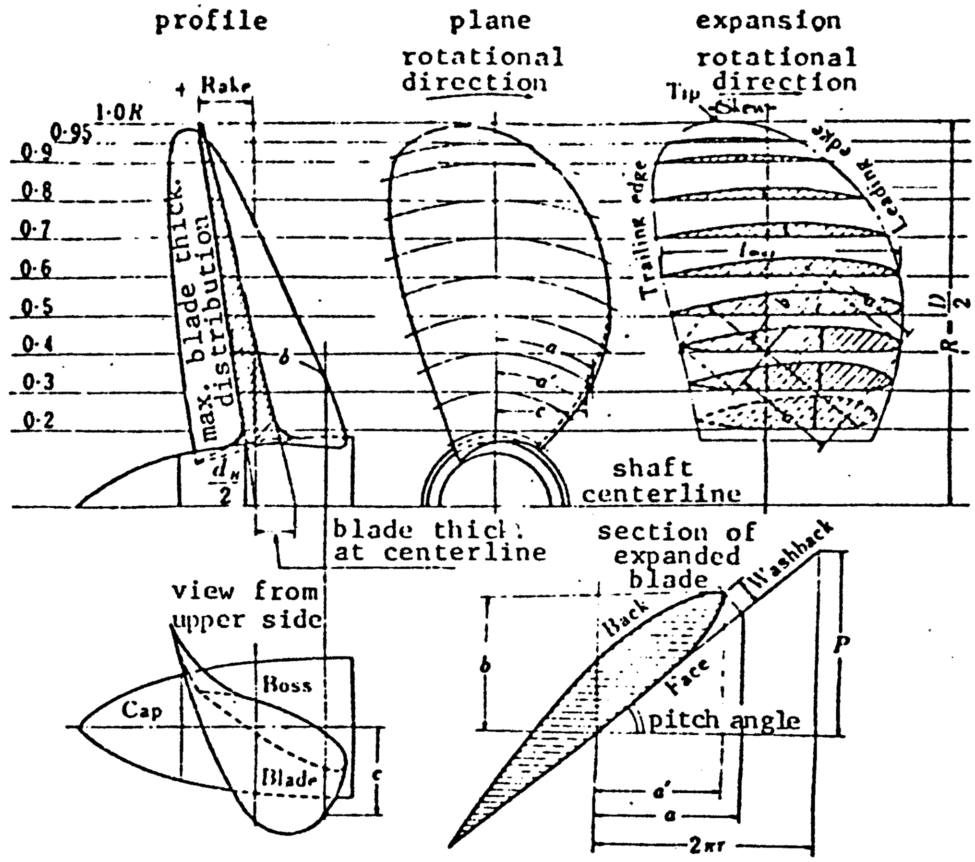


Fig. 56

6.3.2. Major Series Propeller Chart (Table 63 and Table 64)

(1) K_T, K_Q-J charts (non dimensional) (Refer to 6.1.1.)
Thrust coefficient K_T , Torque coefficient K_Q and Propeller efficiency η_o are shown against Advance coefficient J or Slip ratio s . (Fig. 57 (a), (b), (c)) Furthermore, as for the propeller of Troost B series, coefficients are given when K_T and K_Q are approximated by a polynominal using J, p, a_E and Z (Symbols marked ' are in English unit $\rho = 104 \cdot 51 \mathrm{kg \cdot sec^2/m^4}$).

$$J = \frac{V_A}{nD} = p(1 - s_R) = 30 \cdot 87 \frac{V_{KA}}{ND} = 101 \cdot 33 \frac{V_{KA}'}{ND'}$$

$$s_R = 1 - \frac{V_A}{nP} = 1 - \frac{J}{p} = 1 - 30 \cdot 87 \frac{V_{KA}}{NP} = 1 - 101 \cdot 33 \frac{V_{KA}'}{NP'}$$

$$K_T = \frac{T}{\rho n^2 D^4} = 34 \cdot 45 \frac{T}{N^2 D^4} = 5 \cdot 022 \times 10^3 \frac{\mathrm{THP}}{V_{KA} N^2 D^4} = 1 \cdot 5501 \times 10^3 \frac{\mathrm{THP}}{J N^3 D^5} = 1 \cdot 8102 \times 10^3 \frac{T'}{N^2 D'^4}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} = 24\,670 \frac{\mathrm{DHP}}{N^3 D^5} = 9 \cdot 507 \times 10^6 \frac{\mathrm{DHP}'}{N^3 D'^5} \quad , \quad \eta_o = \frac{\mathrm{THP}}{\mathrm{DHP}} = \frac{T V_A}{2\pi n Q} = \frac{J}{2\pi} \frac{K_T}{K_Q}$$

When n or D are eliminated by the combinations of K_T, K_Q and J ,

$$K_{TD} = \frac{K_T}{J^2} = \frac{T}{\rho V_A^2 D^2} = 5 \cdot 271 \frac{\mathrm{THP}}{V_{KA}^3 D^2} \cdot K_{QD} = \frac{K_Q}{J^2} = 0 \cdot 03616 \frac{Q}{V_{KA}^2 D^3}$$

$$K_{Tn} = \frac{K_T}{J^4} = \frac{n^2 T}{\rho V_A^4} = 5 \cdot 533 \times 10^{-3} \frac{N^2 \mathrm{THP}}{V_{KA}^5}$$

$$K_{QD}' = \frac{K_Q}{J^3} = \frac{nQ}{\rho V_A^3 D^2} = 0 \cdot 8389 \frac{\mathrm{DHP}}{V_{KA}^3 D^2}$$

$$K_{Qn} = \frac{K_Q}{J^5} = \frac{n^3 Q}{\rho V_A^5} = 8 \cdot 805 \times 10^{-4} \frac{N^2 \mathrm{DHP}}{V_{KA}^5}$$

Table 63 Ship Research Institute (SRI), C.P.P., Troost, Gawn Series Propeller Details

Series	Symbol	z	a_E	l_{max}/D	t	Blade thickness/breadth (%) at 0.7R	b	p	D mm	I/D	Rake	n 1/sec	$R_n \times 10^6$	Figure
SRI	B	2	0·233	0·263		7·06	0·200	0·6~1·0	220	0·909	10°-18′	7·0	7·9	
		3	0·35					0·4~1·4					8·5	
			0·50	0·376	0·050	4·95							12·1	
	N-AU		0·35	0·267		6·43	0·180	0·4~1·2	250	1·00	10°	9·0	12·4~12·7	
			0·50	0·381		4·50							17·7~18·1	
	A	4	0·40	0·24	0·045	7·05	0·250	0·4~1·4	220	0·909	10°-18′	7·0	7·1	
			0·55	0·33		5·14							8·7	Fig.
	MAU		0·40	0·226		7·59		0·5~1·6				11·5	10·0	61 (a)
			0·55	0·311		5·52							13·7	" 61 (b)
			0·70	0·398		4·31							17·0~17·5	" 61 (c)
	MAU	5	0·50	0·226		7·59		0·4~1·6				11·0	9·3	" 61 (d)
			0·65	0·294	0·050	5·84	0·180		250	1·00	10°		12·0	" 61 (e)
			0·80	0·364		4·71							19·4~20·3	" 61 (f)
	MAU	6	0·55	0·208		8·25		0·5~1·5				12·0	9·8	" 61 (g)
			0·70	0·264		6·50							12·5	" 61 (h)
			0·85	0·322		5·33							15·1~15·3	" 61 (i)
	AU		0·70	0·264		6·50		0·5~1·1				12·0	12·5	
SRI C.P.P.	B	3	0·35	0·319			0·34	0·4~1·0	220			11·0	11·1~13·6	Fig. 63 (a)(b)
			0·50	0·473									18·3~20·3	
	MAU	4	0·40	0·265	0·050					1·00	0°		12·1~18·4	Fig. 63 (c)(d)
			0·55	0·364			0·30	0·6~1·0	250			12·0	16·6~25·3	
			0·70	0·464									21·3~30·8	
Troost (Wageningen)	B	2	0·30	0·33	0·055	5·67						6·0	9·5	
			0·38											
		3	0·35	0·26		6·66	0·180					7·5	8·5	
			0·50	0·37	0·050	4·66						5·5	8·0	
			0·65	0·48		3·59						5·0	10·6	
			0·80											Fig.
		4	0·40	0·22		7·27						7·5	8·0	62 (a)
			0·55	0·30		5·29		0·5~1·4	240	1·00	15°	6·3	8·0	" 62 (b)
			0·70	0·20	0·045	4·16						6·0	10·0	" 62 (c)
			0·85											
			1·00				0·167							Fig.
		5	0·45	0·20		7·31						5·8~8·9	8·0	62 (d)
			0·60	0·26		5·48						6·7~7·9	8·0	" 62 (e)
			0·75		0·040									
			1·05											
	Modified B	6	0·50											
			0·65		0·035		0·167	0·6~1·4						
			0·80											
		7	0·55											
			0·70		0·035		0·180	0·4~2·0			5°			
			0·85											
Gawn	(Elliptical blade)	3	(a_p)											
			0·20											
			0·35											
			0·50		0·060		0·20		610	1·10	0°	8·33	88·0	
			0·65											
			0·80											
			0·95											
			1·10											

Note) 1. Normally it is written as "SRI MAU 4-40". This means a series of tests for the propellers of number of blades $(z)=4$, Expanded area ratio $(a_E)=0.40$.

2. Pitch distribution is as follows:

   Troost B4 Series ... gradual increase ($P_{0.6-1.0R}=1.25\ P_{0.6R}$)
   SRI A4-40 .... constant, gradual increase ($P_{0.7-1.0R}=1.178\ P_{0.3R}$)
   and gradual decrease ($P_{0.7-1.0R}=0.869\ P_{0.3R}$)
   Others .... constant

3. $R_n=(l_{0.75}/D)nD^2/\nu$

4. Other than the above, there are SSPA 3—45, 4—47, 53, 60, 5—60, 6—60, and 85.

5. Blade profile and blade section are shown in Figs. 59 and 60.

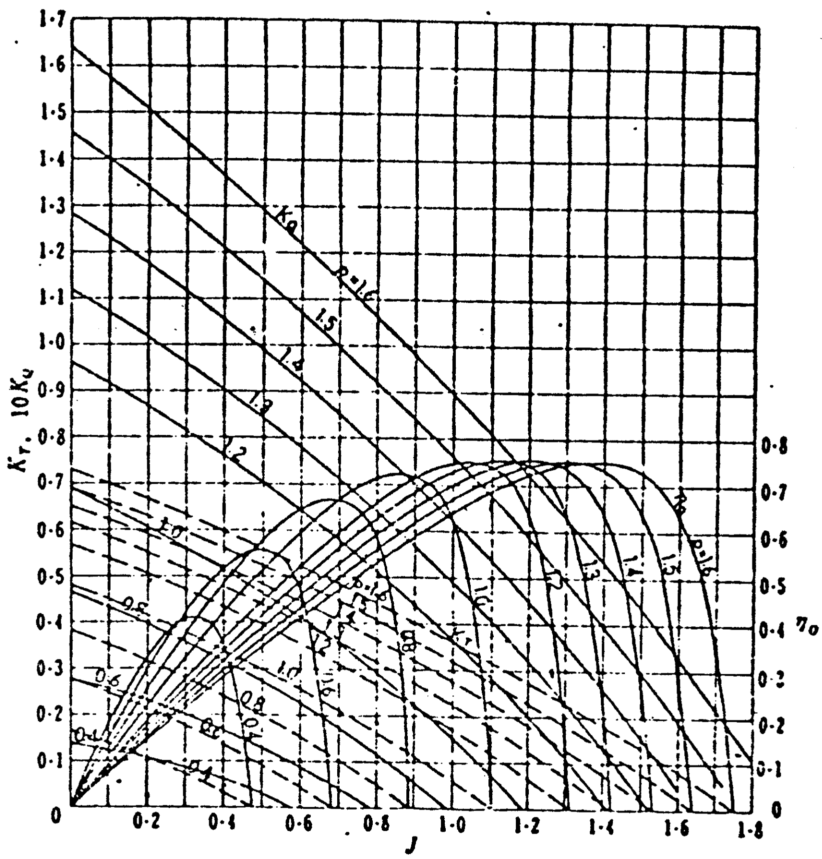


Fig. 57 (a) Ship Research Institute MAU5-65

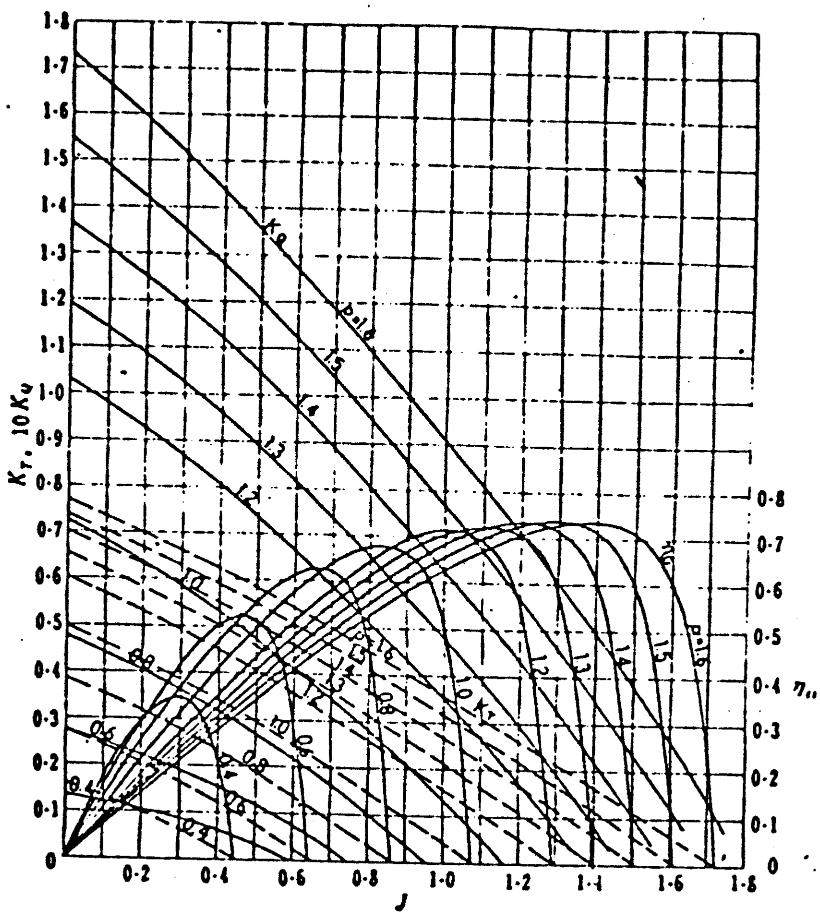


Fig. 57 (b) Ship Research Institute MAU5-80

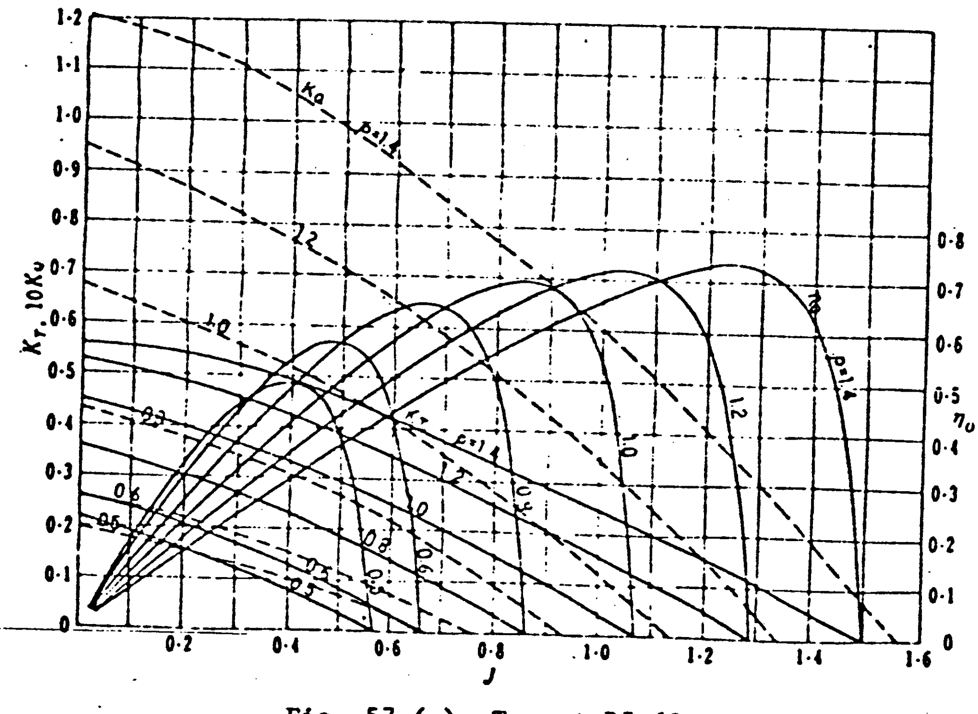


Fig. 57 (c) Troost B5-60

Table 64 Nozzle Propeller of Wageningen

Propeller	Form of Nozzle					
	Nozzle	l/D	s/l	f/l	α_i, deg	Profile
B 4-55	1	axial	circular	cylinder		NACA4415
	2	0·67	0·15	0·04	12·7	
	3	0·50			12·7	
	4	0·83			12·7	
	5	0·50			15·2	
	6			0·04	10·2	NACA4415
	7			0·05	12·7	NACA5415
	8	0·50		0·03		NACA3415
	10	0·40		0·05		NACA5415
B 4-55	11	0·30				
B 4-40	7	0·50				
B 4-70	7					
B 2-30	7					
B 3-50	7					
B 5-60	7	0·50	0·15	0·05	12·7	NACA5415

Note) 1. l = Length of nozzle, s = Thickness of nozzle, f = Nozzle camber, α_i = Angle between nozzle centre line and nose tail line of nozzle section (Fig. 58)

2. Other than the above, there is a propeller using Kaplan blade form.

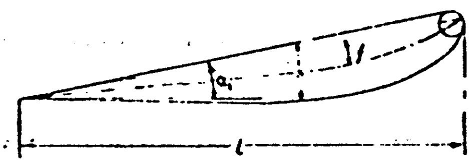


Fig. 58

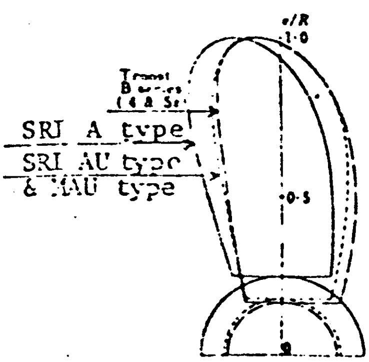


Fig. 59 Blade profiles (when the generating line and the maximum blade breadth are coincided.)

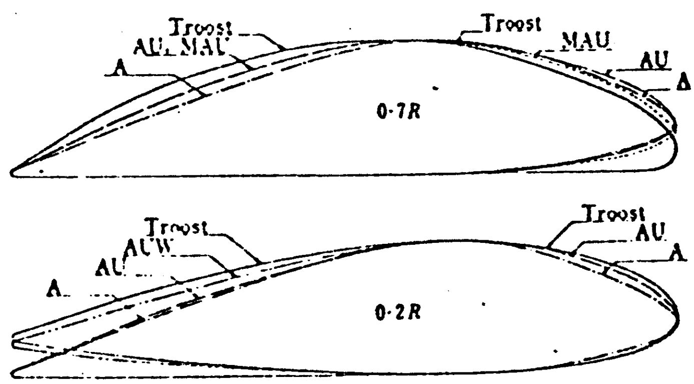


Fig. 60 Comparison of blade sections (when the maximum thicknesses are taken same.)

(2) B_p-δ, B_u-δ charts

(a) Units (Table 65)

Table 65 Units used for B_p-δ Chart

Charts	Density ρ	1 Horsepower	1 kt	Diameter D
Ship Research Institute (SRI)	104·51 kg sec²/m⁴	75 kg m/sec	1 852 m/h	m
Troost	102 kg sec²/m⁴	76 kg m/sec	6 080 ft/h	ft
Taylor	1·990 5 lb sec²/ft⁴	550 lb ft/sec	6 080 ft/h	ft

(b) Ship Research Institute charts (Fig. 61 (a) - (i))

$$B_p=\frac{N(\mathrm{DHP})^{0.5}}{V_{EA}^{2.5}}=11\cdot387\frac{n(\mathrm{DHP})^{0.5}}{V_A^{2.5}}=33\cdot70K_{Qn}^{0.5}=33\cdot70\left(\frac{K_Q}{J^5}\right)^{0.5}$$

$$B_u=\frac{N(\mathrm{THP})^{0.5}}{V_{EA}^{2.5}}=11\cdot387\frac{n(\mathrm{THP})^{0.5}}{V_A^{2.5}}=13\cdot444K_{Tn}^{0.5}=13\cdot444\left(\frac{K_T}{J^4}\right)^{0.5}$$

$$\delta=\frac{ND}{V_{EA}}=\frac{30\cdot87}{J}$$

In addition to the above, and for the convenience of propeller design, δ_{opt} by which D is decided to give the maximum η_o against a certain B_p and δ_{opt} $\pm5\%$ which gives D of $\pm5\%$ from the same D and also $\lambda=\delta^{2.5}/B_p=(N^2D^5/\mathrm{DHP})^{0.5}=157\cdot07/\sqrt{K_Q}$ (refer to 6.4.1(1)) which is used for analyzing wake tactor w are shown in Fig. 61.

(c) Troost charts (Fig. 62 (a) - (e))

The meanings of B_p, B_u are similar to those of Ship Research Institute charts but according to the difference in units adopted, $B_p=33\cdot13K_{Qn}^{0.5}$ $B_u=13\cdot22K_{Tn}^{0.5}$, $\delta=101\cdot33/J$, namely, B_p, B_u in Troost charts = 0.981 x (B_p, B_u in S.R.I Chart), δ in Troost chart = 3.281 x (δ in S.R.I chart), and when DHP (THP) is given by metric horsepower (75 kgm/sec) in sea water, B_p, B_u shall be calculated as

$$\mathrm{DHP'}(\mathrm{THP'})=\frac{1}{1\cdot025}\times\frac{75}{76}\mathrm{DHP}(\mathrm{THP})=0\cdot963\,\mathrm{DHP}(\mathrm{THP})$$

δ_{opt}, δ_{opt} $\pm5\%$ and λ in the charts represent the same meanings as in the S.R.I charts.

(d) SRI charts for C.P.P. (Fig. 63 (a) - (d))

These charts can be used same as the charts for the fixed pitch propeller but in this case there are two kinds of charts, one is the charts (Fig. 63 (a), (c)) for standard pitches made on same basis for the fixed pitch propeller/and the others are the charts (Fig. 63 (b), (d)) for representing the characteristics when the pitch angle is increased or decreased from a certain standard pitch (p_o=0·6, 0·8, 1·0 and so on). Fig. 63 (d) is corresponding to K_T, K_Q-J charts.

(e) Nozzle propeller charts of Wageningen (Fig. 64)

Units adopted are same as those of Troost chart but δ is used as a parameter.

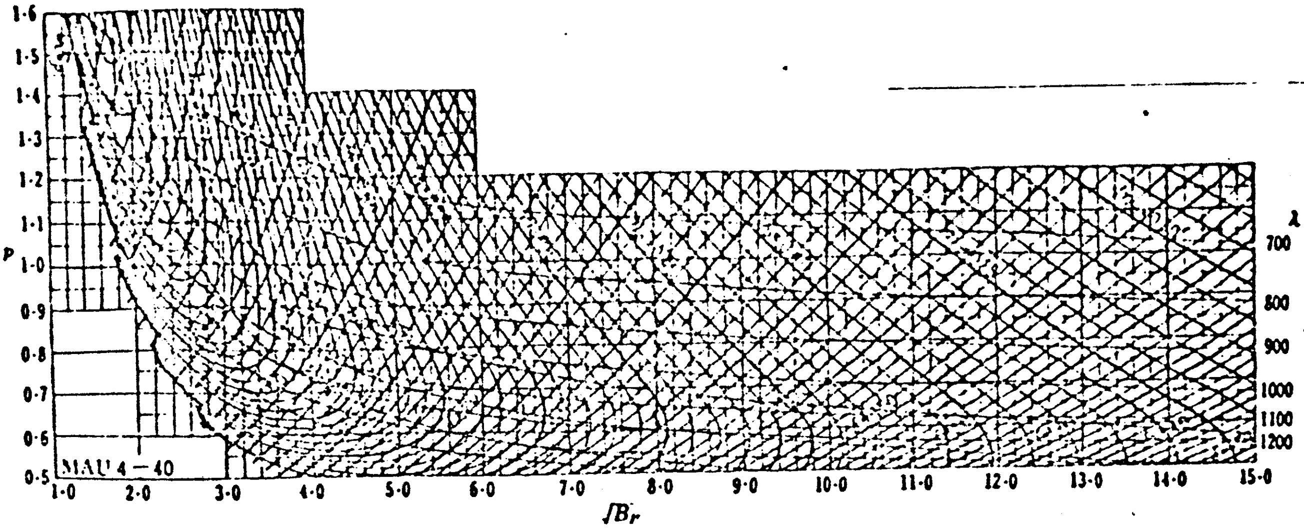


Fig. 61 (a) Ship Research Institute MAU 4-40

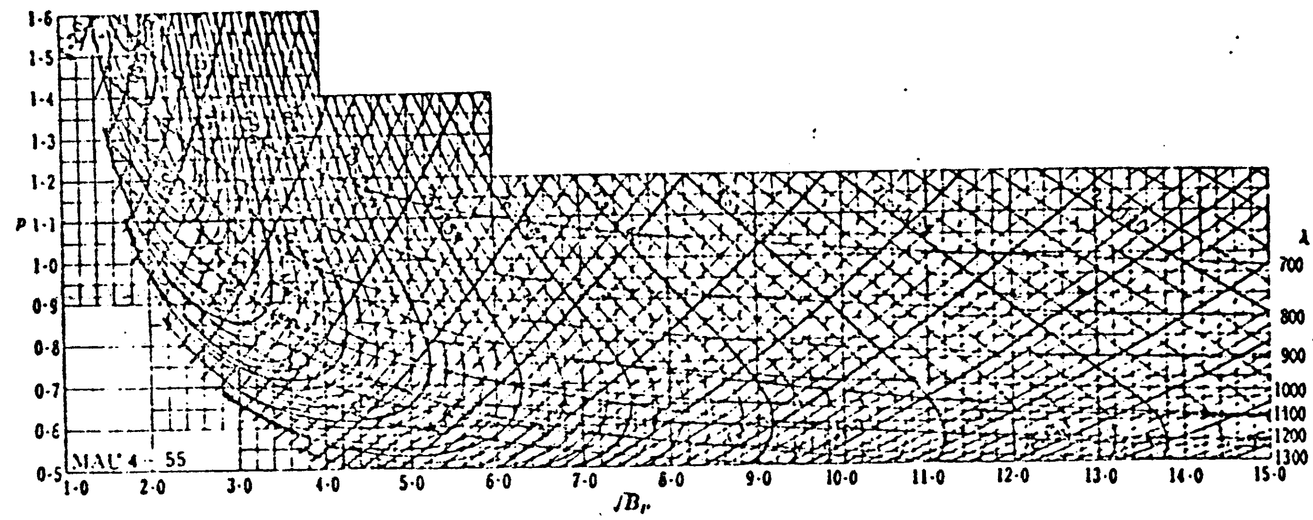


Fig. 61 (b) Ship Research Institute MAU 4-55

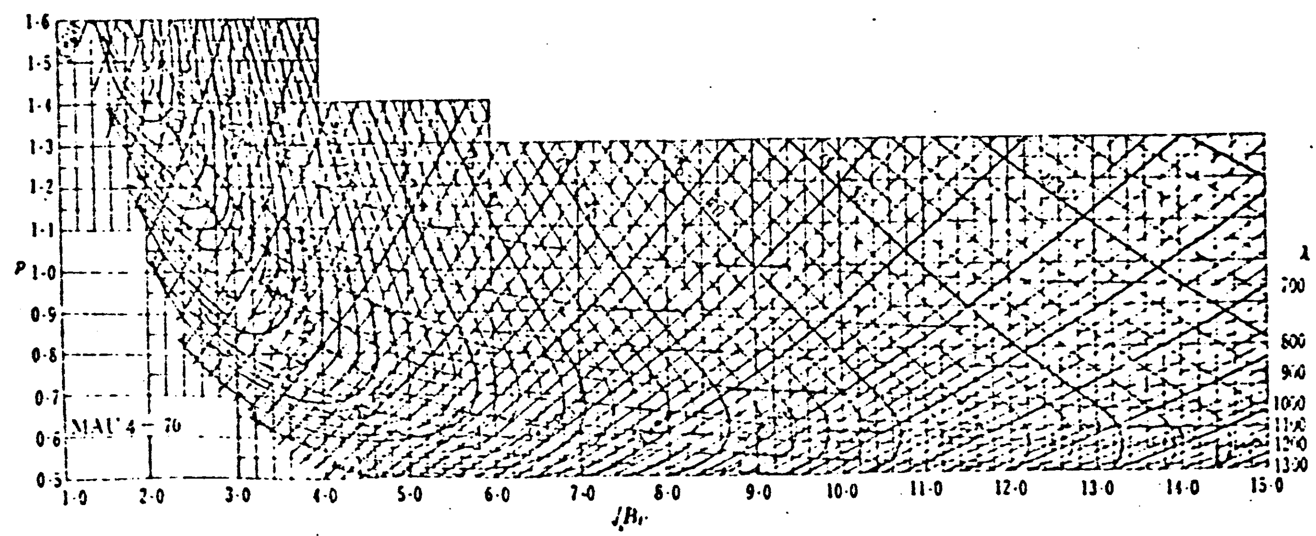


Fig. 61 (c) Ship Research Institute MAU 4-70

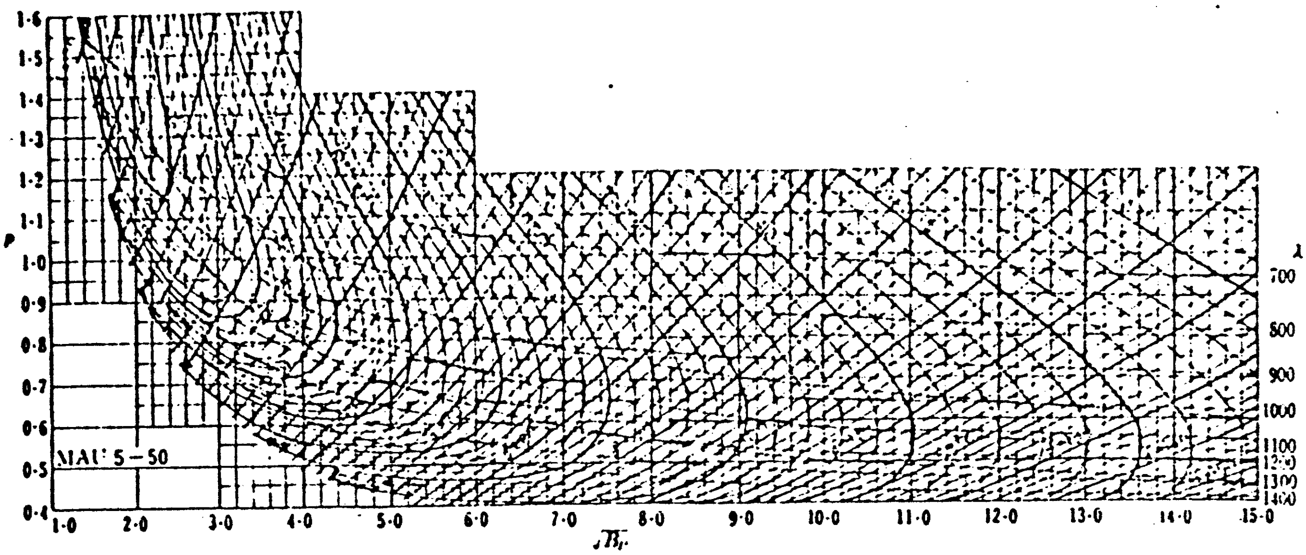


Fig. 61 (d) Ship Research Institute MAU 5–50

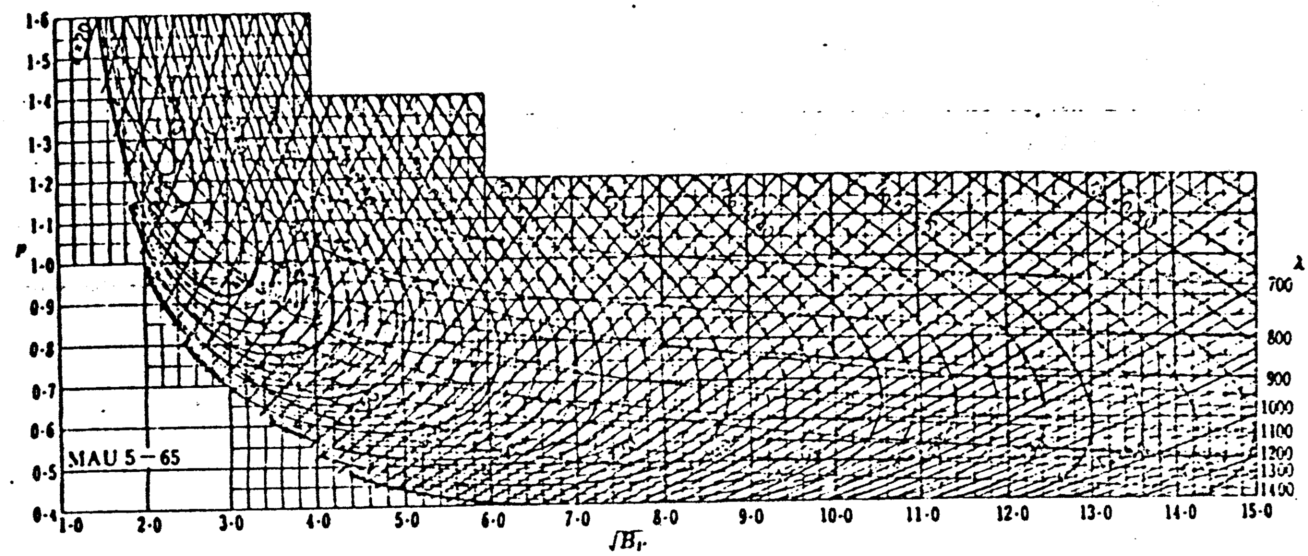


Fig. 61 (e) Ship Research Institute MAU 5–65

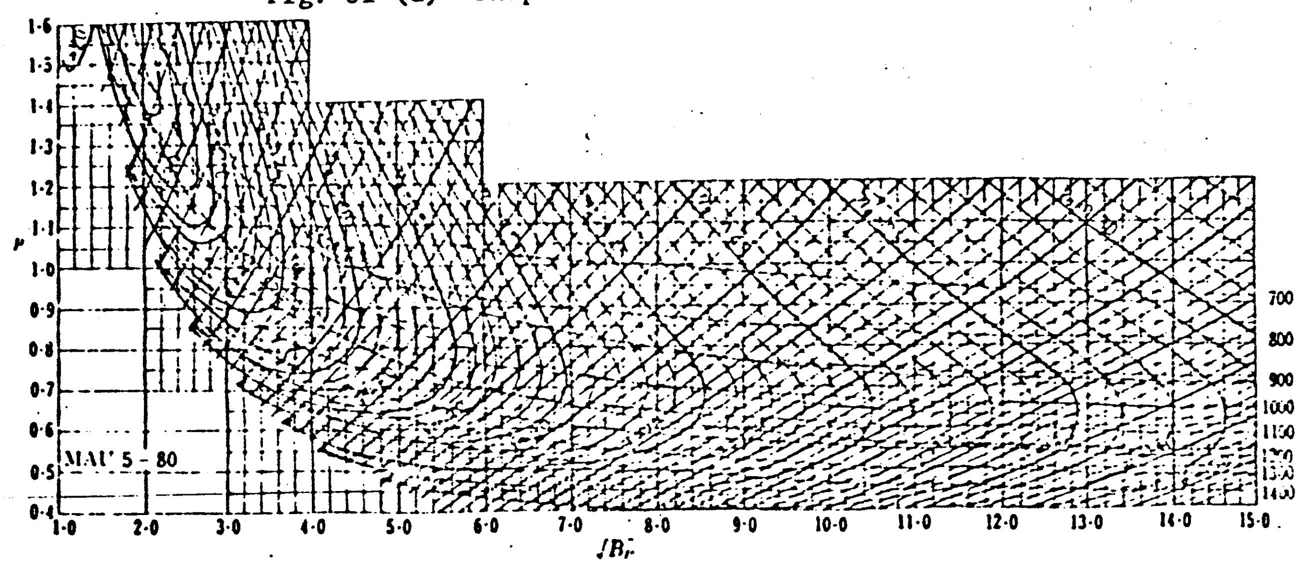


Fig. 61 (f) Ship Research Institute MAU 5–80

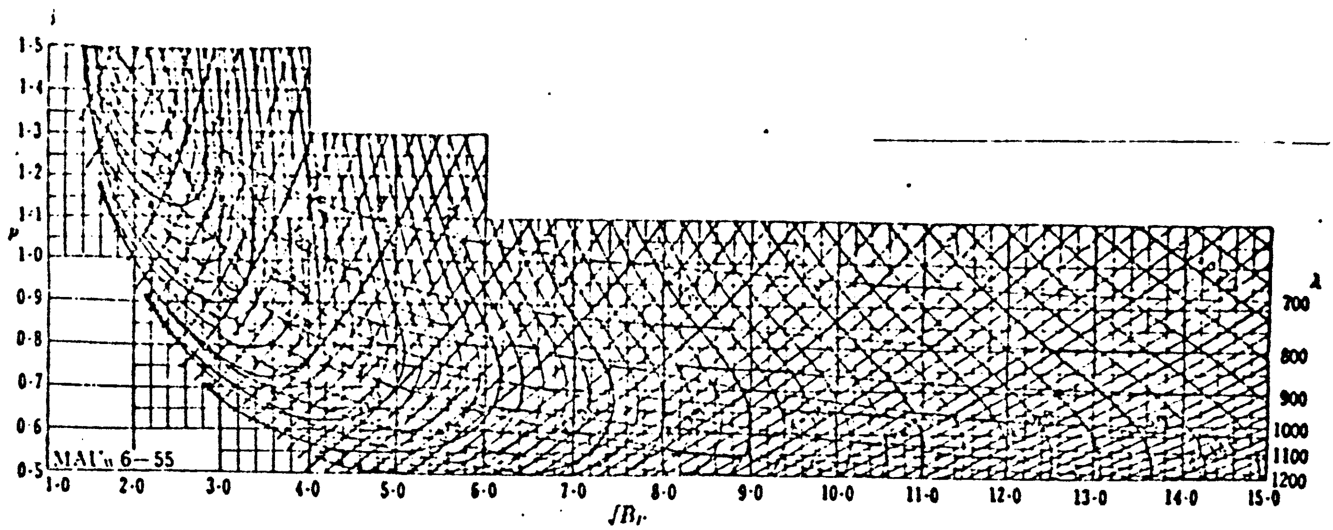


Fig. 61 (g) Ship Research Institute MAUw 6-55

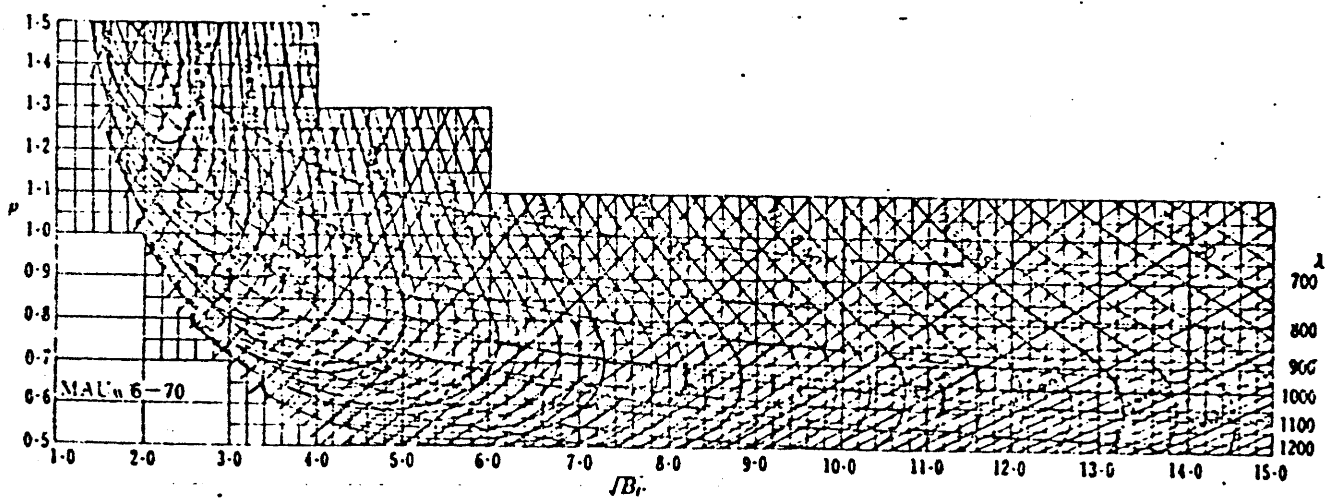


Fig. 61 (h) Ship Research Institute MAUw 6-70

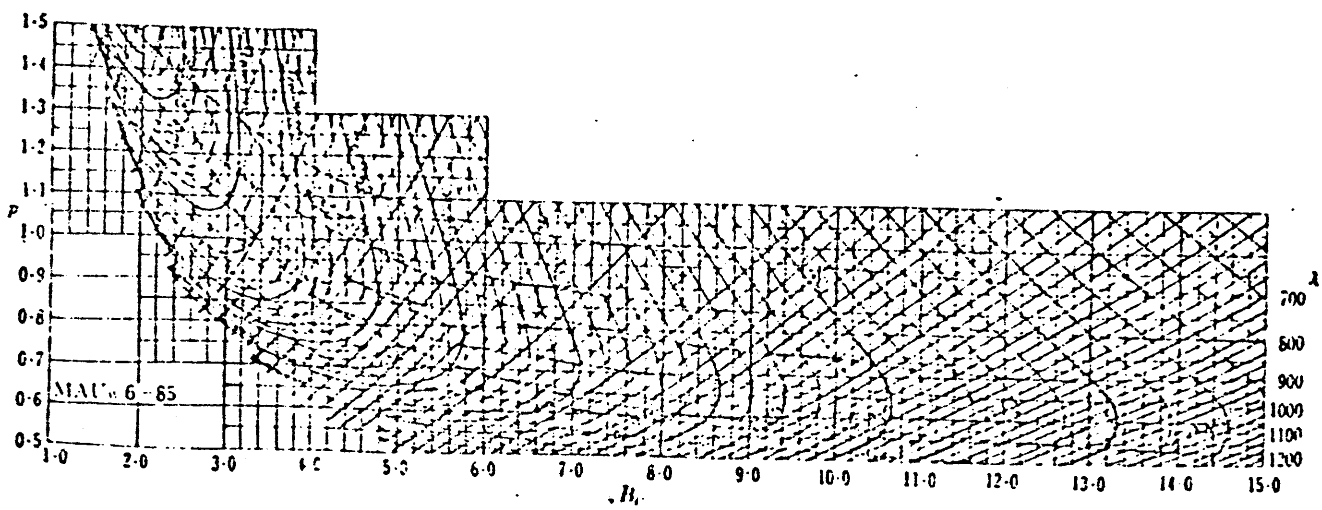


Fig. 61 (i) Ship Research Institute MAUw 6-85

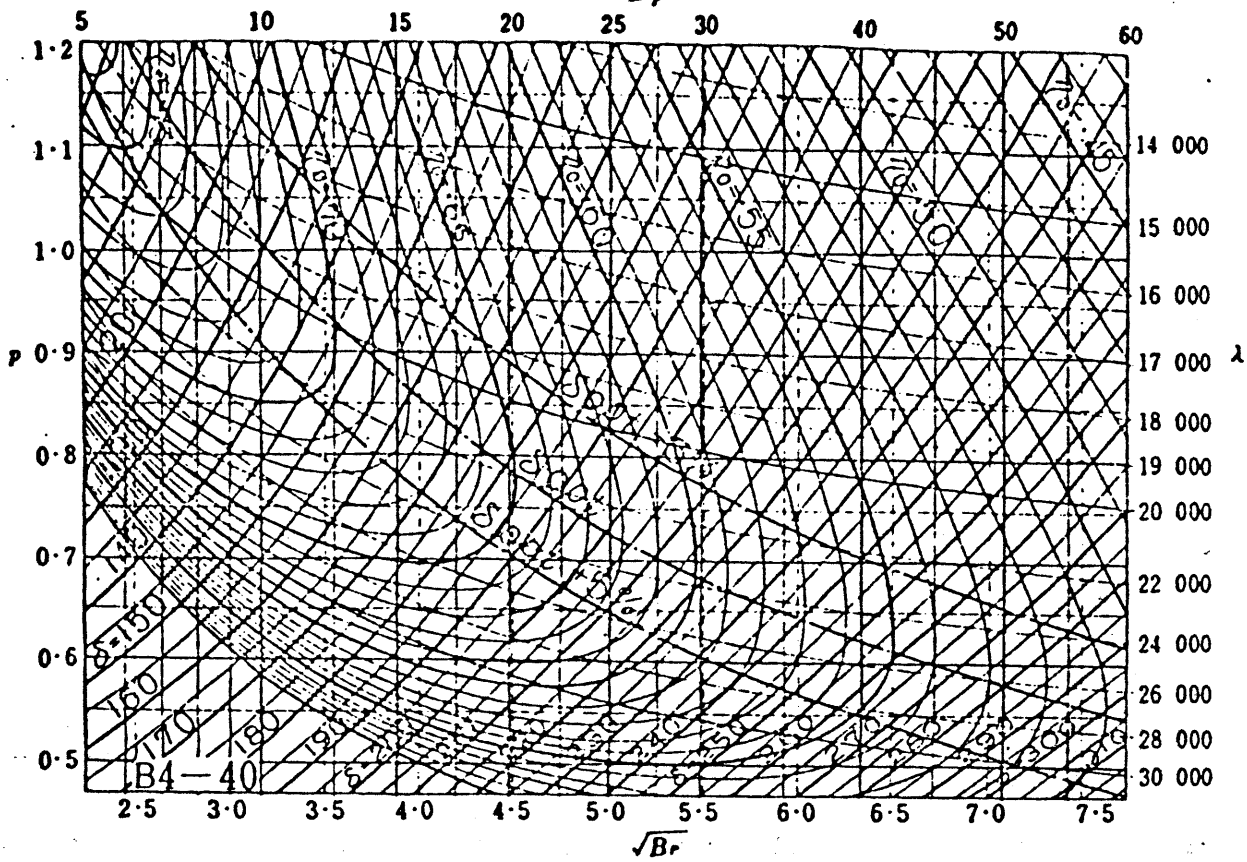


Fig. 62 (a) Troost B 4—40

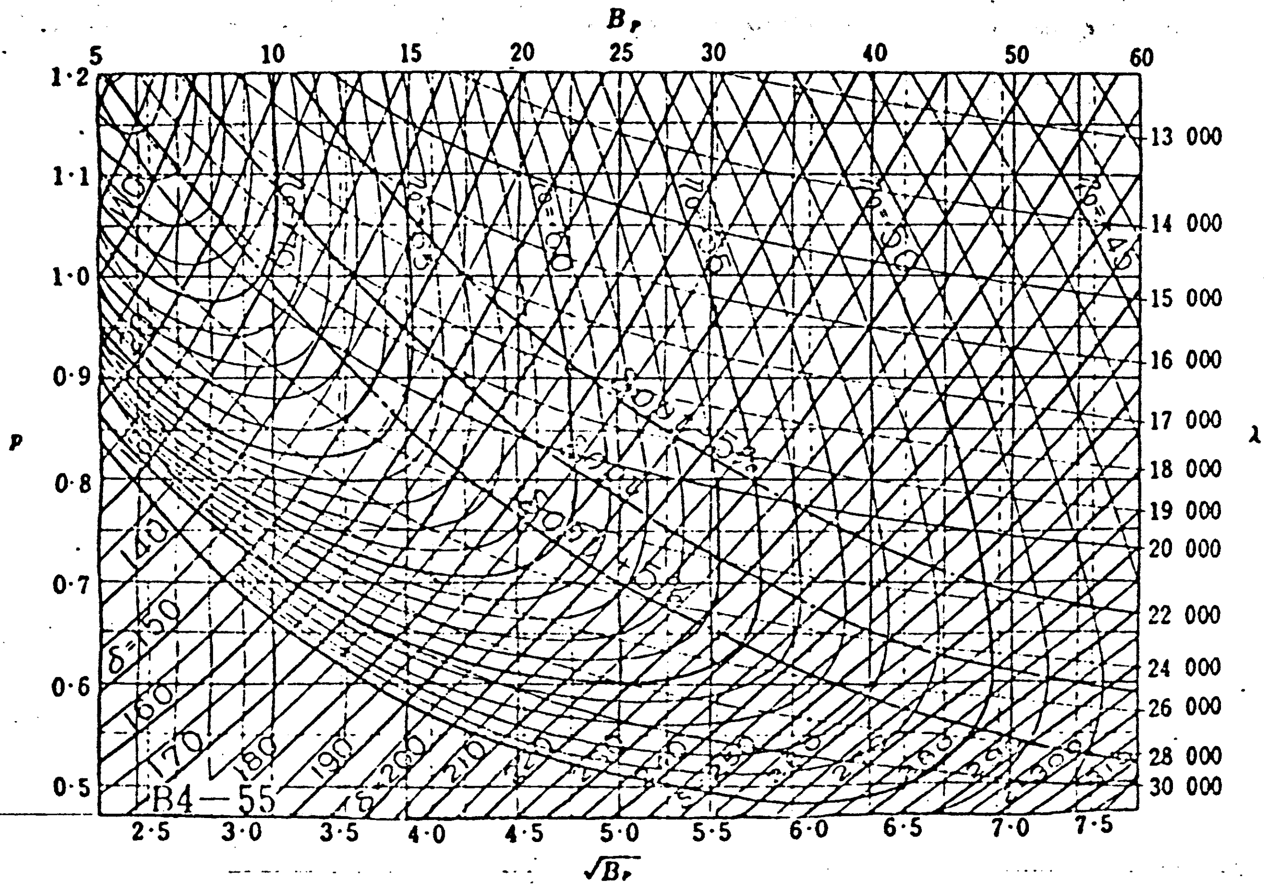


Fig. 62 (b) Troost B 4—55

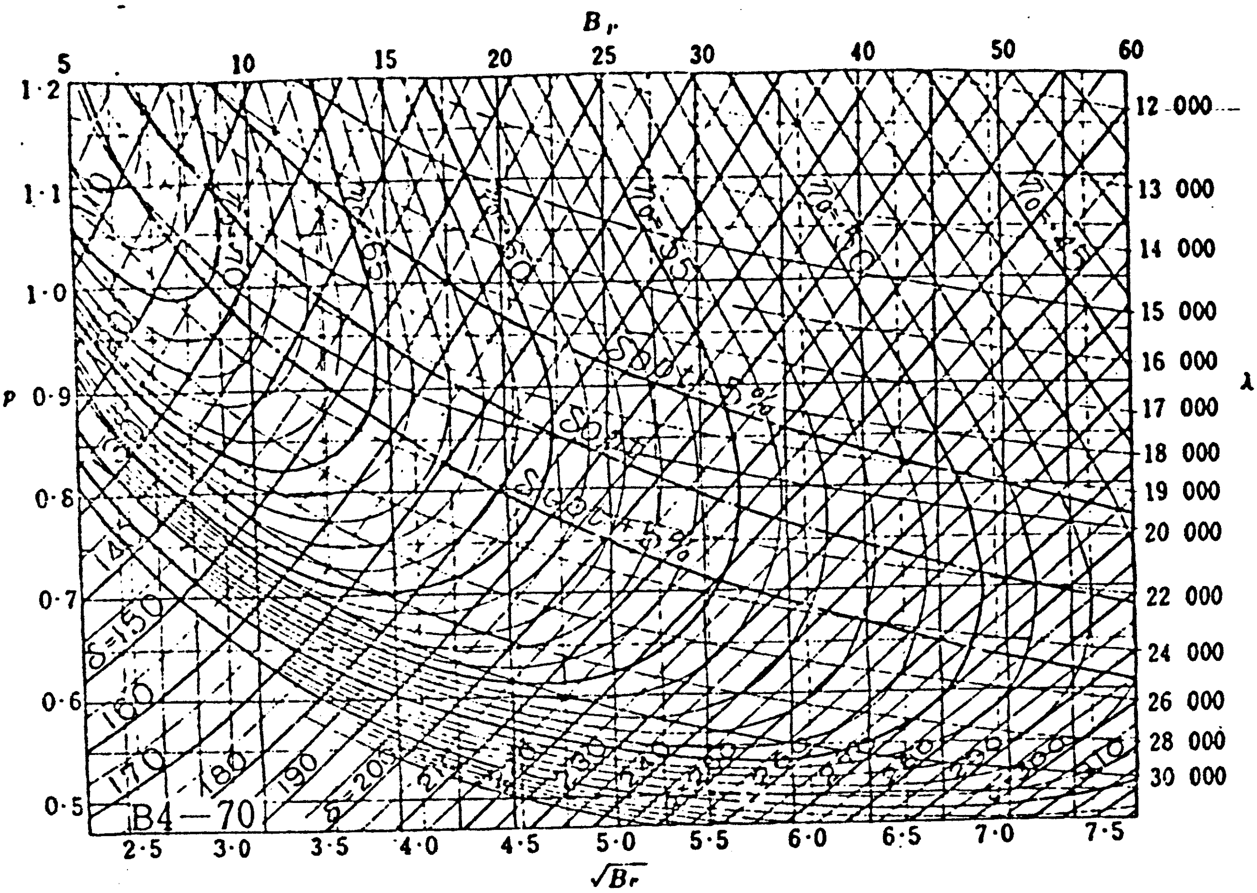


Fig. 62 (c) Troost B 4—70

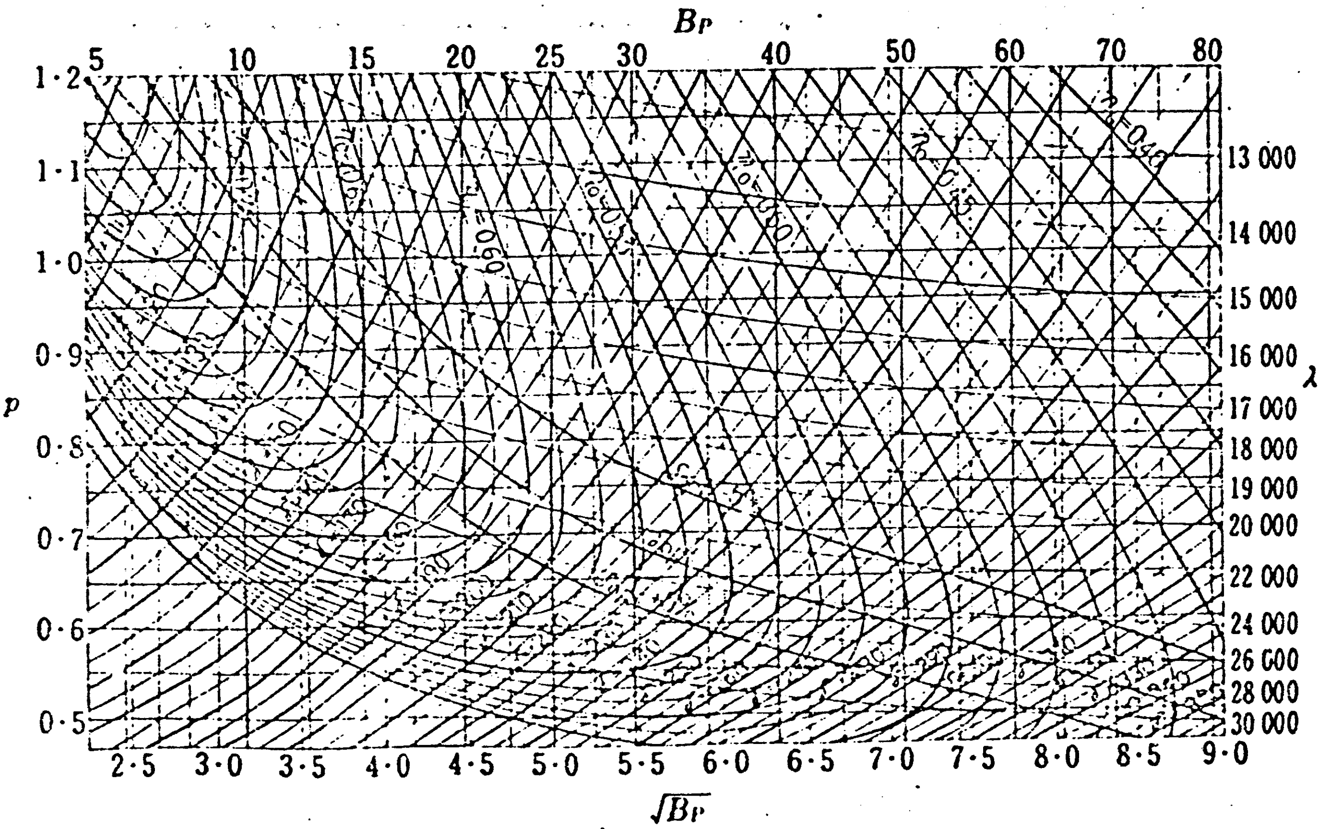


Fig. 62 (d) Troost B 5—45

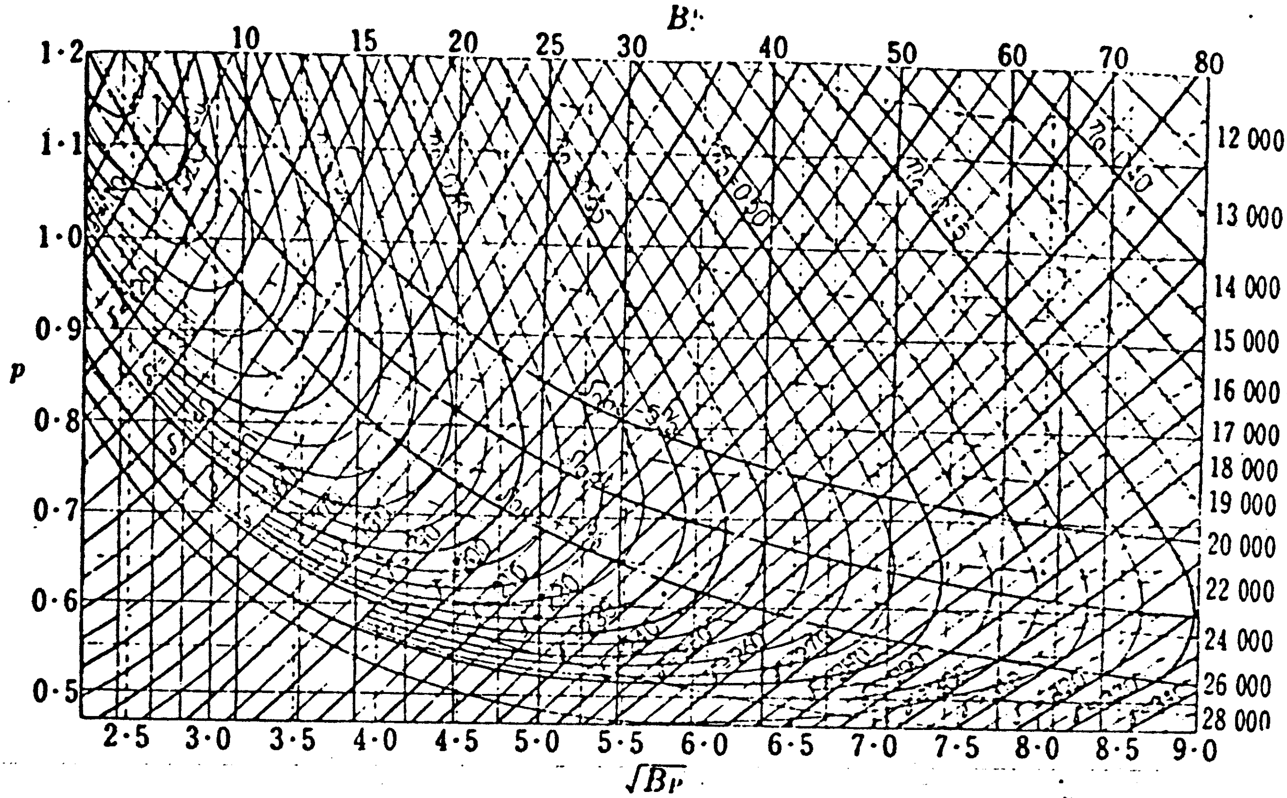


Fig. 62 (e) Troost B5—60

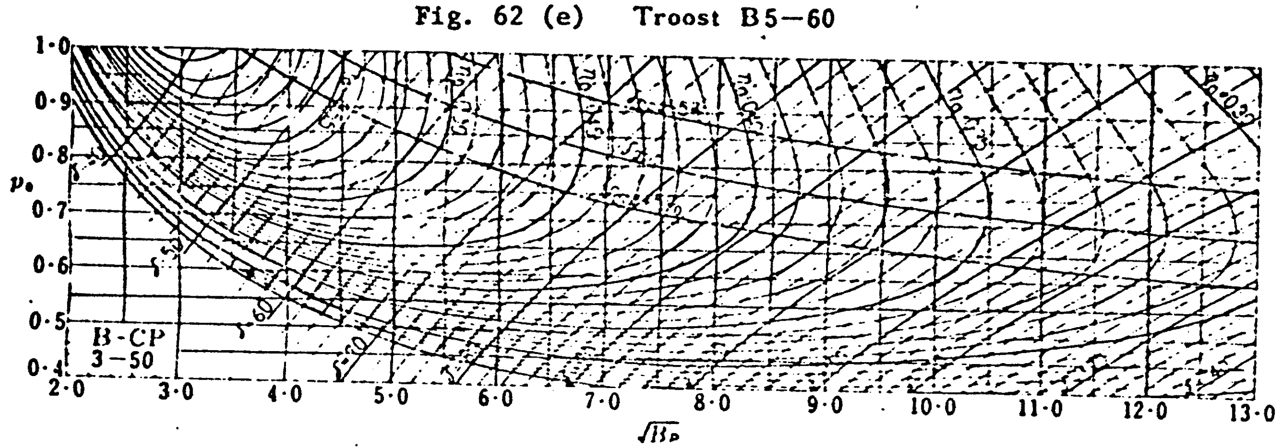


Fig. 63 (a) Ship Research Institute B-CP 3-50

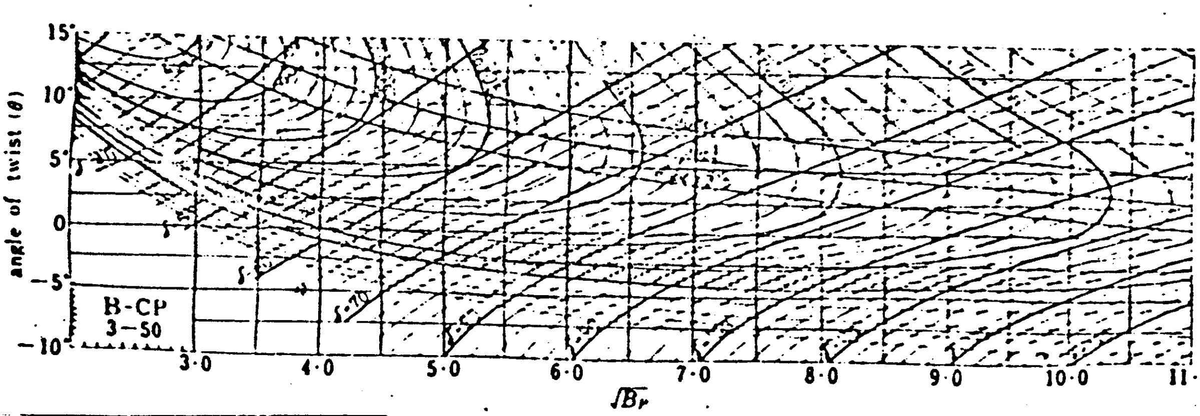


Fig. 63 (b) Ship Research Institute B-CP 3-50 (p_o=0·6)

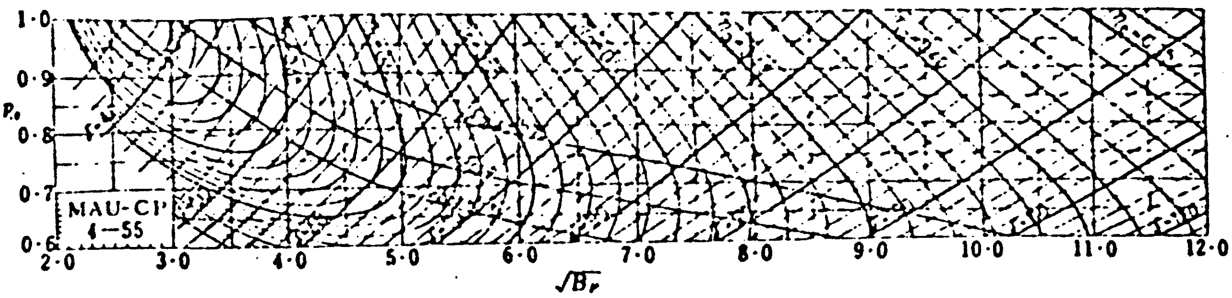


Fig. 63 (c) Ship Research Institute MAU-CP 4-55

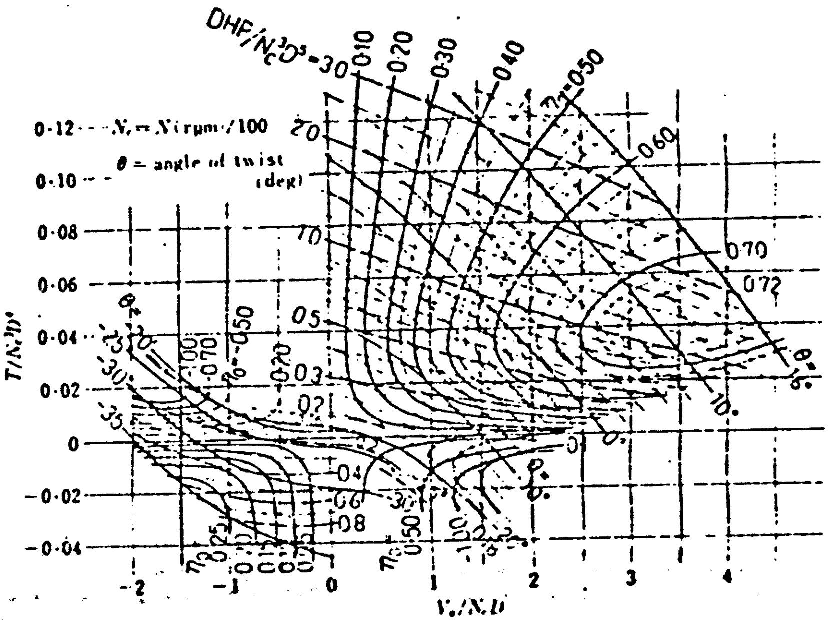


Fig. 63 (d) Ship Research Institute MAU-CP 4-55 (p_o=0·8)

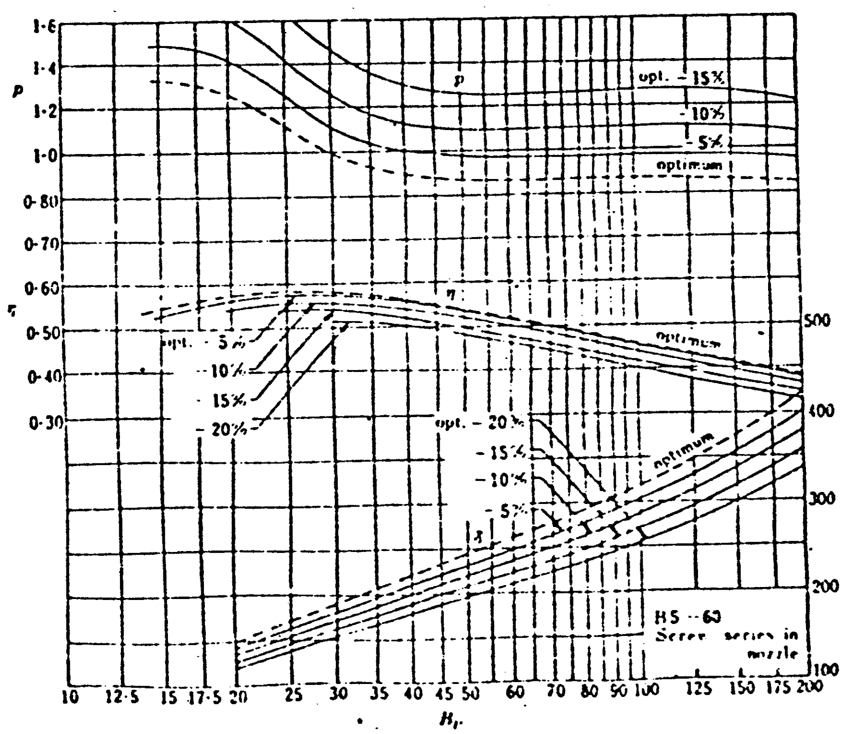


Fig. 64 Nozzle propeller of Wageningen B5-60

(3) $\mu-\sigma$ chart (non-dimensional) (Fig. 65)

$$\mu = n\sqrt{\frac{\rho D^5}{Q}} = \frac{1}{\sqrt{K_Q}}, \quad \sigma = \frac{DT}{2\pi Q} = \frac{1}{2\pi}\frac{K_T}{K_Q} = \frac{\eta_0}{J} \; ; \quad \varphi = V_A\sqrt{\frac{\rho D^3}{Q}} = \frac{J}{\sqrt{K_Q}}$$

When the particulars of propeller and the torque are given and one of T, n or V_A is decided, the other two values and η_0 are able to be easily obtained from this chart. This chart is convenient for the calculation of the performance of controllable pitch propeller and the towing force of the tug boat. $B_p-\delta$, $B_u-\delta$ charts are not convenient because they give extraordinary big values of B_p or B_u when $V_A=0$, but $\mu-\sigma$ chart does not give such extraordinary values and is very convenient for calculating the thrust of slow speed or moored condition. (Refer to 6.3.7.)

(4) Schmidt's charts
Schmidt charts are the converted one from K_Q-J chart to the form of K_Q-p (Fig. 66) or $K_{QD}'-p$ by adopting J as parameter. Each chart is convenient for the analysis of w and N.

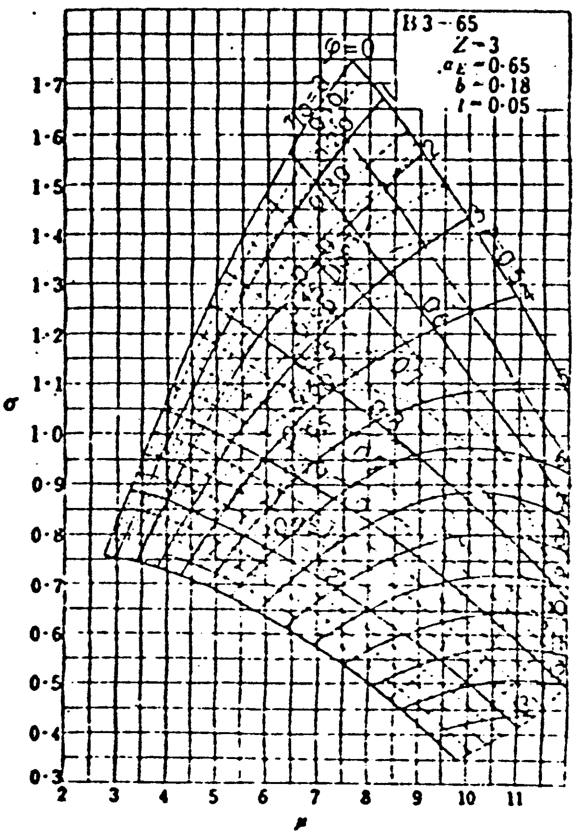


Fig. 65 Troost's $\mu-\sigma$ chart

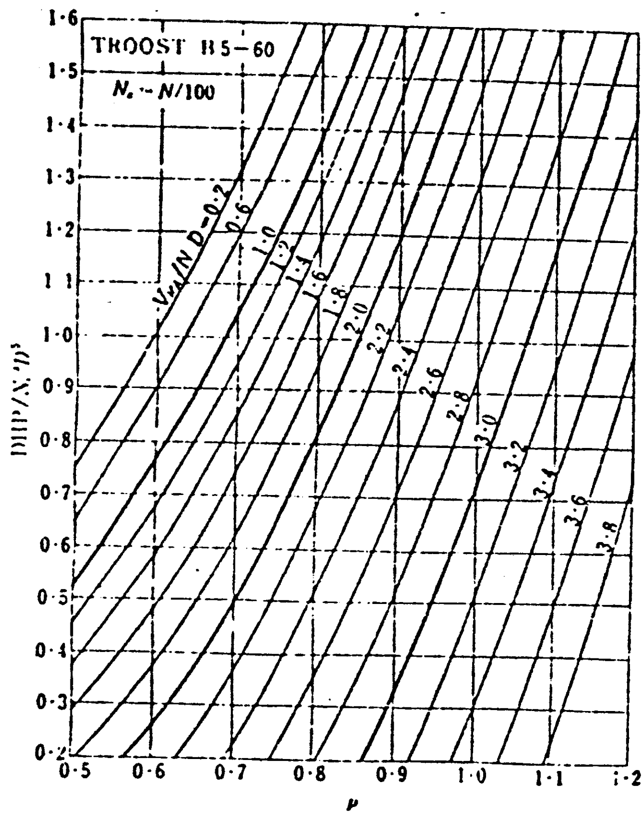


Fig. 66 Schmidt's chart, Troost B5-60

6.3.3. Design Method

Normally, the design is carried out based on the full load condition and maximum continuous or normal output of main engine without sea margin. In case of the merchant ship with normal hull form, the difference of B_P relating to the outputs of main engine is small and the results of the design are almost same because BHP and N are proportional to V^3 and V respectively. The revolution of the propeller N shall be taken 2 - 5% higher than the rated value considering the allowance for the reduction of the revolution due to the fouling of the bottom shell and propeller during the ship is in service. This is particularly important for the diesel propulsion ship because the maximum torque of the diesel engine is limited. It is recommended that for the wake factor the value of an actual type ship as similar as possible analysed on the same charts to be applied to the new ship in question shall be taken, because the wake factor has not so big influence to D but it much affects p and, as the result, the revolution N. (Refer to 6.4.1 (1))

The propeller performances given in the charts represent those in open water and it is necessary to give them some corrections in order to get the best propeller behind the hull. For example it is said that in case of Troost's chart, D shall be reduced by 2 - 5% for single screw vessel and by 2 - 4% for twin screws vessel depending on proportion of the ship's hull (more reduction for fuller hull). The diameter of the propeller given by each chart is a little different from each other. For example, MAU chart gives diameter of propeller about 5% smaller than Troost's chart.

(1) Design method using $B_P-\delta$, $B_U-\delta$ charts

When V_{EA}, N and P=DHP (U=THP) are given, B_P (B_U) is to be calculated and then p and $D=\delta \times V_{EA}/N$ are to be obtained in order to get the maximum η_o corresponding to the B_P (B_U). If δ_{opt} curve is given in the charts like Fig. 61 - 64, it is recommendable to use this curve to obtain the above figures. These procedures are carried out on the charts of every a_E while the values corresponding to a_E decided based on the study of the results of the sister ships and the cavitation are to be obtained by the interpolation method. If there is a limitation on the diameter, δ is to be calculated and then p and η_o are obtained from this δ and B_P (B_U). The result of the design shall be confirmed by reviewing THP and DHP according to this η_o.

(2) Design method using K_T, K_Q-J charts

$J=30\cdot 87 V_{EA}/(ND)=C_1 D^{-1}$, $K_Q=24670$ DHP$/(N^2 D^5)=C_2 D^{-5}$ are calculated on some D using given V_{EA}, N and DHP and then p, η_o are obtained from the charts. From these results, D, p, η_o are to be so decided as to give the maximum η_o. When THP is given, $K_T=5022$ THP$/(V_{EA} N^2 D^4) = C_3 D^{-4}$ is used instead of K_Q.

(3) Simplified design method

Fig. 67 shows the approximate calculation chart of the propeller diameter based on the shaft horsepower and the revolutions. Good approximation are given for 4 and 5 bladed propeller but a little (about 3%) smaller values are given for 6 bladed propeller.

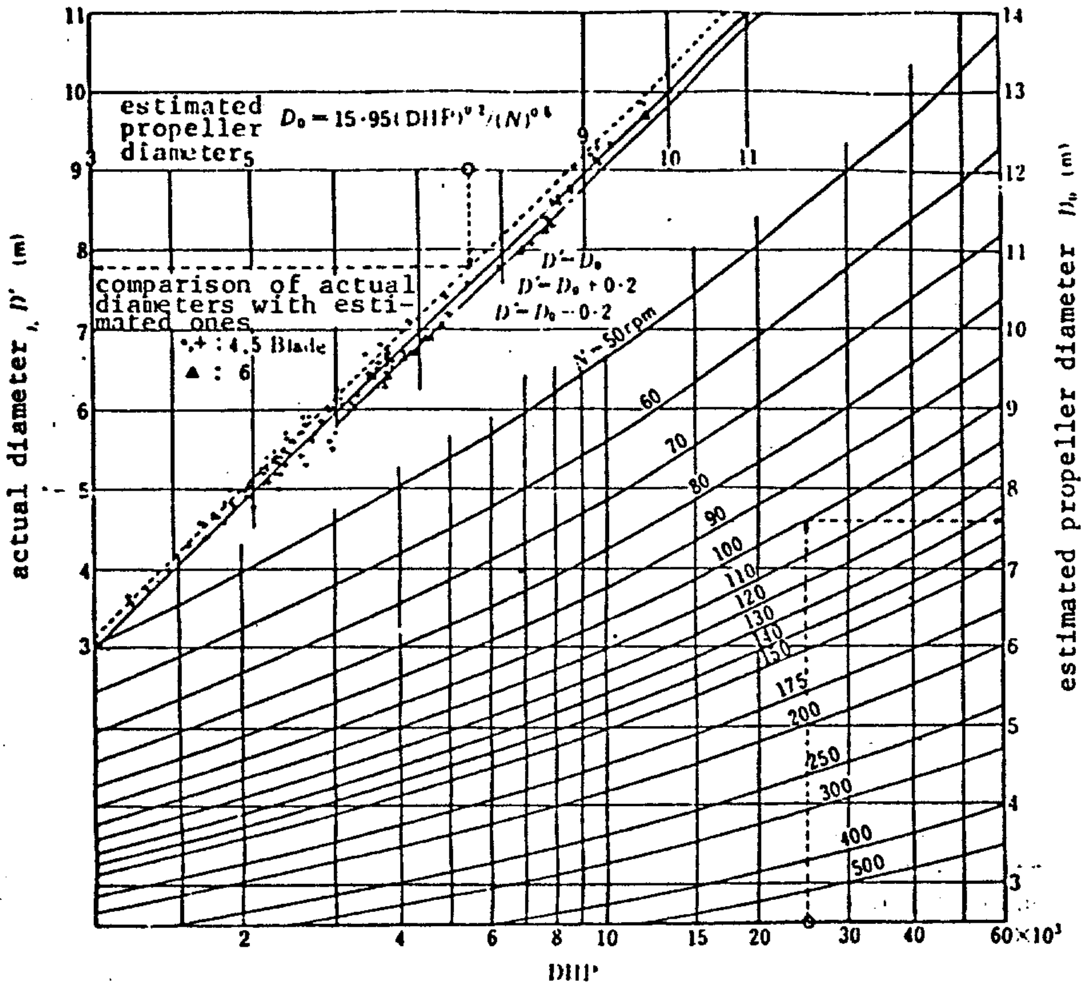


Fig. 67 Approximate calculation chart of propeller diameter

6.3.4. Effect of Various Factors, and Phenomena

(1) Expanded area ratio a_E

The smaller a_E is the higher η_o becomes, but abnormally small a_E is not recommendable because the thrust load on the blades becomes too heavy, which easily causes the cavitation.

(2) Blade profile

The slender tip blade gives larger η_o and is favorable to avoid air drawing but under heavy load the thrust load near the propeller edge is apt to become so heavy as to cause the cavitation.

(3) Skew back

Small influence is given to the performance of the propeller by skew back but it is able to reduce the effect of the turbulence of the wake by increasing the clearance between the stern frame and the propeller tip which is favourable from the viewpoint of prevention of the stern vibration. But abnormally big skew back is apt to cause cavitation and air drawing.

(4) Rake

Small influence is given to the performance of the propeller by rake but it gives prominent effect to increase clearance between the stern frame and the propeller blade. But abnormally big rake requires thick blade to ensure strength of the propeller (when the rake is given forward, the thickness of the blade can be reduced). (Refer to 6.3.6.)

(5) Section of blade

Generally the aero-foil section gives higher efficiency than the circular section, but the circular section is normally applied to tip part of the blade because it generates homogeneous pressure distribution on the blade which is more preventive of cavitation. The circular section is recommendable for a tugboat or an ice breaker because of its higher η_o (10% higher than that of the aero-foil section) in case of reverse revolution.

(6) Blade thickness-breadth ratio

The marine propeller of thinner blade, in general, gives larger η_o and the thicker blade is apt to cause cavitation. The different blade thickness-breadth ratios give the different hydrodynamical characteristics on their blade sections, and it is necessary to modify D, p and η_o when the values of the blade thickness-breadth ratio of the designed propeller are different from the same obtained by the charts applied.

If $\delta(t/l)$ = (Value of thickness-breadth ratio at $0{\cdot}7R$ of the adopted blade) - (value of the blade of the same series (Table 63)),

Correction amount of $D \fallingdotseq -\{0{\cdot}1 \times \delta(t/l) / (\text{thickness-breadth ratio of series propeller})\} D$

Correction amount of $p \fallingdotseq 2J \times \delta(t/l)$

Correction amount of $\eta_o \fallingdotseq -(2J - 0{\cdot}5p) \times \delta(t/l)$

4/3 times of correction to p and η_o are to be adopted for the propeller of the circular blade form.

(7) Boss ratio b

The smaller boss ratio gives the higher η_o. If δb = (adopted value) - (b of chart (Table 63)),

Correction to $p \fallingdotseq 0{\cdot}1\,\delta b$

Correction to $\eta_o \fallingdotseq -0{\cdot}75\,\eta_o (b_m - 0{\cdot}05)\,\delta b$ (in case of $s_a = 0{\cdot}2 \sim 0{\cdot}8$)

Where b_m = Average value of adopted b and b of chart applied. When s_a becomes smaller, η_o decreases further. 4/3 times of correction to each value shall be made in case of the propeller of circular blade form.

(8) Pitch distribution

In the open water, increasing pitch gives higher η_o than constant pitch, but behind the ship, the difference of efficiency between them has varied by each case of experiment and no definite theory has been established.

(9) Shaft rake

The efficiency of the propeller becomes worse according to the increase in angle of the shaft rake.

(10) Propeller immersion

The efficiency of the propeller becomes worse according to the decrease in I/D (Refer to Fig. 68 (a)). When I/D is too small, the equilibrium of the water surface pressure is broken and air draw is caused and then rapid increase in revolution and rapid decrease in thrust may occur.
These are apt to be caused when p and s_a are too large (Fig. 68 (b)).

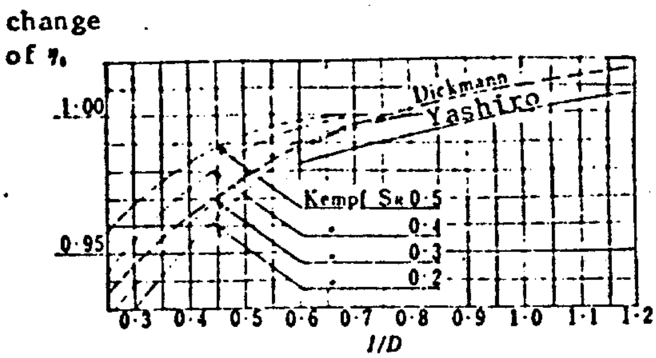


Fig. 68 (a)

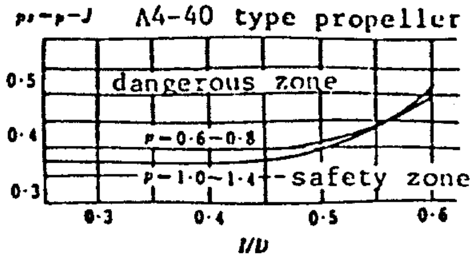


Fig. 68 (b)

(11) Fouling
When the surface of the propeller blades is fouled, η_0 drops to much extent.

(12) Singing phenomenon
Singing is caused by the resonance of the natural frequency of the propeller blades with the periodical pressure of the Karman Vortex (Refer to Chapter I, 4.2.3) caused by the trailing edges of the propeller blades. In order to prevent singing, the thickness and shape of the trailing edges of the propeller blades shall be changed.

6.3.5. Cavitation
There are face cavitation which occurs on the front face of the blade, back cavitation on the back face of the blade and tip vortex cavitation on the blade tip or boss part. Face cavitation occurs in the vicinity of leading edge when the angle of incidence becomes negative. When the wake variation is expected such as the case of a full ship, attention should be paid to avoid this cavitation. Erosion on the leading edge of the blade due to this cavitation should be avoided in order to keep the strength of the blade. Wash-back on the leading edge is effective to prevent face cavitation. The most harmful cavitation is the back cavitation and there are three types of back cavitation as follows;
Sheet cavitation occurs in the vicinity of leading edge of the blade as if the blade is covered by a sheet and excessive negative pressure on the leading edge causes this cavitation. This cavitation is rather stable and considered not to damage the propeller blade.
Cloud cavitation which occurs only in the field of non-uniform flow is most harmful to the propeller blade. This cavitation occurs at the near of the sheet cavitation and seems to have some relation to the collapse of the sheet cavitation. Bubble cavitation caused by the excessive negative pressure near the centre line of the blade or the part of the maximum blade thickness is also harmful to the propeller blade.
Back cavitation occurs when following condition in relation to the propeller form is fulfilled;

$$p-e \leq \text{(partial negative pressure on the blade)} = k\times(\text{lift})/(l\,dr)$$
$$= k\frac{1}{2}\rho V_r^2 C_L$$

Where, p = Absolute static water pressure including atmospheric pressure (10,336 kg/m^2)
e = Vapor pressure of the water at the corresponding temperature (Table 66)
k = Partial load factor
V_r = Inflowing velocity of the water to the propeller blade
C_L = Lift coefficient (Refer to Chapter I, 4.4), l = Blade breadth

Table 66 Water temperature and vapor pressure

Temperature °C	0	5	10	15	20	25	30	35	40
e kg/m^2	62	89	125	174	238	322	433	573	752

Cavitation is caused by excessive V_r and C_L due to too large angle of attack or by excessively small l. And also, unsuitable blade form such as blade of too much thickness, sharp change in curvature of blade section cause cavitations by generating excessive partial load on the blade (suction peak due to excessive k). There are many measures to prevent cavitation such as increasing the blade breadth, reducing the blade thickness and reducing angle of attack, but the most effective measure is to adopt the blade form which gives negative pressure distribution with low peak. Circular blade form is adopted in the vicinity of the blade tip where cavitation is apt to be caused because circular blade gives more uniform pressure distribution compared with the aerofoil blade form. Special attention should be paid to shaping of the part with a sharp change of radius such as the leading edge of the blade. On pressure face of the blade near the root, face cavitation sometimes occurs because of the effect of the negative back pressure of the adjacent blade, but this can be avoided by adjusting the pitch distribution or by giving wash-back.
In case of usual merchant ship, erosion is more troublesome than the decrease of the efficiency and it is important to adopt the resistible material against the corrosion or to give some extent of initial thickness margin against the corrosion to the thin parts of the blade tip or the trailing edge of the blade. It is recommended to investigate the past data about the erosion when the design of the propeller is carried out. Vast erosion research reports are published by the SR 81 as research data No. 48 (1966).

(1) Cavitation number (σ)
Cavitation depends on the external conditions such as static pressure on the propeller, water temperature etc. These external conditions are represented by the cavitation number.

$$\sigma=(p-e)/(\tfrac{1}{2}\rho V^2)$$

(2) Prediction methods of cavitation

(a) Burrill's chart (Fig. 69)
Limitation value of thrust load factor against cavitation number is given based on $V^2=V_a^2+(0.7\,D\pi n)^2$

$$p-e\doteqdot 10\,000+1\,025\times I\ (\mathrm{kg/m^2})\ \text{at } 25°\mathrm{C}$$

where, I = Immersion of the propeller shaft (m)

(b) Amari's chart (Fig. 70)
Allowable limits of thrust load against circumferential πDN are shown.

(c) Lerbs' formula
Critical revolution n(rps) at which thrust reduction occurs due to cavitation is calculated by the following formula:

$$n=\frac{1}{2D}\sqrt{\frac{\pi p_s a_E}{\rho k_c}}$$

Where, $p_s=p-e\ (\mathrm{kg/m^2})$, $k_c=0.213+0.144\,p^{1.4}$ (for 4 blades)
$k_c=0.114+0.153\,p^{1.4}$ (for 3 blades)
p = Pitch ratio

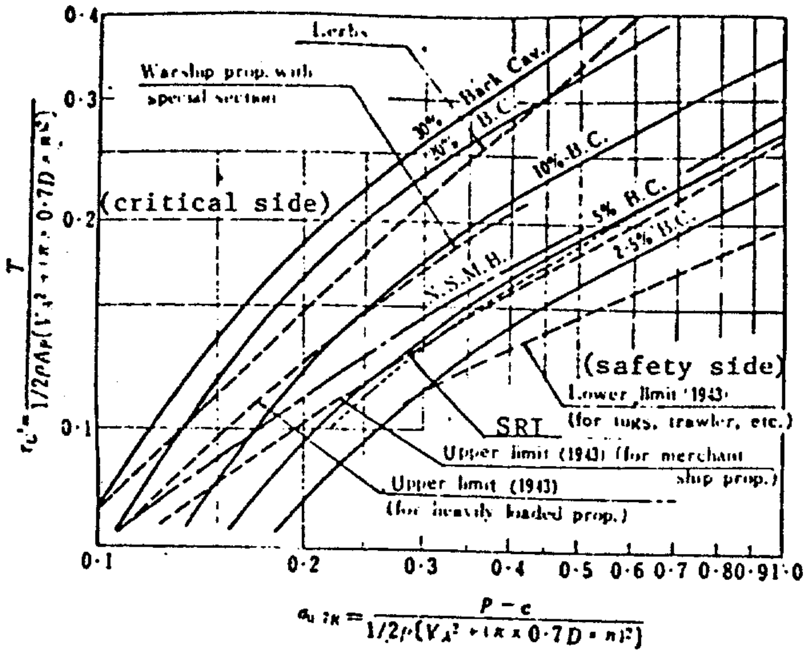


Fig. 69 Burrill Cavitation Chart

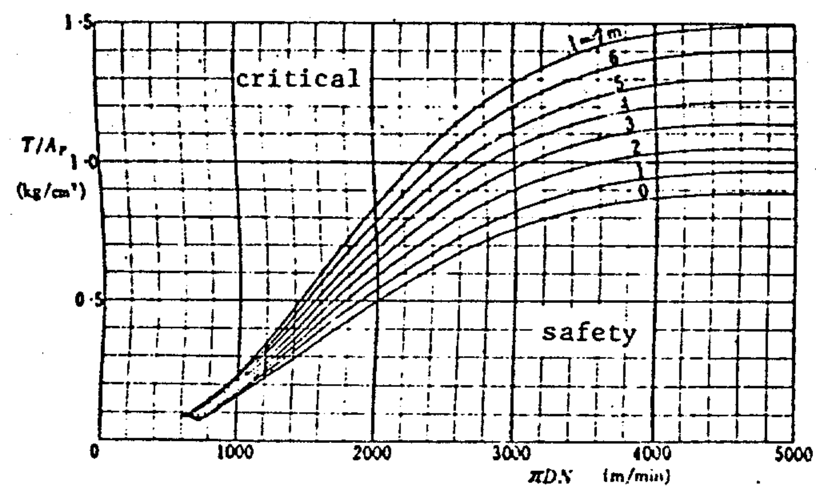


Fig. 70

(d) Eggert's formula

Critical revolution for occurrence of cavitation n_c (rps) are given by the following formula:

$$n_c = \frac{0.635}{D}\sqrt{H \cdot \frac{1+4b}{(a+c)k}}$$

where, $H = 10 + I$ (m) , b = Average blade breadth ratio,

$a = (H/0.9D)(s'/2\pi k)$, s' = Real slip ratio at 0.9R

$= 1 + [(1/\pi)(H/0.9D)]^2 \cdot (1 - s'/2)^2$,

c = Blade thickness-breadth ratio at 0.9R

(e) Nakashima's method

Critical revolutions N_c for a certain radius r can be calculated for circular form, aerofoil form, Troost form and MAU form blades respectively. And also we can predict the type of cavitation based on the sectional lift coefficient and sectional thickness-breadth ratio.

$$N_c = \left[\frac{p-e}{\frac{1}{2}\rho D^2 \{J^2 + \pi^2 (r/R)^2\} \Delta p/q} \right]^{1/2} \times 60 \text{ (rpm)}$$

$$C_L = \frac{a\left\{\tan^{-1}\dfrac{P/D}{\pi(r/R)} - \tan^{-1}\dfrac{J}{\pi(r/R)} + b\dfrac{t}{l}\right\}}{1 + C\left(\dfrac{l}{D}\right)E}$$

where, $p-e = 10\,100 + 1\,025 \times I - e \text{ (kg/m}^2\text{)}$, $\rho = 104.5 \text{ (kg sec}^2\text{/m}^4\text{)}$

I = Immersion of propeller shaft (m).

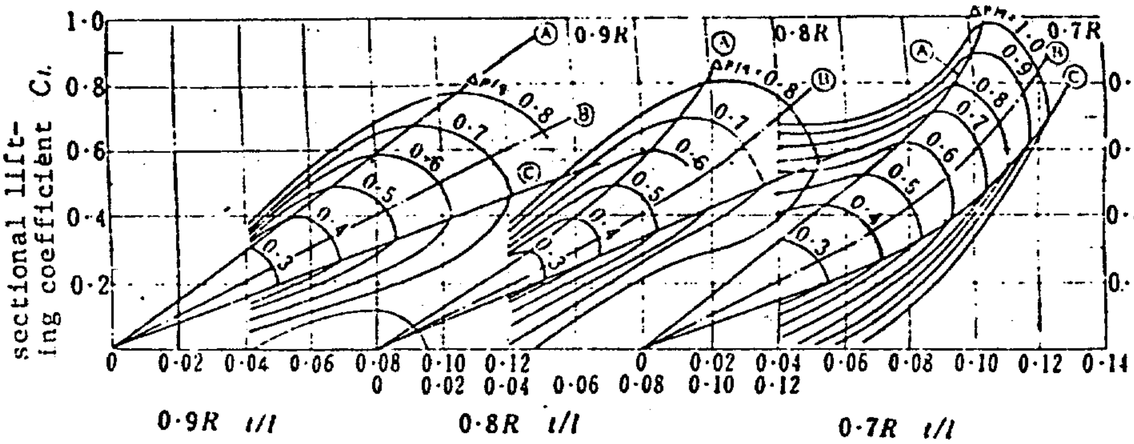
t/l = Sectional thickness-breadth ratio

b = 0.75 (aerofoil section), 1.00 (circular section)

a = 5.46 (ditto), 5.15 (ditto)

C, E: Refer to Table 67

$\Delta p/q$: Refer to Fig. 71 (a), (b)



Ⓐ = upper limit (back cavitation apt to cause on the left of this limit)

Ⓑ = design curve

Ⓒ = lower limit (face cavitation apt to cause on the right of this limit)

Fig. 71 (a) Cavitation chart for Troost type propeller

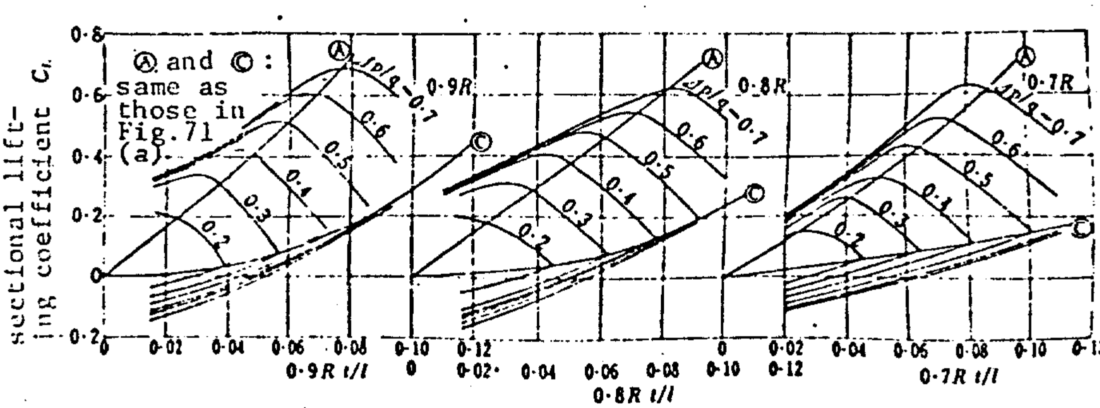


Fig. 71 (b) Cavitation chart for MAU type propeller

Table 67 Coefficient *C* and *E*

Affecting coefficient *C*, *E* for finite blade

$$C=\frac{khl}{4\pi}\frac{R}{r} \qquad E=F\sqrt{1+\pi^2\left(\frac{r}{R}\right)^2/J^2}=a_0+a_1\frac{1}{J}+a_2\frac{1}{J^2}$$

r/R \ Number of blade			6 Circular section	6 Aerofoil section	5 Circular section	5 Aerofoil section	4 Circular section	4 Aerofoil section	3 Circular section	3 Aerofoil section	2 Circular section	2 Aerofoil section
0·9	*C*		2·74	2·90	2·28	2·41	1·82	1·93	1·37	1·45	0·91	0·97
	E	a_0	1·558		1·954		2·526		3·437		5·199	
		a_1	1·803		1·635		1·459		1·291		1·137	
		a_2	0·177		0·194		0·204		0·199		0·172	
0·8	*C*		3·14	3·33	2·62	2·77	2·10	2·22	1·57	1·66	1·05	1·11
	E	a_0	0·633		0·789		1·060		1·547		2·503	
		a_1	2·081		1·962		1·775		1·500		1·148	
		a_2	0·080		0·103		0·135		0·175		0·205	
0·7	*C*		3·65	3·86	3·04	3·22	2·43	2·58	1·82	1·93	1·22	1·29
	E	a_0	0·496		0·548		0·662		0·919		1·535	
		a_1	1·896		1·851		1·758		1·566		1·199	
		a_2	0·054		0·063		0·081		0·117		0·173	
0·6	*C*		4·32	4·58	3·60	3·81	2·88	3·05	2·16	2·29	1·44	1·52
	E	a_0	0·515		0·531		0·574		0·699		1·079	
		a_1	1·587		1·573		1·535		1·432		1·158	
		a_2	0·052		0·054		0·062		0·082		0·132	

6.3.6. Strength

(1) Propeller material

Corrosive resistibility and toughness are required for propeller material and Manganese Bronze (MnBr), Nickel Aluminium Bronze (NiAlBr), Cast Iron or Cast Steel are used for this purpose. Classification societies' requirements for the bronze materials are shown on Table 68. Tensile strength(s) of cast iron commonly used for spare propeller is 19-25 kg/mm^2 (NK). NiAlBr has a properties of $S \fallingdotseq 50 \sim 60$ kg/mm^2, specific gravity ≒ 7.6, each greater by 25% and less by 10% compared with MnBr, which result in weight saving of about 15% in total. NiAlBr also has good corrosive resistibility.

Table 68

Class	Material	Tensile strength S		Elongation %
		Same sample	Separate sample	
NK	Mn Br	>44 kg/mm²	>47 kg/mm²	>20
	Ni Al Br	>60 〃	>63 〃	>15
	Hi Mn Al Br	>60 〃	>63 〃	>15
AB	Mn Br	>60 000 psi	>65 000 psi	>20
	Ni Al Br	>85 000 〃	>85 000 〃	>15
	Hi Mn Al Br	>90 000 〃	—	>20
LR	Mn Br	>44 kg/mm²	>47 kg/mm²	>20
	Ni Al Br	>63 〃	>66 〃	>15
	Hi Mn Al Br	>60 〃	>63 〃	>15
NV	Mn Br	>45~50 kg/mm² >50~55 〃	same as left.	>22 >20
	Ni Al Br	>55~60 〃 >60~65 〃 >65~70 〃	same as left	>18 >16 >14
	Hi Mn Al Br	>60 〃	>60 kg/mm²	>16 (same sample) >22 (separate sample)

(2) Calculations of blade thickness

MnBr has approximately same strength against both compression and tension, so the blade thickness is decided based on the maximum compressive stress which is larger than maximum tensile stress, while the blade thickness of cast iron, tensile strength of which is lower than compressive strength, is determined by the maximum tensile stress. Actual forces working on the propeller are so much complicated and the calculation of stress is so difficult that the simplified calculations are carried out under some assumptions and it is commonly adopted to decide the blade thickness giving about 10 times of safety factor at the blade root taking into account the past actual results.

(a) Stress due to thrust and torque

Compound bending moment caused by thrust M_t and torque M_q is estimated as follows;

$M_p = M_t \cos\theta + M_q \sin\theta$ $M_l = M_t \sin\theta - M_q \cos\theta$ (Refer to Fig. 72)

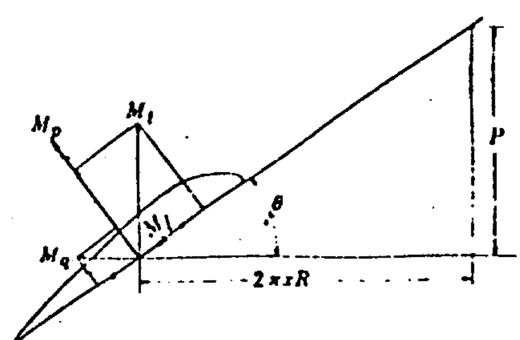


Fig. 72

Assuming the distribution of thrust being proportional to the radius and the efficiency of each blade being equal, and taking the pitch $P_x=p_xD$ at a certain radius $r=xR$, the values of M_p and M_t at this position are:

$$M_{px}=\frac{4500(1-x)^2}{2\pi(1-b^2)\sqrt{p_x^2+\pi^2x^2}}\left\{\frac{\pi^2}{3}\frac{x(2+x)}{p_{0.7R}}\frac{\eta_0}{1-s_a}+p_x\right\}\frac{\mathrm{DHP}}{ZN}$$

$$M_{tx}=\frac{4500(1-x)^2}{2\pi(1-b^2)\sqrt{p_x^2+\pi^2x^2}}\left\{\frac{\pi^2}{3}\frac{p_x(2+x)}{p_{0.7R}}\frac{\eta_0}{1-s_a}-\pi x\right\}\frac{\mathrm{DHP}}{ZN}$$

Taking the pitch $P_b=p_bD$ at blade root, the moment (kg·mm) at the blade root are:

$$M_{pb}=k_1\left(k_2\frac{\eta_0}{1-s_a}+p_b\right)\frac{\mathrm{DHP}}{ZN},\quad M_{tb}=k_1\left(k_2\frac{p_b}{\pi b}\frac{\eta_0}{1-s_a}-\pi b\right)\frac{\mathrm{DHP}}{ZN}$$

where, $k_1=\frac{4500(1-b)}{2\pi(1+b)(p_b^2+\pi^2b)}$, $k_2=\frac{\pi^2}{3}\frac{b(2+b)}{p_{0.7R}}$ (Refer to Fig. 73)

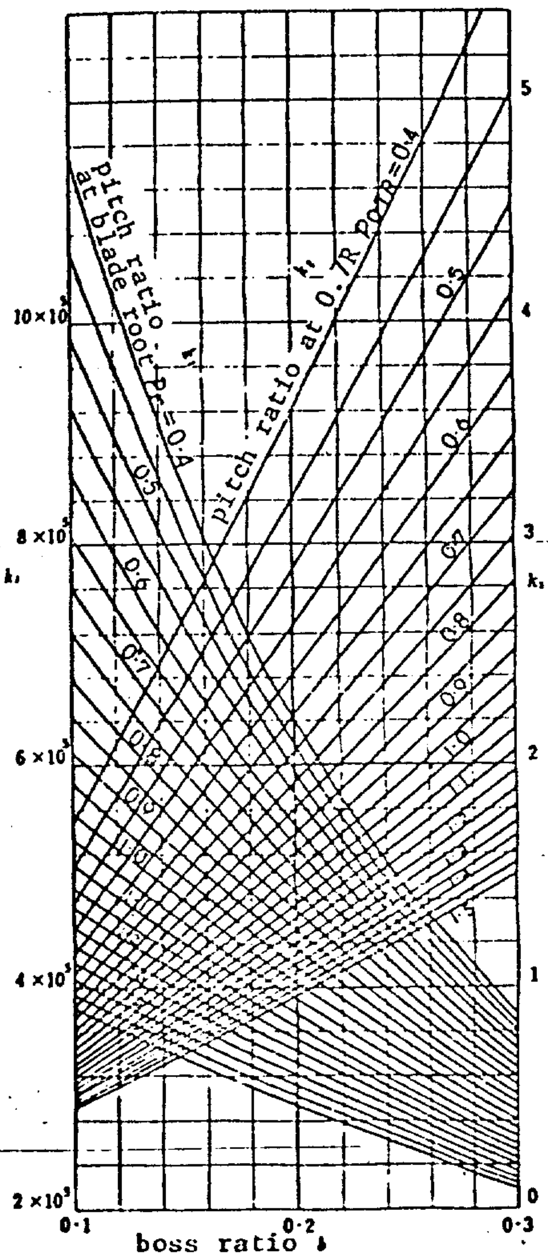


Fig. 73

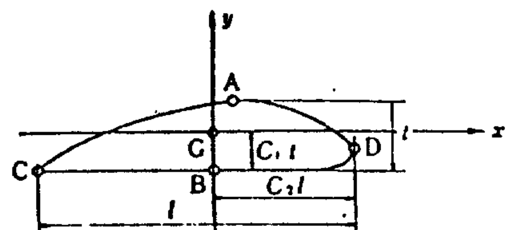


Fig. 74

Assuming the moment of inertia of the blade section about the x axis being $I_p=k_plt^3$ and about the y axis being $I_t=k_tl^3t$ as shown in Fig. 74,

Maximum compressive stress by M_p is

$$\sigma_c=\frac{1-c_1}{k_p}\frac{M_p}{lt^2}\quad\text{(at point A)}$$

Maximum tensile stress by M_p is

$$\sigma_t=\frac{c_1}{k_p}\frac{M_p}{lt^2}\quad\text{(at point B)}$$

Maximum compressive stress by M_t is

$$\sigma_c'=\frac{c_2}{k_t}\frac{M_t}{l^2t}\quad\text{(at point D)}$$

Maximum tensile stress by M_t is

$$\sigma_t'=\frac{1-c_2}{k_t}\frac{M_t}{l^2t}\quad\text{(at point C)}$$

Each coefficient around 0.2R is shown in Table 69.

Table 69

Blade Section		S.R.I. MAU Form	Troost B Form	Circular Blade Form
Position of Centre of Gravity	c_1	0.407	0.462	0.40
	c_2	0.434	0.439	0.50
Coefficient of Moment of Inertia	k_p	0.045	0.042	0.045
	k_t	0.036	0.039	0.033
Area Coefficient	a	0.680	0.701	0.75
Maximum Compressive Stress	Position	A	A	A
	Value	$13.1\frac{M_p}{lt^2}$	$12.8\frac{M_p}{lt^2}$	$13.33\frac{M_p}{lt^2}$
Maximum Tensile Stress	Position	C	B	C
	Value	$9.1\frac{M_p}{lt^2}+15.6\frac{M_t}{l^2t}$	$11.0\frac{M_p}{lt^2}$	$8.89\frac{M_p}{lt^2}+15.15\frac{M_t}{l^2t}$

Note) The position of maximum stress is shown in Fig. 74.

(b) Stress due to centrifugal force

Assuming the tensile stress uniformly distributing on the section due to centrifugal force σ_1 (kg/mm^2) and the compressive stress at point A due to the bending moment caused by the blade rake σ_2 (kg/mm^2),

$$\sigma_1 = A(B-x)\left(\frac{N}{100}\right)^2\left(\frac{D}{10}\right)^2 \qquad \sigma_2 = \theta\Phi\left(\frac{N}{100}\right)^2\left(\frac{D}{10}\right)^2\Big/T$$

where θ represents the inclining angle of the rake (deg).
For the propeller of MnBr of specific gravity of 8.33, A, B and T are shown in Table 70 and Φ is shown in Fig. 75.

Table 70

Blade Thickness Distribution	A	B	T
Linear Distribution	0.671	1.10	t
Hollow Distribution by Table 71	0.422	1.46	$(0.602\,b+0.899)\,t$

Maximum stress used for deciding the propeller blade thickness of MnBr is the compressive stress at point A which equals $\sigma_c-\sigma_1+\sigma_2$. The values of σ_1 and σ_2 for the usual propeller with rake of about 10 degrees are approximately 5% and 15 - 20% of σ_c respectively.

(c) Blade thickness distribution

By the results of the above calculations in which the thrust distribution is assumed to be proportional to the radius, and on the ground that allowable stress or safety factor is constant, the blade thickness distribution along the radius becomes linear but hollow distribution as shown by Table 71 can be applied if the calculation is made based on the eddy theory.

Table 71

r/R	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	0·95	1·00
$t/t_{0.1}$	1·00	0·840	0·701	0·574	0·463	0·361	0·261	0·166	0·072	0·036	0

The thickness of the blade tip shall be kept about 0.32% of D to avoid damage by foreign material.

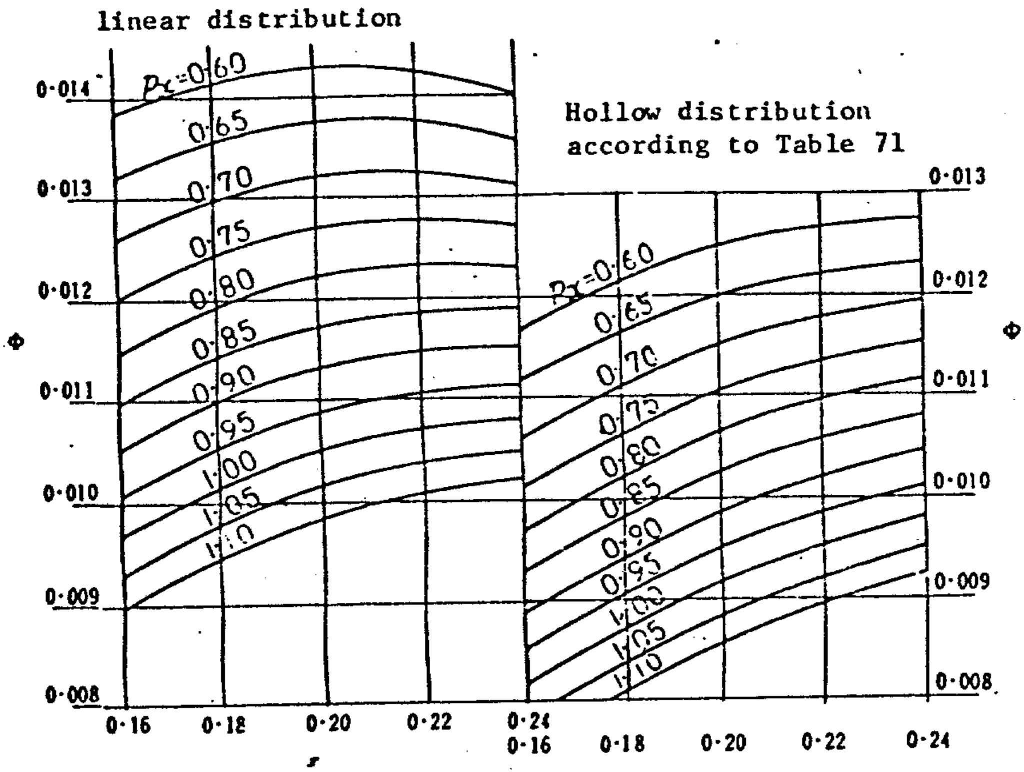


Fig. 75 Bending Stress Function Φ due to Centrifugal Force

(3) Boss

Boss is decided by the calculation of the expansive stress due to the thrust on the taper part of the propeller shaft.

$$\sigma_t=\frac{\alpha}{\pi}\,\frac{T}{r_1 l}\,\frac{(r_2/r_1)^2+1}{(r_2/r_1)^2-1} \doteqdot \frac{45\alpha}{\pi r_1 l}\,\frac{\mathrm{DHP}}{PN}\,\frac{(r_2/r_1)^2+1}{(r_2/r_1)^2-1} \qquad (\mathrm{kg/mm^2})$$

where, α = (Length of taper part)/(Decrease in shaft diameter on taper part) (Normally $\alpha=12\sim12{\cdot}5$)

l = Contact length (m)

r_1, r_2 = Inner and outer diameter of boss (m)

P = Pitch at 0.7R (m)

N = rpm

(4) Blade thickness, etc. required by rules of classification societies

(a) NK (1974)

$$t=\sqrt{\frac{K_1}{K_2}\frac{H}{ZNl}}$$

t = Blade thickness at radius of $0{\cdot}125D$ (cm)
H = Maximum continuous output of main engine (PS)
Z = Number of blades
N = Value of propeller maximum continuous RPM divided by 100 (rpm/100)
l = Blade breadth at radius of $0{\cdot}125D$ (cm)
D = Diameter (m)
P' = Pitch at radius of $0{\cdot}125D$ (m)
P = Pitch at radius of $0{\cdot}350D$ (m)
E = Rake at blade tip (on blade face) (cm)
t_0 = Blade thickness at shaft centre line (on the extention of the straight line between the both ends of thickness of the blade tip and the thickness at radius of $0{\cdot}125D$ on the projected plan of maximum blade thickness) (cm)

$$K_1=4{\cdot}5\left\{\left(4{\cdot}122-1{\cdot}755\frac{P'}{D}\right)\frac{D}{P}+\left(2{\cdot}561-1{\cdot}090\frac{P'}{D}\right)\frac{P'}{D}\right\}$$

or the value given by the plan of regulations

$$K_2=K-\left(1{\cdot}92\Big/\frac{E}{t_0}+1{\cdot}71\right)\frac{D^2N^2}{1000}$$

K = Coefficient given by Table 72.

Table 72 K Value for NK Blade Thickness Calculation

Material	Gray Iron (FC20 & over)	Cast Steel			Copper Alloy Casting		
		KSC42 or KSC42M	KSC46 or KSC46M	KSC49M	KH BsC1	KAI BC2	KAI BC3
K	0·6	0·9		1·0	1·0	1·1	1·3
Tensile Strength kg/mm^2	>20	>42	>46	>49	>44	>50	>60

Note) 1. Gray iron shall be of FC20 of JIS G5501 or of equivalent or higher quality
2. K shall be given for case if the material not listed above is to be used.
3. Following K, may be used instead of K for the small propeller of not more than 2.5 m in diameter.
for $2{\cdot}5 \geq D \geq 2{\cdot}0$ $K_1=(2-0{\cdot}4D)K$
for $2{\cdot}0 \geq D$ $K_1=1{\cdot}2K$

(b) Other classification societies' rules

i) AB, LR and NV define the blade thickness at the following position. Figures in ( ) show those for C.P.P.

AB: $0{\cdot}25R$
LR: $0{\cdot}25R$ $(0{\cdot}35R)$ and $0{\cdot}6R$
NV: $0{\cdot}25R$ $(0{\cdot}35R)$ and $0{\cdot}6R$

ii) NK and AB have the rules for the studs of a built-up propeller in addition to the blade thickness.

(5) Manufacturing tolerance (Table 73) and balancing

Table 73 Propeller Manufacturing Tolerance (ISO R484) $D \geq 0{\cdot}8$ m, $N \leq 1\,000$ rpm

Grade			S	I	II	III
Accuracy			High Accuracy	Medium Accuracy		Low Accuracy
Radius		%	±0.25	±0.5	±0.5	±0.5
		mm	2	3	3	5
Pitch	Local pitch (min.)	%	±1.5	±2.0	±3.0	
		mm	15	20	30	
	Average of 1 section of 1 blade (min.)	%	±1.0	±1.5	±2.0	±5.0
		mm	10	15	20	50
	Average of 1 blade (min.)	%	±0.75	±1.0	±1.5	±4.0
		mm	7.5	10	15	40
	Average of all blades (min.)	%	±0.625	±0.75	±1.0	±3.0
		mm	6	7.5	10	30
Blade thickness	For maximum blade thickness for each section (max.)	%	+2.0	+3.0	+4.0	+8.0
		mm	2	2.5	3	6
	Ditto (min.)	%	-1.0	-1.5	-2.0	-4.0
		mm	1	1.5	2	4
Blade breadth	For each section breadth	%	±1.0	±1.0	±1.5	±2.0
		mm	1.5	5	10	10
	(Difference of centre line)/D	%	±0.25	±0.5	±0.75	±1.0
		mm	5	10	15	20
Rake	(Longitudinal difference at 0·3 R, and 0·95 R /D	%	±0.5	±1.0	±1.5	±3.0
		mm	5	10	15	30
Finishing of blade surface	Maximum value of average roughness of blade		3	9	19	

6.3.7. Calculation of Performances

(1) Towing force and stopping thrust
Towing force = $(1-t)T-R$ is calculated from the simplest $\mu-\sigma$ chart based on relations of Table 74 among the particulars of the propellers. For example, if Q is constant, φ is calculated making V_A as variable, μ and σ are obtained from the cross point of φ and p and then N and T are obtained from μ and σ respectively,
where, t = Thrust reduction coefficient (Refer to 6.4.1 (1)),
R = Natural resistance of the vessel.
In case of calculating the stopping thrust, μ and σ are obtained taking $V=0$ or $\varphi=0$, and then $T=2\pi\rho n^2D^4\sigma/\mu^2$. $\mathrm{SHP}=\frac{2\pi\rho}{75\mu^2}n^3D^5$, but effective thrust $T'=T(1-t)$, $t\fallingdotseq0{\cdot}04$

Table 74

Given value		DHP	N	Q
Variables		N	DHP	N
Relation formula	$Q=\frac{75}{2\pi}\frac{DHP}{n}$	k_1N^{-1}	k_1' DHP	k_1''
	$\mu=n\sqrt{\frac{PD^5}{Q}}$	$k_2N^{1\cdot5}$	k_2' DHP$^{-0\cdot5}$	$k_2''N$
	$V_A=\varphi\sqrt{\frac{Q}{PD^3}}$	$k_3\varphi N^{-0\cdot5}$	$k_3'\varphi$ DHP$^{0\cdot5}$	$k_3''\varphi$
	$T=\sigma\frac{2\pi Q}{D}$	$k_4\sigma N^{-1}$	$k_4'\sigma$ DHP	$k_4''\sigma$

If $\mu-\sigma$ chart is not available, calculations shall be made using K_T, K_Q at $J=0$ on the K_T, K_Q-J charts.

(2) Revolutions
To calculate the revolution per minute N from the given particulars of propeller V_{EA} and DHP, $K_{QD}'=0{\cdot}8389\frac{\mathrm{DHP}}{V_{EA}^3D^2}$ is calculated first, and on the other hand $K_{QD}'=\frac{K_Q}{J^3}$ is also calculated based on the K_Q-J chart taking J as variable and using J which gives same value for both cases $N=30{\cdot}87\frac{V_{EA}}{JD}$ is calculated.
When the resistance varies such as in the case of displacement change, $K_{TD}=5{\cdot}27\times\frac{\mathrm{THP}}{K_{VA}^3D^2}$ is calculated and on the other hand $K_{TD}=\frac{K_T}{J^2}$ is obtained from K_T-J chart as J being variable, and then N is obtained from the J which gives coincidence between the both cases.

(3) Resistance of free propeller and its revolutions
Estimating the point of torque being 0 or $K_Q=0$ on the K_T, K_Q-J chart and by using these J and K_T, the revolution and the negative thrust are obtained. As the results of the above calculations we are able to obtain the revolutions and resistance of free propeller without any friction loss on propeller shaft. If we need to consider the friction loss on propeller shaft, K_Q shall be obtained by the corresponding negative torque to the

friction loss and then the revolutions and resistance are obtained from the corresponding J and K_T .

(4) Resistance due to the fixed propeller

$$R_r = \frac{62 \cdot 0}{\sqrt{1+0 \cdot 52 p^2}} A_E V_A^2 \text{ (kg)}, \quad A_E = (\text{m}^2) \quad V_A = (\text{m/sec})$$

(5) Flow velocity behind the propeller V_r (near rudder)
(Refer to 8.1.1.(2))

(a) Jinnaka's formula

$$V_r^2 = [0 \cdot 4 V_A + 0 \cdot 6 \sqrt{V_A^2 + 10 n^2 K_T (D/2)^2}]^2 \fallingdotseq V_A^2 + 6 n^2 K_T (D/2)^2 \quad (\text{m}^2/\text{sec}^2)$$

where, V_A = Inflowing velocity to the propeller (m/sec)
n = Revolution of the propeller (rps)

(b) Shiba's formula

$V_r = nH_e$ (when the ship speed ≒ 0)

where, H_e = Effective pitch (m)

(6) Other special performances
Studies on the abnormal conditions such as normal and reverse revolution during forward advancing or astern moving of the ship or various performances when a blade is lost have been reported.

6.3.8. Weight and Moment of Inertia

(1) Weight
The following explanation is made on the propeller of MnBr of $\sigma = 8 \cdot 33$. Corrections due to the differences in specific gravities σ (Table 75) shall be required for other materials. And linear blade thickness distribution is taken up unless otherwise noted.

Table 75 Specific Gravity of Propeller Material

Material	MnBr	Cast Iron	Cast Steel	NiAlBr
σ	8·1～8·3	7·1～7·3	7·8～7·9	7·6

(a) Approximate weight
Solid type $0 \cdot 08 D^3$ (t) . Built-up type $0 \cdot 1 D^3$ (t). D in m

(b) Estimation of total weight can be made by Fig. 76 if D is given.

(c) Weight of the blade $Z\sigma \int_{R_B}^{R} A dr \fallingdotseq \varphi a_E D^3$ (t)

φ for Troost blade form are shown in Fig. 77,

where, R = Radius of the propeller (m)
R_B = Radius of the boss (m)

For the other blade form, the value shall be corrected by the area coefficient a listed in Table 69.

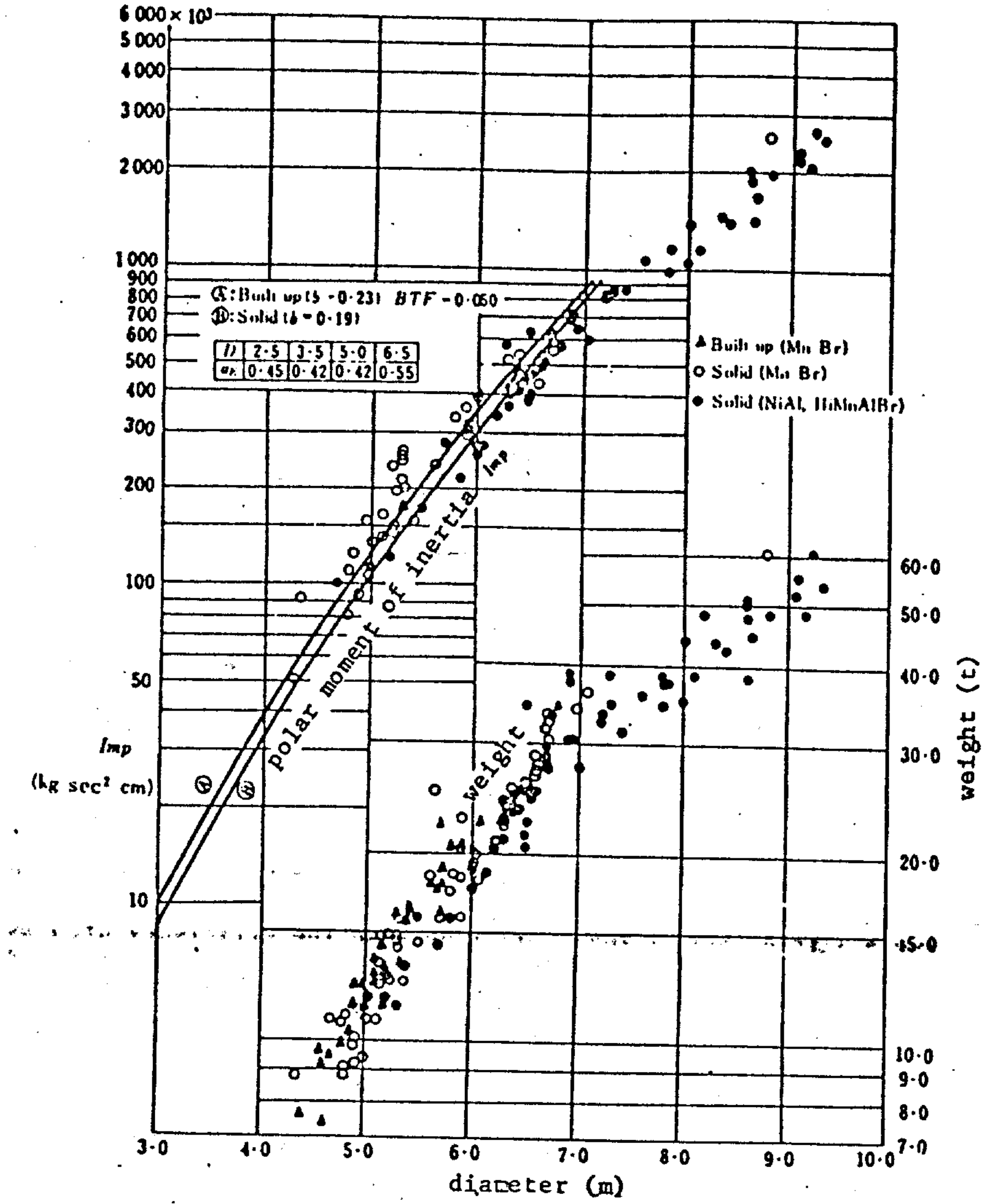


Fig. 76

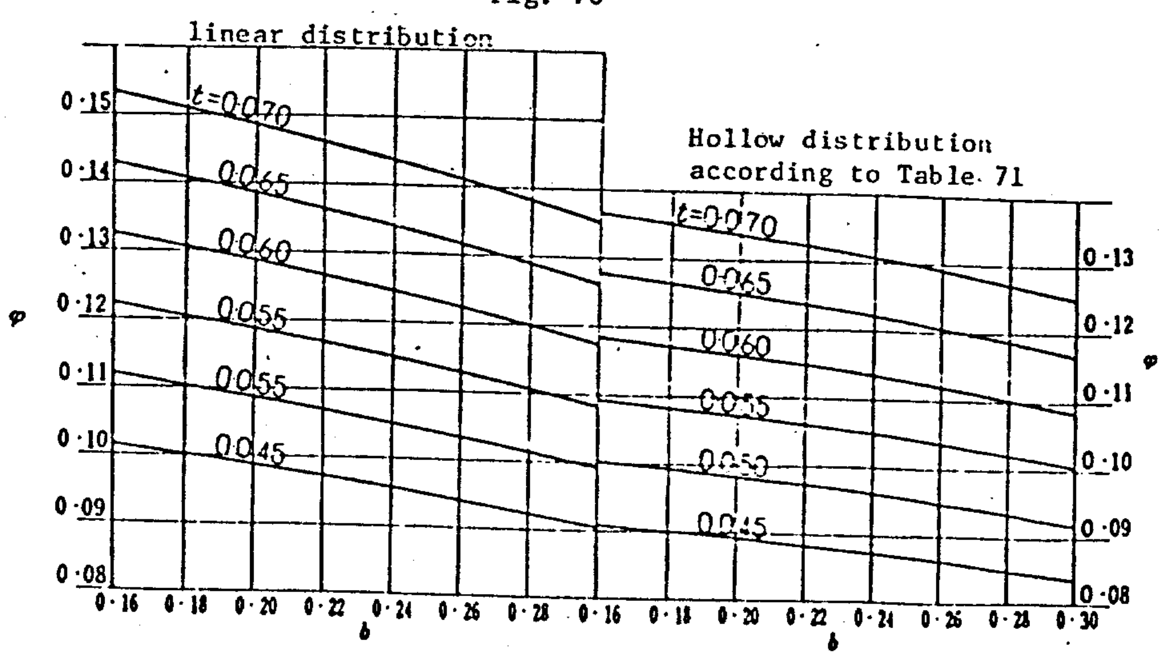


Fig. 77 Weight Function φ

(2) Moment of inertia

(a) When the boss is approximated to a cylinder of diameter = length,

$$I_{mp} = \frac{\sigma}{g}\left(Z\int_{R_B}^{R} A r^2 dr + \frac{\pi b^4 D^4}{32} l\right) \fallingdotseq \left(\frac{k a_E t}{1\cdot 115 - b} + 8\cdot 35 b^5\right) D^5 \times 10^4 \quad (\text{kg cm sec}^2)$$

where, R = Radius of the propeller (m)
R_B = Radius of boss (m)
A = Sectional area of the blade at a certain radius of propeller (m^2)
b = Boss ratio, l = Length of the boss (m)
t = Blade thickness ratio
k = 1.375 when the blade thickness is linearly distributed and $0\cdot 707b + 1\cdot 056$ when hollow distribution of Table 71 is adopted,
Unit of D : m

(b) When G = Propeller weight (kg) and D in m, following approximate formula is given.

$$I_{mp} = 2\cdot 548 G D^2 \quad (\text{kg cm sec}^2)$$

When the propeller works in the water, virtual mass effect of the water shall be considered. Increase in moment of inertia due to the virtual mass effect is proposed as 25 - 30%.

6.3.9. Special Propellers

(1) Controllable pitch propeller (C.P.P.)
Design charts shown in Table 63 are proposed. Representative ones are shown on Fig. 63 (a) - (d). It is reported that the standard pitch shall be decided a little smaller than normal, because the efficiency drop is bigger when the pitch angle is reduced than when the same is increased from the standard pitch.

(2) Nozzle propeller
Nozzle propellers have been applied to the vessels of heavy propeller load such as tugboats, trawl fishing boats, etc., but recently they are also applied to large full vessels. 6 - 7% of propulsive efficiency increase is obtained by applying the nozzle propeller to the large full vessels both for fully loaded and ballasted conditions, but slight increase in the range of unstable loop regarding manoeuvrability is reported. Combinations of nozzle rudder and propeller are widely applied to small ships and some designs of nozzle + propeller are disclosed (Refer to Fig. 64). Standard performance of the bollard pull of the tugboat is reported as shown in Table 76.

Table 76

Kind of Propeller	F P P	C P P	FPP with Nozzle	CPP with Nozzle
Unit bollard pull (t/100 PS)	1.0 - 1.1	1.2	1.3	1.4 - 1.5

6.4. Shaft Horse Power (SHP)

In general, there are two kinds of estimating method of the required shaft horse power, the one is to estimate SHP by combining the effective horse power and the propulsive efficiency and the other is direct estimation of SHP from the actual performances of the sister vessels.

6.4.1. Estimating Methods by Combining Effective Horse Power and Propulsive Efficiency

The required shaft horse power of the propulsive machinery is expressed by the following formula.

(BHP or SHP) = $EHP/(\eta_P \times \eta_T)$

where, η_P = Propulsive efficiency = $\eta_H \times \eta_B = \eta_H \times \eta_O \times \eta_R$

η_H = Hull efficiency $= (1-t)/(1-w)$, $1-t = R/T$, $1-w = V_A/V$

η_B = Propeller efficiency behind the hull = $TV_A/(2\pi nQ)$

η_O = Propeller efficiency in open water = $T_O V_A/(2\pi n Q_O)$

η_R = Relative rotative efficiency $= \eta_B/\eta_O$

= Q_O/Q (Coincide method of thrust) or

T/T_O (Coincide method of torque)

η_T = Shaft transmission factor = DHP/(BHP or SHP)

Shaft horse power, BHP or SHP, can be obtained from EHP mentioned in 6.2 and estimated η_P and η_T. η_P is able to be divided into the self-propulsive elements (t, w, η_R) and it is the common practice to calculate η_P by estimating the self-propulsive elements. There are two kinds of estimating methods of these self-propulsive elements, the one is a method of using the charts composed from a series of model test and the other is the method of conducting the model tank test.

(1) Estimating methods of self-propulsive elements

(a) Estimations by charts

i) Wake factor $w = (V - V_A)/V$

It is considered that the wake is composed of frictional wake, streamline wake and wave wake. The frictional wake, under the influence of R_n, for an actual vessel is less than that of the corresponding model and the wake for a model is not applicable directly to the actual vessel (Refer to Fig. 81). In addition, w depends on C_B, diameter of propeller, propeller aperture, form of the rudder and form of stern.

w for models and actual vessels of single screw is shown on Fig. 78. There are some other data available in this connection such as SR 61 hull form (Refer to Fig. 80), SR 45 hull form etc.

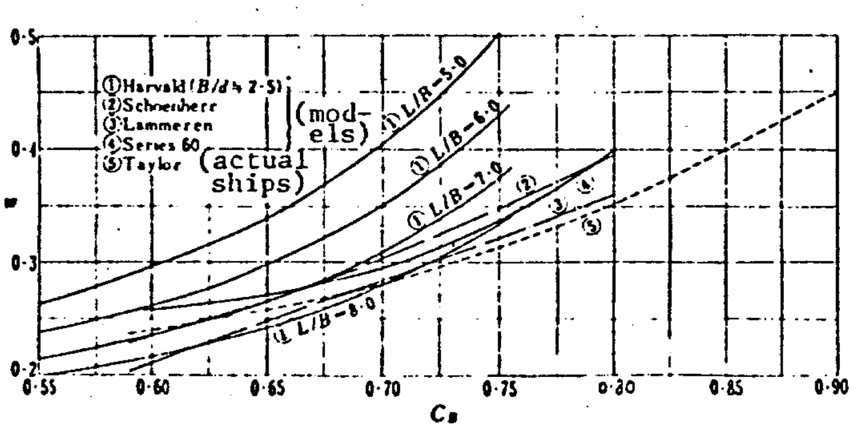


Fig. 78 Wake factor (single screw ship)

Following approximate formulas to estimate the wake factor around the propellers of a twin-screw ship are proposed.

Outward rotative propeller with bossing	$w = 2C_b^5(1-C_b) + 0.2\cos^2(1.5\alpha) - 0.02$
Inward rotative propeller with bossing	$w = 2C_b^5(1-C_b) + 0.2\cos^2(60^\circ - 1.5\alpha) + 0.02$
Propeller with strut	$w = 2C_b^5(1-C_b) + 0.04$

(The aboves are proposed by Schoenherr.)

Propeller with strut $w = (5C_b/6) - 0.353$ (Lammeren's formula)

where, α = Vertical rake of bossing (deg.)

The above formulas are applicable to the normal merchant ships with F_n of 0.3 and below and the wake factor for high speed ships becomes further less as follows:

Propeller with bossing : $w = 0.04 \sim 0.08$
Propeller with strut : $w = -0.02 \sim 0.05$

Besides the aboves, some data for car ferry etc. are available.
w much affects propulsive performance and it is recommended to estimate this figure from the analysis of the data on actual vessel as many as possible. In order to obtain w from DHP, N and V of the performance results of the actual vessel, the following methods can be applied:

1) Use of B_p chart (Fig. 61, Fig. 62) in 6.3.2.:
Firstly, λ is calculated from the performance results of the actual ship and then using the corresponding chart to the propeller, the corresponding value of δ shall be obtained which are derived from the cross point of P and λ on the chart where $\lambda = N^{1.5}D^{2.5}/\mathrm{DHP}^{0.5} = \delta^{2.5}/B_p = 157.1/\sqrt{K_Q}$. Finally the wake factor is obtained by the formula of $1 - w = ND/(\delta V_s)$.

2) Use of K_T, $K_Q - J$ chart (Fig. 57):
Firstly $K_Q = 24\,668\,\mathrm{DHP}/(N^3D^5)$ is calculated and then using the corresponding $K_Q - J$ chart to the propeller, the value of J is obtained on the chart. Finally the wake factor is obtained by the formula of $1 - w = NDJ/(30.867\,V_s)$.

3) Use of Schmidt's chart (Fig. 66) which is developped from the calculation method of 1):
The values of $V_A/(ND)$ are directly derived from the known values of P and $\mathrm{DHP}/(N^3D^5)$ on the chart. Therefore $1 - w = (V_A/V)$ are easily obtained by calculating V_A .

ii) Thrust deduction factor $t = (T-R)/T$ (T = Thrust, R = Resistance)
t is usually estimated from the actual results of the sister ships or the model tank test. The figures of the models are directly applied to the actual ships. For reference, the relations between t and w proposed for the single screw ship are as follows:

Schoenherr's formula $t = k \times w$, k is shown in Table 77.

Table 77

Form of Rudder	Stream Line Rudder	Double Plate Rudder with Rudder Post	Single Plate Rudder
k	0·5~0·7	0·7~0·9	0·9~1·05

Lammeren's formula $t=(w/1\cdot5)+0\cdot01$
Yamagata's formula $t/w=1\cdot63+1\cdot50C_B-2\cdot36C_v$

Other data are also available such as Series 60 hull form (Refer to Fig. 79), SR 61 hull form (Refer to Fig. 80) and SR 45 hull form (SR report 45, 1964) for single screw ships and car ferry hull form for twin screw ships.

iii) Relative rotative efficiency η_R
η_R for general merchant ships varies within the range of 0.95 - 1.05.

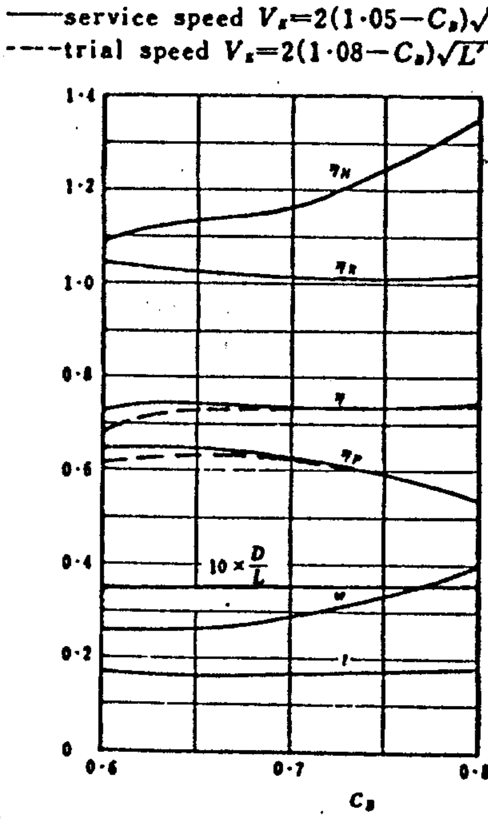


Fig. 79 Series 60, Coefficients of model test

Note) D/L = Diameter of propeller/ Length of ship
$= 0\cdot00317+0\cdot0005\times C_B$

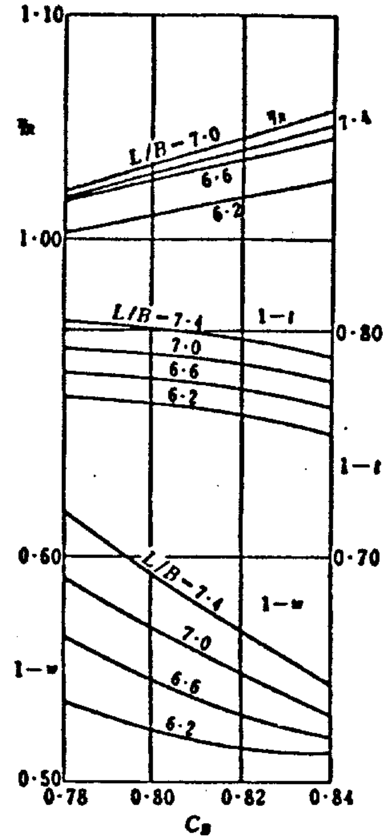


Fig. 80 SR 61 hull form, self-propulsive elements (fully loaded condition $D/L=3\cdot3\%$)

(b) Estimating methods by model tank test
The self-propulsion tests are carried out in accordance with the Froude's Law of Comparison and frictional corrections ΔR are applied to the test results to equalize the propeller load factor for both actual vessel and model.

$$\Delta R=-0\cdot5\rho_M S_M V_M^2\ \{C_{FM}-(C_{FS}+\Delta C_F)\}$$ (Two dimensional Extrapolation Method)

$$\Delta R=-0\cdot5\rho_M S_M V_M^2\ \{(C_{FM}-C_{FS})(1+k)-\Delta C_F\}$$ (Three Dimensional Extrapolation Method)

Firstly K_T, K_Q are obtained from V, n, T and Q measured in the self-propulsion tests and then J, η_R $(=J/2\pi\times K_T/K_Q)$ and η_o are obtained from the performance curves of the propeller adopted for the model test based on the obtained K_T . In general such thrust coincidence method is adopted for estimation. w, t and η_R are calculated by the following formulas using the values of obtained J, η_B, η_T mentioned above and the values of R_T etc. obtained from the towing tank tests:

$$1-w=JnD/V,\quad 1-t=(R_T-\Delta R)/T,\quad \eta_R=\eta_B/\eta_O$$

Sometimes, the wake is measured directly when the local water flow is to be considered (such as cavitation etc.). The average figure derived from the results of the above experiments is called "Nominal Wake" and the wake obtained from the former method is called "Effective Wake". These two wakes are separated clearly and usually there are some differences between these two figures. It is common to use the effective wake when the propulsion performances are discussed.

(2) Estimation of propeller efficiency η_O

(a) If the main particulars of the propeller are not given, the main particulars of the propeller are decided by the method in 6.6.3 while η_O is also obtained to confirm that these values satisfy the design conditions of the propeller.

(b) If the main particulars of the propeller are already given, $J-K_T/J^2$ curve shall be composed from the appropriate propeller charts. $K_T/J^2=T/(\rho D^2V_A^2)$ are calculated from T and V_A of the actual vessel and then η_O and N can be obtained from J to be found on the above curve.

(3) Estimation of shaft transmission factor η_T

In general, such figures listed in the Table 78 and Table 79 are adopted. η_T varies according to the revolution of the propeller and the ratio of transmission loss $(1-\eta_T)$ is shown on Table 80.

Table 79 η_T for Shaft Components

Components and Type of Shafting		η_T
Stern Tube		0.990
Inter-mediate Bearing (1 set)	Diesel engine, Reciprocating engine	0.997-0.9975
	Turbine, Electric Propulsion	0.998
Thrust Bearing	Collar Type	0.985
	Michel Type	0.995
Reduction Gear and Coupling	1-Stage Gear	0.975
	2-Stage Gears	0.950
	Hydraulic Coupling	0.975
	Electro-magnetic Coupling	0.975

Table 78

Location of M/E \ η_T	DHP/SHP	DHP/BHP
Midship	1/1.03	1/1.05
Aft	1/1.02	1/1.03

Table 80 Transmission Loss Ratio for Partial Loads

Load Ratio	1/4	1/2	3/4	4/4	115/100
Loss Ratio	2.53	1.59	1.21	1.00	0.91

(4) Estimations of wake relation factor $(1-w_s)/(1-w_M)$
One example of the estimation chart is shown on Fig. 81. Fig. 82 shows an example of the analysis results of the sea trials of actual vessels and the principal particulars of these actual vessels are shown on Table 81.

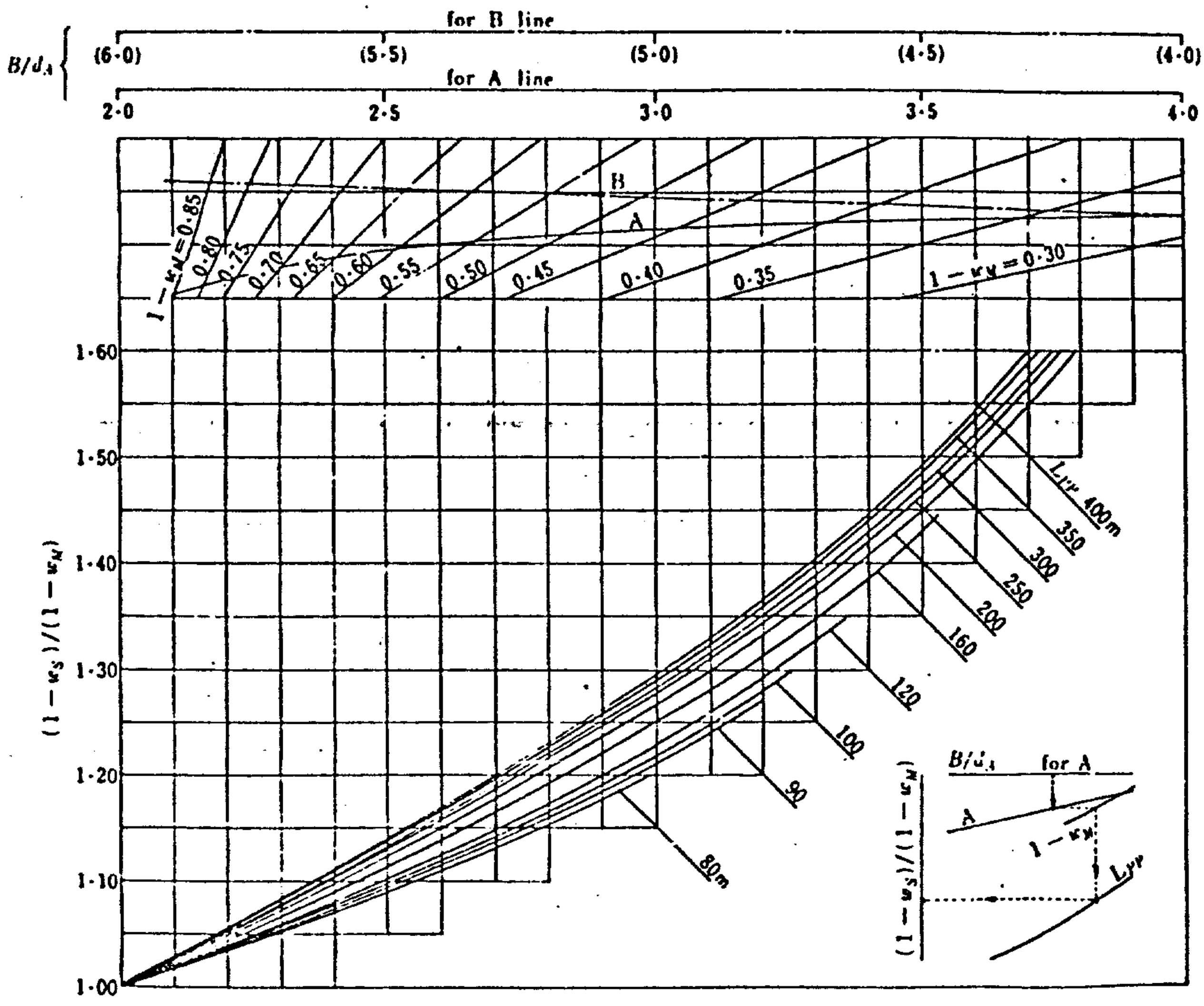


Fig. 81 Estimation Chart of $\frac{(1-w_s)}{(1-w_M)}$ for Single Screw Ship

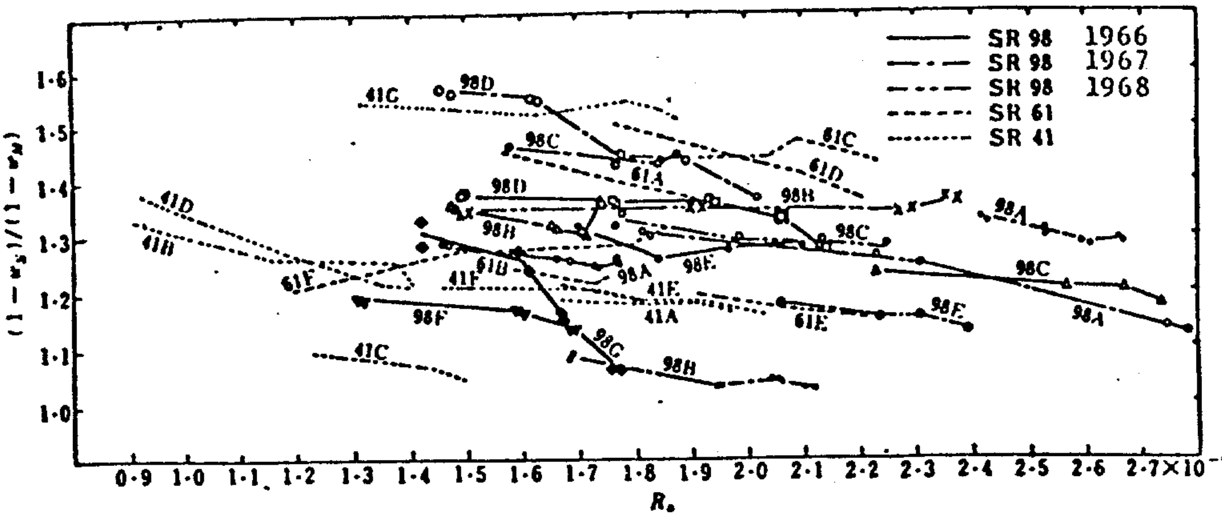


Fig. 82 $(1-w_s)/(1-w_M)$ (Fully Loaded Condition)

Table 81 Principal Particulars of Actual Ship (Tanker)

Marks	L_{pp}(m)	B(m)	d(m) (Full)	C_b (Full)	MCR M/E Output PS	MCR Revolution rpm	Trial Cond.	Bow Form
SR98 (1968) A	313.00	48.20	19.089	0.8356	28,000	90	Half	with Bulb
B	290.00	48.16	18.52	0.8347	29,000	90	Full	"
C	244.00	38.94	14.30	0.8208	20,700	115	Full	"
SR98 (1967) A	281.00	46.20	16.60	0.817	28,000	85	Full	"
B	243.20	37.20	13.06	0.818	24,335	108.5	Full	"
C	246.00	39.40	15.50	0.813	23,000	114	Full	"
D	255.00	42.00	16.47	0.808	23,000	115	Full	"
E	310.00	47.16	18.86	0.849	28,000	85	Half	"
SR98 (1966) A	237.00	38.90	13.02	0.813	21,600	119	Full	"
B	232.00	37.12	12.46	0.825	20,700	119	Full	"
C	256.00	42.50	15.80	0.808	24,000	105	Full	"
D	242.62	31.70	12.16	0.838	20,700	114	Full	"
E	290.00	47.50	16.00	0.805	30,000	97	Full	"
F	265.00	44.20	16.75	0.822	27,600	114	Full	"
G	260.00	42.00	15.468	0.807	24,750	114	Full	"
SR61 A	225.00	32.80	12.05	0.813	18,500	114	Full	without Bulb
B	242.00	37.20	14.63	0.812	24,000	105	Full	"
C	249.00	40.40	14.795	0.786	27,600	119	Full	with Bulb
D	248.41	38.10	14.27	0.798	26,500	110	Full	without Bulb
E	241.00	36.80		0.820	20,700	114	Half	"
F	228.00	35.80	12.169	0.819	20,700	119	Full	"
SR41 A	213.00	30.50	11.322	0.798	17,600	110	Full	with Bulb
B	213.00	30.50	11.33	0.800	16,000	119	Full	without Bulb
C	211.84	31.70	11.23	0.786	17,500	105	Full	"
D	213.00	30.50	11.35	0.800	17,600	105	Full	with Bulb
E	245.00	32.90	13.26	0.820	22,000	105	Full	"
F	213.00	30.50	11.394	0.795	17,600	105	Full	without Bulb
G	213.00	30.50	11.367	0.800	17,600	105	Full	with Bulb

6.4.2. Direct Estimation of Propulsive Power from Actual Performance of Sister Ships

(1) Admiralty constant (C_{adm}) method

It is considered that the vessels of similar hull form have the same $C_{adm}=\Delta^{2/3}V_s^3/DHP$ on the same $V/\sqrt{L}$ so that it is possible to estimate DHP of the new vessel directly from C_{adm} of the similar vessels. But C_{adm} relates only to the propulsive efficiency and resistance coefficients and the scale effect on these coefficients are not considered strictly. Therefore it is necessary to adopt the type ship having similarity with the new ship not only in the ratio of principal dimensions but also in L, hull form elements and type of main engine installed.

(2) Estimation method by correction to the ratios on resistances and efficiencies of similar ships

If we have the speed-power curves and particulars of the similar vessels, we can estimate the required shaft horse power according to the following procedures (Refer to Table 82, Fig. 83).

Table 82 Example of Calculation Sheets of Shaft Horse Power

$V/\sqrt{L}$	V_s	EHP_s	V_T	EHP_T	DHP_T	EHP_T/DHP_T	DHP_s'	DHP_s''

1) If the power curves corresponding to several displacements of the similar vessel are available, the power curve corresponding to the same displacement $\Delta_T=\Delta_s\times(L_T/L_s)^3$ which gives the same $C_v=\nabla_s/L_s^3$ as that of the new vessel by the interpolation method. (This curve is marked as Curve I. When we have only one speed-power curve of the similar vessel, this curve shall be used as it is.)

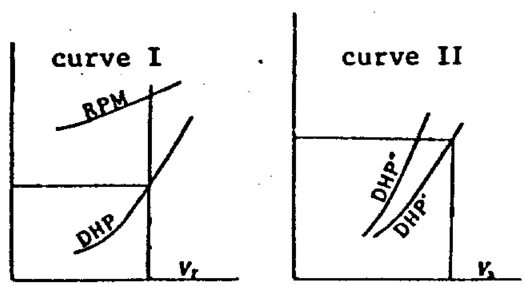


Fig. 83 Estimation method of shaft horse power from the power curves of the similar vessels

2) EHP_s and EHP_T shall be calculated by the same calculation method on several $V/\sqrt{L}$ (Refer to 6.2).

3) DHP_T for V_T which correspond to $V/\sqrt{L}$ of the step 2) shall be taken from the Curve I.

4) The first Approximate Curve II for the power of the new vessel shall be made corresponding to the same $V/\sqrt{L}$ by calculating

$$DHP_s'=DHP_T\times EHP_s/EHP_T$$

5) V_s corresponding to 100% (or normal) output of the new vessel shall be found in the Curve II.

6) $V_T=V_s\times(L_T/L_s)^{0.5}$ shall be calculated using the above V_s and η_{OT} shall be obtained by analyzing $(1-w_T)$ for this V_T.

7) η_{Os} shall be calculated by estimating $(1-w_s)$ referring to $(1-w_T)$.

8) $(\eta_{OT}\eta_{RT})/(\eta_{Os}\eta_{Rs})$ shall be calculated assuming that the values of η_O and η_R are constant for each speed.

9) The final estimation value for the new vessel corresponding to the same $V/\sqrt{L}$ shall be obtained by calculating $DHP_s'' = DHP_s' \times (\eta_{or}\eta_{Rr})/(\eta_{os}\eta_{Rs})$.

10) By introducing the propeller particulars to the final estimation value, the propeller revolution can be derived from the following method:

$K_{Qp}' = 0{\cdot}8389\,DHP/(V_{sA}^3 D^2)$ shall be calculated while $K_{Qp}' = K_Q/J^3$ shall be calculated by making J variable on $K_Q - J$ chart.
N are calculated by $N = 30{\cdot}87\,V_{sA}/JD$ using J which gives the same value to the both K_{Qp}' .

6.4.3. Rough Process to decide the Most Preferable Principal Dimensions, Main Engine and Propeller

There may be many combinations of the principal dimensions and the main engines to fulfill the required design conditions (mainly deadweight and speed). The rough process to estimate the shaft horse power and to decide the most preferable principal dimensions and main engine is as follows.

1) Assumptions of the groups of the principal dimensions to fulfill the design conditions.

2) Estimation of approximate shaft horse power (Refer to 6.4.1 and 6.4.2) for each group of principal dimensions and the selection of the main engine.

3) Decision of the principal dimensions and main engine (Most preferable combination shall be chosen from the combinations of above 2), and it shall be confirmed that the design conditions are maintained.)

4) Decision of the particulars of the propeller (Refer to 6.3.3). The propeller diameter is confirmed to be within the allowable limit and the judgement on the cavitation (Refer to 6.3.5) shall be made.

5) Detail design of the propeller (Refer to 6.3.4 and 6.3.6).

6) The final estimation of the shaft horse power and the confirmation of the adaptability of the main engine (Refer to 6.4.1 and 6.4.2).

6.5. Sea Trial and Analysis of the Data

6.5.1. Sea Trial

(1) Conditions of hull and propeller

(a) The surface of hull and propeller should be clean as far as possible. It is desirable that the sea trial shall be conducted within two weeks after final docking.

(b) Displacement is specified by the shipbuilding contract or the specifications. In general, the sea trial of tankers are carried out at fully loaded condition and the same of the normal cargo vessels, ore carriers, bulk carriers etc. are conducted at 1/5 deadweight condition.

(c) Trim
The most suitable trim to achieve the maximum speed shall be chosen such as even keel for fully loaded condition or appropriate draught to keep the necessary immersion for the propeller or the bulbous bow in the case of light weight condition. The exact condition shall be confirmed by the model tank test, if necessary.

(d) Propeller immersion

The propeller shall be immersed as deep as possible in order to avoid deterioration of the propulsive efficiency such as by air draw etc. It is desirable that the propeller shall be immersed fully and at least the depth of the propeller shaft shall exceed 0.4 times of the propeller diameter.

(2) Trial running

(a) Trial course

The trial sea shall have an appropriate water depth and also an appropriate water area wide enough for approach running and turning of the vessel (Refer to (c) and (d)).

(b) Measurement of speed

The usual practice is to run the ship on a measured-mile course but for the very large ships and extra high speed ships, it is very difficult to keep the appropriate trial area in the inland sea so that the course is set in the open sea and the measurements are carried out by the radio log.
It is also important to make the round run of the ship on the same course to eliminate the affect of the irregular current or tide which may be occured on account of irregularity of land shape.

(c) Water depth

The minimum water depths with negligible shallow water effect are shown on Fig. 84 for the ships with standard hull form.

(d) Approach run

It is necessary to take an approach run in the linear extension of the trial course before entering into measurement. Necessary approach run for the cargo vessel of 10,000 TDW (light load condition) is about 1.5 minutes (or 0.5 sea miles) for MCR and 5.2 minutes (or 1.5 sea miles) for 1/2 MCR. The large full ships which have the smaller values of (Engine output/Displacement) need longer approach run. The necessary distance of approach run for turbine driven, standard large full ships to keep error of the measurement within 1% is shown on Fig. 85. About 10% longer distance for approach run is necessary for the diesel driven vessels of the similar type and size.

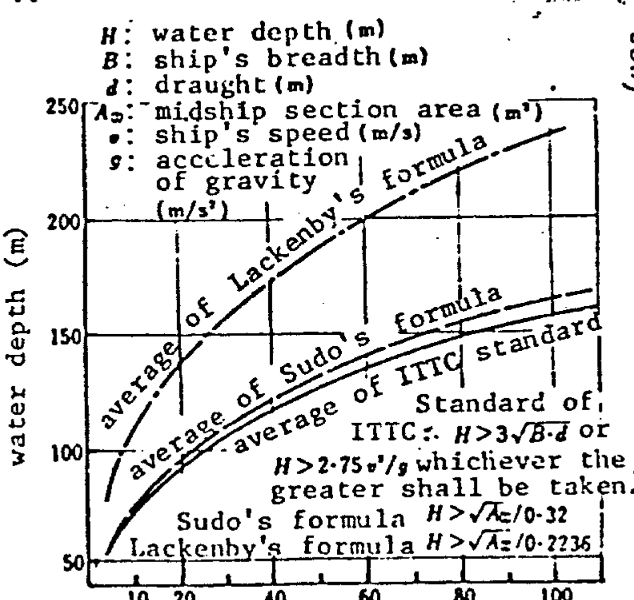


Fig. 84 Standard water depth necessary for sea trial

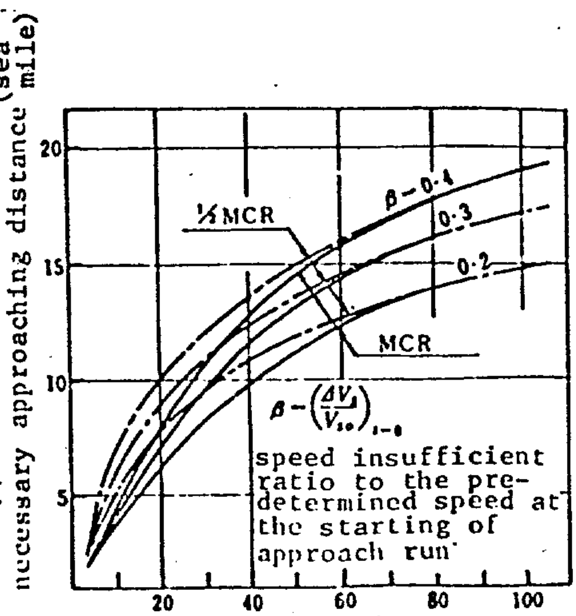


Fig. 85 Standard for necessary distance for approach run (Turbine ship)

(e) "Mean of means" method of the measured values
The mean speed is obtained by the following formulas in accordance with the numbers of the round runs.

1 round run $V_m = (V_1 + V_2)/2$

3 consecutive runs $V_m = (V_1 + 2V_2 + V_3)/4$

2 round runs $V_m = (V_1 + 3V_2 + 3V_3 + V_4)/8$

Where, V_i represents the measured speed against the ground. Similar representations are also applied to the measured values of the propeller revolutions per minute and shaft horse power.

(f) Others
It is also desirable that during the sea trials of round run, the propeller revolutions per minute shall be kept as constant as possible, each run shall be carried out consecutively and the intervals between each run shall be kept nearly equal.
Following documents may be referred to for the execution of the trials:

SNAME:	Standardization Trial Code (1949)
	Code on Manoeuvering and Special Trials and Tests (1950)
	Code on Instruments and Apparatus for Ship Trials (1952)
NV :	Standardization Code for Trials and Testing of New Ships (1965)
BSRA :	Code of Procedure for Measured-Mile Trials (1964)
ITTC :	Propulsion Trial Code (1963)
RR2 :	Research Report No. 12R (1972)
JG :	Gazette No. 8479 (1955)

6.5.2. Analysis of Sea Trials
The calculations of Table 83 shall be carried out in order to obtain the test result at calm sea and no wind condition, eliminating the influences by the wind and the tide from the values measured at the sea trials.

(1) Wake factor to correct the speed against the wind

(a) Torque coefficient

$$K_Q = \frac{Q}{\rho n^2 D^5} = \frac{24670}{D^5} \frac{\text{DHP}}{N^3}$$

(b) Reading of J
The value of J corresponding to K_Q is to be found on the propeller characteristic curves ($K_Q \sim J$ curves)

(c) Wake factor w

$$1 - w = \frac{V_A}{V} = \frac{D}{30 \cdot 87} \frac{NJ}{V}$$

where, V and V_A are expressed by kt .

The value of $(1-w)$ shall be decided by the mean of means of all consecutive runs at the same output because V is influenced by the tide.

(2) Correction for the wind
In the following explanations, suffix w represents the values along the wind and a against the wind. The correction for the wind shall be made by calculating the difference of the torque coefficient ΔK_Q based on the difference of air resistance running at the same propeller revolutions per minute N both for with the wind and without the wind and by calculating the corresponding difference in horse power and speed. For the wind direction factor k , refer to 7.3.3 Fig. 114.

(a) Calculation of K_Q' (Values converted to no wind condition)

$$K_Q' = K_Q + \Delta K_Q'$$

where, along the wind $\Delta K_Q' = (K_{Qa} - K_{Qw}) \times \frac{V^2 - k_w W_w^2}{k_a W_a^2 - k_w W_w^2}$

against the wind $\Delta K_Q' = (K_{Qa} - K_{Qw}) \times \frac{V^2 - k_a W_a^2}{k_a W_a^2 - k_w W_w^2}$

When the absolute wind direction is normal to the running course of the ship, this correction cannot be applied. The wind correction for such case shall be made by the other methods such as Taniguchi's Proposal.

(b) K_{Q0}
Torque coefficient curve at the no wind condition is obtained by plotting the values of K_Q' to the base of N. The readings from this curve corresponding to each N shall be the values of K_{Q0}.

(c) $\Delta K_Q = K_{Q0} - K_Q$

(d) Change of the advance speed of the propeller after correction for wind $\Delta V_A = nD \times \Delta J = aND \times \Delta K_Q$ (kt)

where, $a = (1/30 \cdot 867) \times (dJ/dK_Q)$,

Assuming maximum and minimum values of measured K_Q, K_{Q1} and K_{Q2} respectively and the corresponding values of J, J_1 and J_2,

$$dJ/dK_Q = (J_1 - J_2)/(K_{Q1} - K_{Q2})$$

Corresponding change of the speed of the ship

$$\Delta V = \frac{\Delta V_A}{1-w} = \frac{aND}{1-w} \times \Delta K_Q \qquad \text{(kt)}$$

(e) Speed against ground at no wind condition $V_0 = V + \Delta V$ (kt)

(f) Delivered horse power at no wind condition $DHP_0 = DHP \times (K_{Q0}/K_Q)$

(3) Correction for the tide
The subscripts w and a refer to the values along and against the tide in the following explanations.

(a) Speed against ground at no wind condition V_{0a} (Propeller revolutions per minute N_a) shall be converted to the speed at the revolutions N_w

$$V_{0a}' = V_{0a} \times (N_w/N_a)$$

(b) Mean tide speed at intermediate time between the round runs

$$V_{cm} = (V_{0w} - V_{0a}')/2 \qquad \text{(kt)}$$

(c) Tide speed V_c at intermediate time of each round run can be obtained from the tide speed curve derived by plotting the results of the above (b) for each round run based on the time on abscissa.

(d) Speed against water at no wind condition

along the tide $V_s = V_{0w} - V_{cw}$

against the tide $V_s = V_{0a} + V_{ca}$

Table 83 Standard Analysis Method of Sea Trial Results

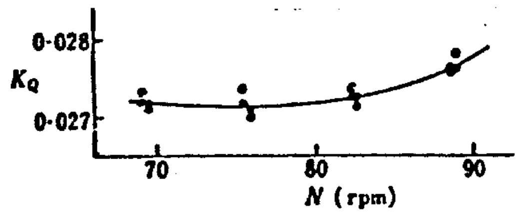
	Items	Claculation formula	Calculation examples	
	Main engine load		3/4	
	Run No. & direction		5. S 190°	6. N 10°
Measured Values	Speed against land V_s(kt)	①	15·203	15·352
	Propeller revolution per minute N	②	82·53	82·30
	Shaft horsepower SHP (PS)		24 900	24 940
Calculation of Wake Factor	Delivered horsepower DHP (PS)	③	*1 24 340	*1 24 380
	K_Q	④ $=\frac{24\,668}{D^5}\cdot\frac{③}{②^3}$	0·027 12	0·027 39
	J	⑤	*2 0·456	*2 0·449
	$1-w$	⑥ $=\frac{30·864}{D}\cdot\frac{②\times⑤}{①}$	0·665	0·647
	$(1-w)_m$	⑥′	0·656	
Correction for Wind	Wind, along or against		along	against
	Relative wind speed W(kt)	⑦	9·7	19·4
	Wind direction factor k	⑧ Refer to 7.3.3.	1·20	1·20
	kW^2	⑨=⑦^2×⑧	112·9	451·7
	$\Delta K_Q'$	⑩=(④$_a$−④$_w$) $\times\frac{①^2-⑨}{⑨_a-⑨_w}$	0·000 09	−0·000 17
	K_Q'	=④+⑩	0·027 21	0·027 22
	K_{Qe}	⑪	*3 0·027 22	*3 0·027 21
	ΔK_Q	⑫=⑪−④	0·000 10	−0·000 18
	ΔV_s(kt)	⑬ $=\frac{a\times②\times D\times⑫}{⑥′}$	−0·078	0·140
	V_e(kt)	⑭=①+⑬	15·125	15·492
	DHP$_e$(PS)	⑮=③×⑪/④	24 420	24 210
Correction for Tide	Tide, along or against		along	against
	V_{ea}	⑯=⑭$_a$×②$_w$/②$_a$	15·082	*4 15·492
	V_c'(kt)	$=\frac{⑯_a-⑯_w}{2}$	N↑ 0·205	
	V_c(kt)	⑰	*5 +0·195	*5 −0·195
	V_{se}(kt)	⑱=⑭+⑰	15·320	15·297
	SHP$_e$ (PS)		24 980	24 770
	C_{adm}	$=\Delta^{2/3}\times⑱^3/⑮$	537	539

Remarks

*1 Detail calculation result at the position of torsion metre.
Lost horsepower for each rpm is calculated by the following formula, assuming the lost horsepower at normal output being of 1.8%.
34 000×0·018=612
612×N/N_r = Lost horsepower at rpm N, where N_r is the rated rpm.

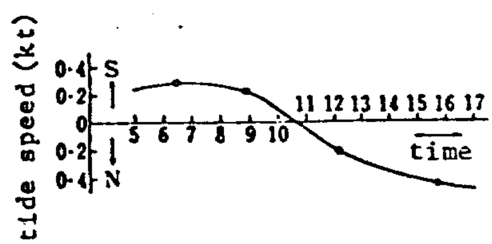
*2 To be found in the propeller characteristic curves.

*3 To be found in N~K_Q curve composed as follows:



*4 The same value as ⑭$_w$

*5 To be found in time-mean tide speed curve composed as follows:



6.5.3. ΔC_r Analysis

The values of roughness correction factor ΔC_r and the wake correlation factor shall be obtained (by the coincide thrust method) after the analysis shown on Table 84 is executed by using the final results derived from the preceeding article and the results of the model tank test.

(1) Estimation of effective horse power

(a) $K_{Q0}' = K_{Q0} \times \eta_R$

η_R of the model obtained by the tank test is used.

(b) The read-outs of J and K_T corresponding to K_{Q0}' on the propeller characteristic chart are defined as J_0 and K_{T0} respectively.

(c) $EHP = 1.992 \times 10^{-4} D^4 V_s^3 N^2 (1-t) K_{T0}$

t of the model obtained by the tank test is used.

(2) Calculation of total resistance coefficient

$$C_T = \frac{R_T}{(1/2)\rho S V^2} = 10.548 \times \frac{EHP}{S V_s^3}$$

(3) Calculation of skin friction or viscosity resistance coefficient

Two Dimensional Extrapolation Method (skin friction resistance) $C_f = C_T - C_R$

Three Dimensional Extrapolation Method (viscosity resistance) $C_v = C_T - C_w$

C_R or C_w of the model obtained by the tank test are used.

(4) Calculation of ΔC_f

Two Dimensional Extrapolation Method $\Delta C_f = C_f - C_{f0}$

Three Dimensional Extrapolation Method $\Delta C_f = C_v - (1+k) C_{f0}$

C_{f0} is the frictional resistance coefficient of equivalent plank. k of the value of the model obtained by the tank test is used.

(5) Wake correlation factor

(a) Wake factor w_{TS} according to the thrust coincide method

$$1 - w_{TS} = \frac{D}{30.87} \times \frac{N J_0}{V_s}$$

(b) Correlation factor = $(1 - w_{TS})/(1 - w_{TM})$

Table 84 ΔC_f Analysis (Three Dimensional Extrapolation Method)

Item	Calculation formula	Calculation examples		Remarks
Main Engine Load		3/4		
V_s (kt)	① Table 83—⑫	15·320	15·297	*1 Shown by $R_n \times 10^{-9}$
N (rpm)	② Table 83—②	82·53	82·30	*2 Obtained based on F_n from the results of the model tank test.
DHP_s (PS)	③ Table 83—⑮	24 420	24 210	*3 The values corresponding to K_Q' on the propeller characteristic curve are obtained.
F_n	$= \frac{① \times 0\cdot5144}{\sqrt{gL}}$	0·144 4	0·144 2	*4 Shown by $C_T \times 10^3$
R_n	$= \frac{0\cdot514\,4 \times ① \times L}{\nu}$	*1 2·324	*1 2·320	*5 Appropriate skin friction resistance coefficient is taken based on R_n. (Schoenherr is applied in here.)
K_{Qs}	④ Table 83—⑪	0·027 22	0·027 21	
η_R *3	⑤	1·000	1·000	
K_{Qs}'	⑥=④×⑤	0·027 22	0·027 21	
J_s *3	⑦	0·452	0·452	
K_{Ts} *3	⑧	0·199 8	0·199 7	
$1-t$ *3	⑨	0·780	0·780	
EHP (PS)	⑩$=1\cdot992\times10^{-4}\times D^4$ ×①×②²×⑧×⑨	15 370	15 250	
C_T	⑪$=10\cdot548\times\frac{⑩}{S\times①^3}$	*4 2·014	*4 2·008	
C_W *2	⑫	*4 0·068	*4 0·068	
C_V	⑬=⑪−⑫	*4 1·946	*4 1·940	
C_{Fs} *5	⑭	*4 1·715	*4 1·715	
ΔC_f	⑮=⑬−(1+k)×⑭	*4 0·231	*4 0·225	
$1-w_s$	⑯$=\frac{30\cdot864}{D}\times\frac{②\times⑦}{①}$	0·656	0·655	
$1-w_m$	⑰	0·527	0·527	
$1-w_s/1-w_m$	=⑯÷⑰	1·245	1·243	

7.1. Motion of Ships

7.1.1. General Description of Ship Motions

(1) Equation of ship motions based on the strip theory
A coordinate system is a right-hand orthogonal system as shown in Fig. 86.
The wave and ship motion can be shown as follows:

$$\zeta = \zeta_a \cos(\omega_e t - kx\cos\chi + ky\sin\chi)$$
$$s = s_a \cos(\omega_e t + \varepsilon_s)$$

where,
- ζ = Elevation of surface-wave profile
- ζ_a = Surface-wave amplitude
- ω_e = Circular frequency of encounter
- k = Number of wave
- χ = Angle of encounter
- s_a = Ship motion amplitude
- ε_s = Phase lag (positive in the forward direction and the origin is taken at the time when the crest comes on the center line at the position of midlength of the ship)

In considering the bilateral symmetry of the ship body, the motion of the ship is classified to the symmetrical motion (x_G (surge), z_G (heave), θ (pitch)) and the dissymmetrical motion (y_G (sway), ϕ (roll), ψ (yaw)).

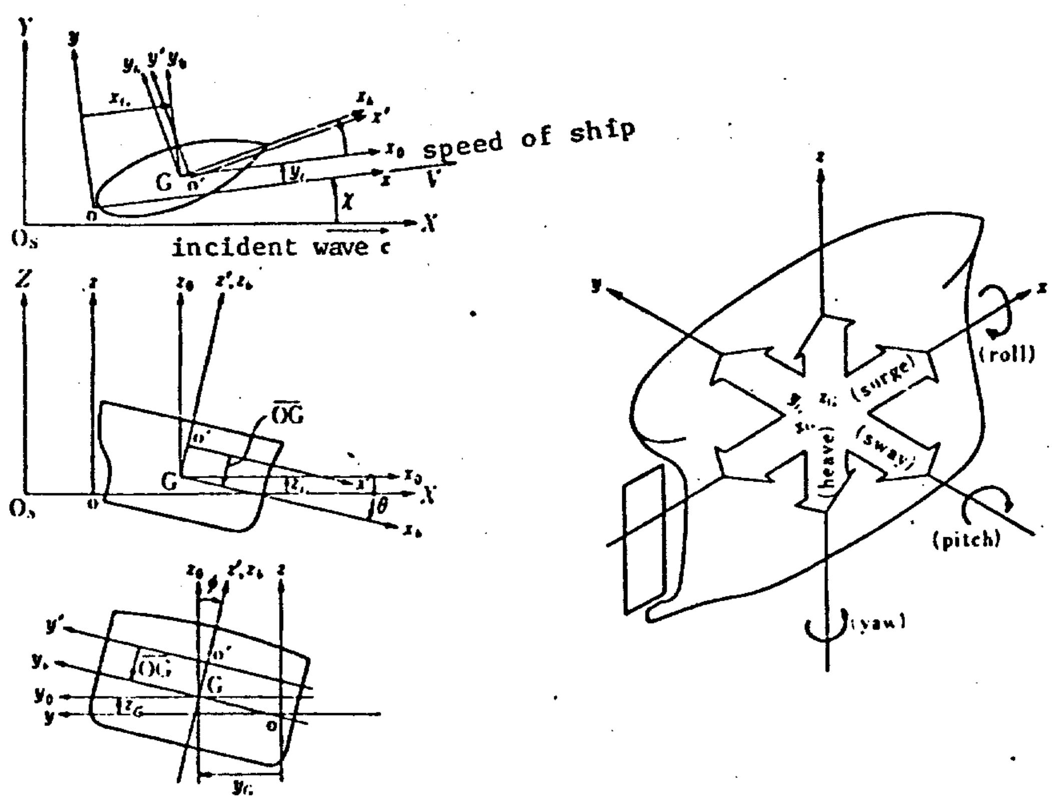


Fig. 86 Coordinate System

In the strip theory, the hull is assumed to be made up of a number of transverse strips and segments and then the hydrodynamical differential coefficients and wave exciting force of the equation of ship motion are obtained by the longitudinal integration of the two-dimensional fluid forces to each strip (Refer to Chapter I, 4.6). The equation of ship motions is:
For the symmetrical motion,

$$\left.\begin{aligned} a_{zz}\ddot{z}_c + b_{zz}\dot{z}_c + c_{zz}z_c + a_{z\theta}\ddot{\theta} + b_{z\theta}\dot{\theta} + c_{z\theta}\theta = F_{zc}\cos\omega_e t + F_{zs}\sin\omega_e t \\ a_{\theta\theta}\ddot{\theta} + b_{\theta\theta}\dot{\theta} + c_{\theta\theta}\theta + a_{\theta z}\ddot{z}_c + b_{\theta z}\dot{z}_c + c_{\theta z}z_c = M_{\theta c}\cos\omega_e t + M_{\theta s}\sin\omega_e t \end{aligned}\right\}$$

For the dissymmetrical motion,

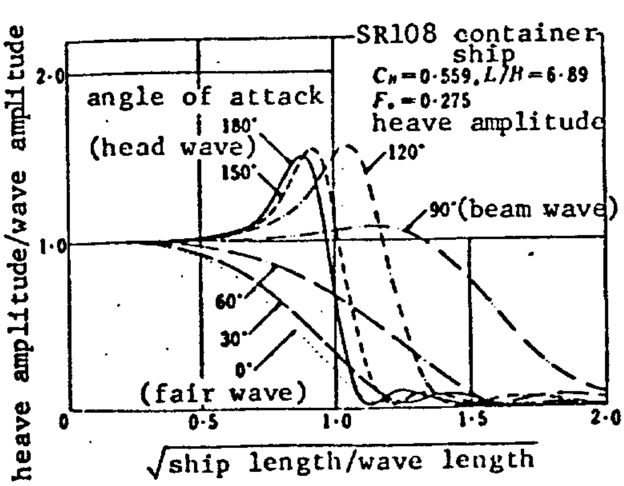
$$\left.\begin{aligned} a_{yy}\ddot{y}_c + b_{yy}\dot{y}_c + c_{yy}y_c + a_{y\psi}\ddot{\psi} + b_{y\psi}\dot{\psi} + c_{y\psi}\psi + a_{y\phi}\ddot{\phi} + b_{y\phi}\dot{\phi} + c_{y\phi}\phi = F_{yc}\cos\omega_e t + F_{ys}\sin\omega_e t \\ a_{\psi\psi}\ddot{\psi} + b_{\psi\psi}\dot{\psi} + c_{\psi\psi}\psi + a_{\psi\phi}\ddot{\phi} + b_{\psi\phi}\dot{\phi} + c_{\psi\phi}\phi + a_{\psi y}\ddot{y}_c + b_{\psi y}\dot{y}_c + c_{\psi y}y_c = M_{\psi c}\cos\omega_e t + M_{\psi s}\sin\omega_e t \\ a_{\phi\phi}\ddot{\phi} + b_{\phi\phi}\dot{\phi} + c_{\phi\phi}\phi + a_{\phi y}\ddot{y}_c + b_{\phi y}\dot{y}_c + c_{\phi y}y_c + a_{\phi\psi}\ddot{\psi} + b_{\phi\psi}\dot{\psi} + c_{\phi\psi}\psi = M_{\phi c}\cos\omega_e t + M_{\phi s}\sin\omega_e t \end{aligned}\right\}$$

The damping coefficient of roll in the equation of dissymmetrical motion, which cannot be accurately found by the linear theory, shall be preferably the experimental figure. In case that only the rolling motion is taken up neglecting the combination with the other motions, the conventional Froude-Kriloff theory is preferably adopted (Refer to 7.1.3).
In the calculation of the hydrodynamical differential coefficients and the term of wave forces, OSM (Ordinary Strip Method), NSM (New Strip Method), STF (Salvesen, Tuck, Faltinsen Method), etc. are adopted. The formulas of the differential coefficients by OSM are shown in Table 85. The oscillation amplitude and the phase lag of incident wave are obtained by solving the equation of motion using the differential coefficient gotten by OSM. The calculation results are shown on Fig. 87 as an example.
In considering Froude-Kriloff force as an exciting external force and neglecting added mass and damping force, the calculation on surge, one of symmetrical motion, is done with the following formulas.

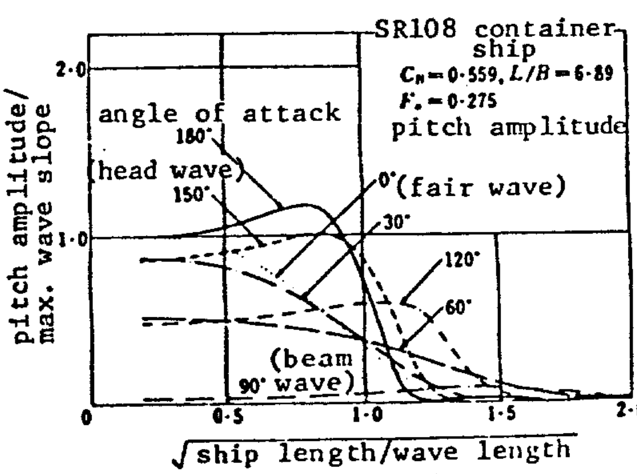
$$(\Delta/g)\ \ddot{x}_c = 2\int_{-d}^{0} dz \int_L p\left\{\frac{d}{dx}f(x,z)\right\}dx$$

$$p = \rho g \zeta_a e^{kz}\cos(kx+\omega t) - \rho g z$$

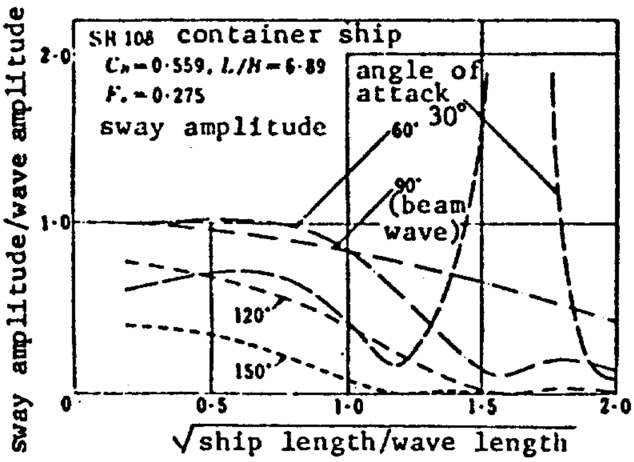
where, Δ is the displacement of ship, $f(x,z)$ the surface of ship body, p the pressure at water depth z and $\int_L$ the longitudinal integration (Refer to Fig. 88 of the example of calculation).



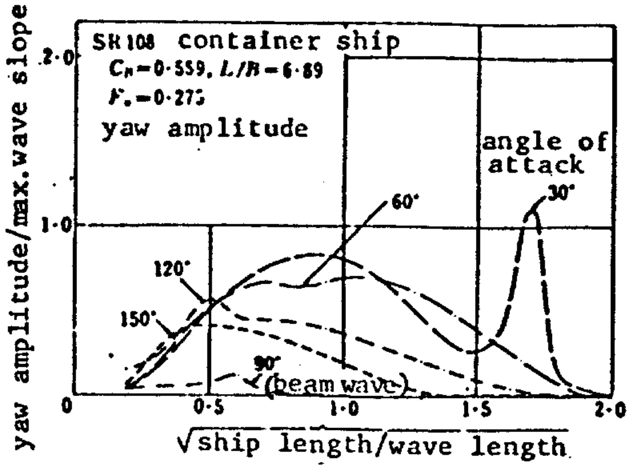
(1) Example of Heaving Calculation in Regular Waves



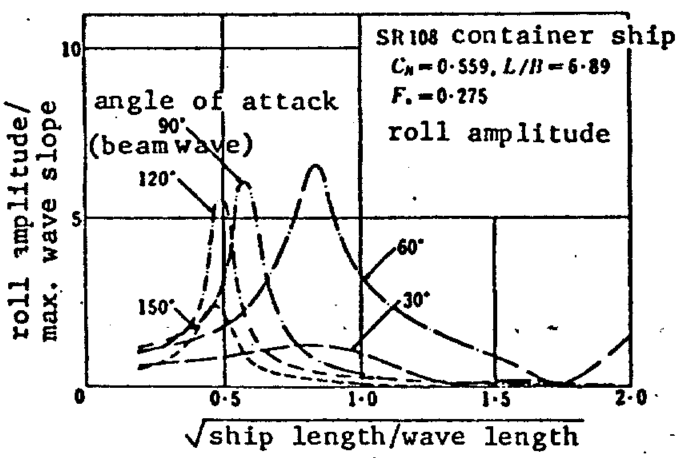
(2) Example of Pitching Calculation in Regular Waves



(3) Example of Swaying Calculation in Regular Waves



(4) Example of Yawing Calculation in Regular Waves



(5) Example of Rolling Calculation in Regular Waves

Note) The examples of calculation for SR 108 container ship in Fig. 87 - Fig. 91 are for $L = 175$m

Fig. 87

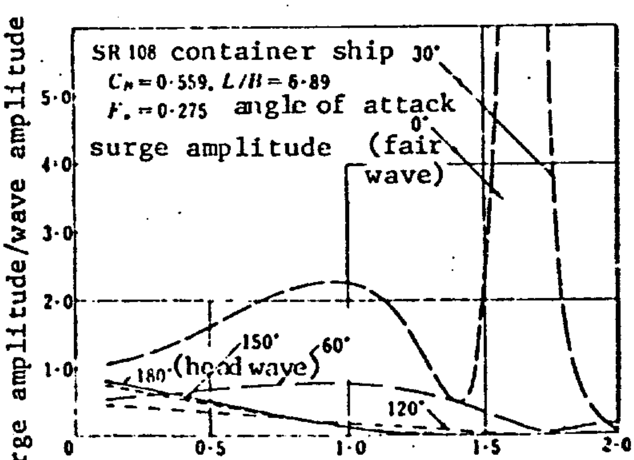


Fig. 88 Example of Surging Calculation in Regular Waves

(2) Acceleration of the parts of ship body
The vertical acceleration $\ddot{z}_p$ at a certain position on the ship body P (x, y, z) is:

$$\ddot{z}_p = z_{pa}\exp i(\omega_e t + \varepsilon_{az}),\quad z_{pa} = \sqrt{z_{ac}^2 + z_{as}^2},\quad \varepsilon_{az} = \tan^{-1}(z_{as}/z_{ac})$$
$$z_{ac} = -\omega_e^2(z_{ca}\cos\varepsilon_z - x\theta_a\cos\varepsilon_\theta + y\phi_a\cos\varepsilon_\phi)$$
$$z_{as} = -\omega_e^2(z_{ca}\sin\varepsilon_z - x\theta_a\sin\varepsilon_\theta + y\phi_a\sin\varepsilon_\phi)$$

where, z_{ca}, θ_a, and ϕ_a are heaving amplitude, pitching amplitude and rolling amplitude respectively, and ω_e is circular frequency of encounter with incident wave (Refer to Fig. 89 of the example of calculation). Including the gravity component by roll, the transverse acceleration $\ddot{y}_p$ is shown as follows:

$$\ddot{y}_p = y_{pa}\exp i(\omega_e t + \varepsilon_{ay}),\quad y_{pa} = \sqrt{y_{ac}^2 + y_{as}^2},\quad \varepsilon_{ay} = \tan^{-1}(y_{as}/y_{ac})$$
$$y_{ac} = -\omega_e^2\{x\psi_a\cos\varepsilon_\psi + y_a\cos\varepsilon_y - (z + l_{zc})\phi_a\cos\varepsilon_\phi - g\phi_a\cos\varepsilon_\phi\}$$
$$y_{as} = -\omega_e^2\{x\psi_a\sin\varepsilon_\psi + y_a\sin\varepsilon_y - (z + l_{zc})\phi_a\sin\varepsilon_\phi + g\phi_a\sin\varepsilon_\phi\}$$

where, y_a, ψ_a are swaying amplitude and yawing amplitude, and l_{zc} is vertical distance between the center of gravity of ship body and the point P (Refer to Fig. 90 of the example of calculation).

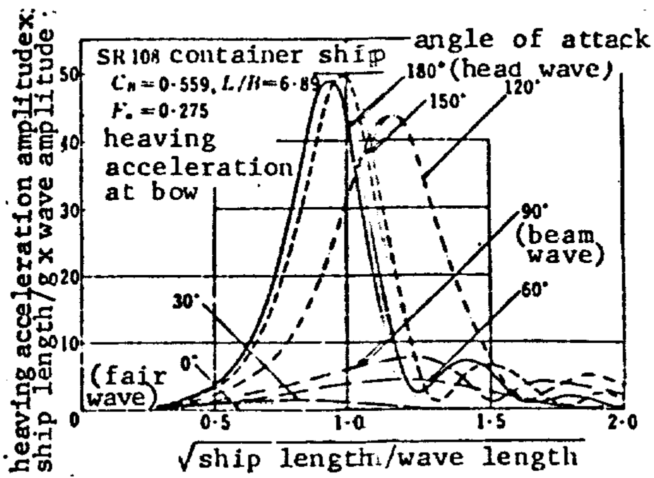


Fig. 89 Example of Heaving Acceleration Calculation (at bow) in Regular Waves

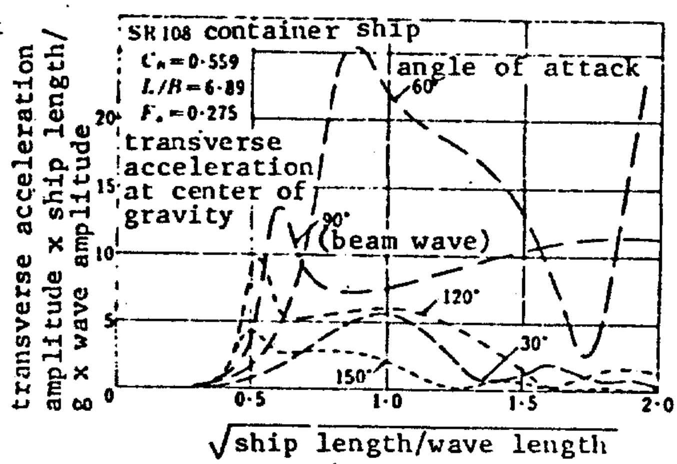


Fig. 90 Example of Transverse Acceleration Calculation at Center of Gravity in Regular Wave

(3) Relative water level
The relative water level z_{pr} at a certain position P (x, y, z) of the ship body is

$$z_{pr} = z_c - (x - l_{xc})\theta + y\phi - \zeta$$

where l_{xc} is the longitudinal level distance between center of gravity and position P, and ζ is elevation of wave surface. Whereas "dynamical swell-up" and "statical swell-up" (Refer to T.2.2.(2)) shall be considered for more precise solution (Fig. 91 to be referred to on the example of calculation).

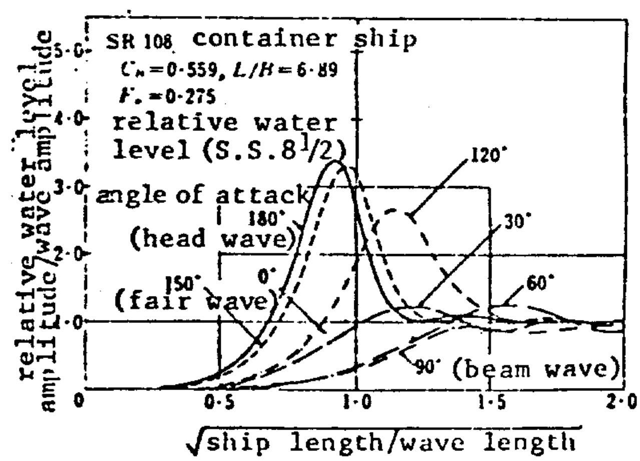


Fig. 91 Example of Relative Water Level Calculation in Regular Wave

Table 85 (1) Coefficients of the Equations of Ship Motions (Symmetrical Motion)

coefficient	Equation	coefficient	Equation
a_{zz}	$M+\int_L m_z dx$	$a_{\theta\theta}$	$I_{yy}+\int_L m_z(x-x')^2 dx$
b_{zz}	$\int_L N_z dx$	$b_{\theta\theta}$	$\int_L N_z(x-x')^2 dx$
c_{zz}	$2\rho g\int_L y_w dx$	$c_{\theta\theta}$	$2\rho g\int_L y_w(x-x')^2 dx$
			$-V\int_L N_z(x-x')dx$
			$-V^2\int_L m_z dx$
$a_{z\theta}$	$-\int_L m_z(x-x')dx$	$a_{\theta z}$	$-\int_L m_z(x-x')dx$
$b_{z\theta}$	$-\int_L N_z(x-x')dx+V\int m_z dx$	$b_{\theta z}$	$-\int_L N_z(x-x')dx-V\int_L m_z dx$
$c_{z\theta}$	$-2\rho g\int_L y_w(x-x')dx+V\int N_z dx$	$c_{\theta z}$	$-2\rho g\int_L y_w(x-x')dx$
F_{zc}	$\omega\zeta_a\int_L C_1C_2N_z\sin k^*x dx$	$M_{\theta c}$	$-\omega\zeta_a\int_L C_1C_2\rho N(x-x')\sin k^*x dx$
	$-\omega\omega_e\zeta_a\int_L C_1C_2m_z\cos k^*x dx$		$+\omega\omega_e\zeta_a\int_L C_1C_2\rho s_{mz}(x-x')\sin k^*x dx$
	$+2\rho g\zeta_a\int_L C_1C_2y_w\cos k^*x dx$		$-\omega V\zeta_a\int_L C_1C_2m_z\sin k^*x dx$
			$-2\rho g\zeta_a\int_L C_1C_2y_w(x-x')\cos k^*x dx$
F_{zs}	$-\omega\zeta_a\int_L C_1C_2N_z\cos k^*x dx$	$F_{\theta s}$	$\omega\zeta_a\int_L C_1C_2N_z(x-x')\cos k^*x dx$
	$-\omega\omega_e\zeta_a\int_L C_1C_2m_z\sin k^*x dx$		$+\omega\omega_e\zeta_a\int_L C_1C_2m_z(x-x')\sin k^*x dx$
	$+2\rho g\zeta_a\int_L C_1C_2y_w\cos k^*x dx$		$+\omega V\zeta_a\int_L C_1C_2m_z\cos k^*x dx$
			$-2\rho g\int_L C_1C_2y_w(x-x')\sin k^*x dx$

Note) 1. M = Mass of ship, I_{yy} = Mass moment of inertia of ship, m_z = Added mass of two-dimensional section, N_z = Damping force of two-dimensional section, ω = Circular frequency of incident wave, ω_e = Circular frequency of encounter, x' = Level distance from midship to center of gravity, y_w = Half breadth of water plane, ζ_a = Amplitude of wave, ρ = Density of water, V = Speed of ship, χ = Angle of attack.

2. $\int_L$ shows the longitudinal integration and does not include the effects at the ends.

3. $C_1 = \sin(ky_w\sin\chi)/ky_w\sin\chi$, $C_2 = e^{-kd_m}$, d_m = Sectional area/ $2y_w$, $k^* = k\cos\chi$

Table 85 (2) Coefficients of the Equations of Ship Motions (Dissymmetrical Motion)

Coefficient	Equation	Coefficient	Equation
a_{yy}	$M+\int_L m_y dx$	F_{yc}	$-2\rho g\zeta_a\int_L \sin k^* x\int_d e^{kz}(ky\sin\chi)dzdx$
b_{yy}	$\int_L N_y dx$		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y e^{kd'}\sin k^* x dx$
c_{yy}	0		$+\omega\zeta_a\sin\chi\int_L N_y e^{kd'}\cos k^* x dx$
$a_{y\psi}$	$\int_L m_y(x-x')dx$	F_{ys}	$-2\rho g\zeta_a\int_L \cos k^* x\int_d e^{kz}(ky\sin\chi)dzdx$
$b_{y\psi}$	$\int_L N_y(x-x')dx-V\int_L m_y dx$		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y e^{kd'}\cos k^* x dx$
$c_{y\psi}$	$-V\int_L N_y dx$		$-\omega\zeta_a\sin\chi\int_L N_y e^{kd'}\sin k^* x dx$
$a_{y\phi}$	$\int_L m_y l'_{sa} dx$		
$b_{y\phi}$	$\int_L N_y l'_w dx$	$M_{\psi c}$	$-2\rho g\zeta_a\int_L(x-x')\sin k^* x\int_d e^{kz}\sin(ky\sin\chi)dzdx$
$c_{y\phi}$	0		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y(x-x')e^{kd'}\sin k^* x dx$
$a_{\psi\psi}$	$I_{zz}+\int_L m_y(x-x')^2 dx$		$+\omega\zeta_a\sin\chi\int_L N_y(x-x')e^{kd'}\cos k^* x dx$
$b_{\psi\psi}$	$\int_L N_y(x-x')^2 dx$		$+\omega V\zeta_a\sin\chi\int_L m_y e^{kd'}\cos k^* x dx$
$c_{\psi\psi}$	$-V^2\int_L m_y dx$	$M_{\psi s}$	$-2\rho g\zeta_a\int_L(x-x')\cos k^* x\int_d e^{kz}\sin(ky\sin\chi)dzdx$
$a_{\psi\phi}$	$\int_L m_y l'_{sa}(x-x')dx$		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y(x-x')e^{kd'}\cos k^* x dx$
$b_{\psi\phi}$	$\int_L N_y l'_w(x-x')dx+V\int_L m_y l'_{sa}dx$		$-\omega\zeta_a\sin\chi\int_L N_y(x-x')e^{kd'}\sin k^* x dx$
$c_{\psi\phi}$	0		$-\omega V\zeta_a\sin\chi\int_L m_y e^{kd'}\sin k^* x dx$
$a_{\psi y}$	$\int_L m_y(x-x')dx$	$M_{\phi c}$	$\overline{OG}\cdot Fyc$
$b_{\psi y}$	$\int_L N_y(x-x')dx+V\int_L m_y dx$		$+2\rho g\zeta_a\int_L \sin k^* x\int e^{kz}\sin(ky\sin\chi)(ydy+zdz)dx$
$c_{\psi y}$	0		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y l_{sa}e^{kd'}\sin k^* x dx$
$a_{\phi\phi}$	$I_{xx}+\int_L(I_a-2m_y l_{sa}\overline{OG}+M_s\overline{OG}^2)dx$		$+\omega\zeta_a\sin\chi\int_L N_y l_w e^{kd'}\cos k^* x dx$
$b_{\phi\phi}$	$\int_L N_y l'^2_w dx$	$M_{\phi s}$	$\overline{OG}\cdot Fys$
$c_{\phi\phi}$	$w\cdot\overline{GM}$		$+2\rho g\zeta_a\int_L \cos k^* x\int e^{kz}\sin(ky\sin\chi)(ydy+zdz)dx$
$a_{\phi y}$	$\int_L m_y l'_{sa} dx$		$-\omega\omega_e\zeta_a\sin\chi\int_L m_y l_{sa}e^{kd'}\cos k^* x dx$
$b_{\phi y}$	$\int_L N_y l'_w dx$		$-\omega\zeta_a\sin\chi\int_L N_y l_w e^{kd'}\sin k^* x dx$
$c_{\phi y}$	0	$b_{\phi\psi}$	$\int_L N_y l'_w(x-x')dx-V\int_L m_y l'_{sa}dx$
$a_{\phi\psi}$	$\int_L m_y l'_{sa}(x-x')dx$	$c_{\phi\psi}$	$-V\int_L N_y l'_w dx$

Note) 1. M = Mass of ship, I_{zz} = Mass moment of inertia about z-axis of ship body, m_y = Added mass of two-dimensional section (sway), N_y = Damping force of two-dimensional section (sway), x' = Level distance from midship to center of gravity, $l'_{sa}=l_{sa}-\overline{OG}$, $l'_w=l_w-\overline{OG}$, l_{sa}, l_w = "refer to Chapter I, 4.6.1", $\overline{OG}$ = "refer to Fig. 86", $kd' : -kd/2$, I_{xx} = Mass moment of inertia about x-axis of ship body, $\overline{GM}$ = Metacentric height, I_a = Added mass moment of inertia of two-dimensional section.

2. $\int_L$ shows the longitudinal integration and does not include the effects at the ends, and $\int_d$ shows the integration to the direction of draught.

(4) Synchronism of ship motion and incident wave
The frequency of encounter T_e of the ship body with the incident wave is

$$T_e = \frac{gT_w^2}{2\pi} \Big/ \left(V\cos\chi + \frac{gT_w}{2\pi}\right), \qquad T_w = \text{Wave period}$$

Since the synchronism of the ship motion and incident wave occurs at the rate of synchronism $T_e/T_n = 1 \cdot 0$, the speed of ship V at that moment is as follows (Fig. 92):

$$V = \frac{gT_w}{2\pi\cos\chi}\left(\frac{T_w}{T_n} - 1\right), \qquad T_n = \text{Natural period of motion}$$

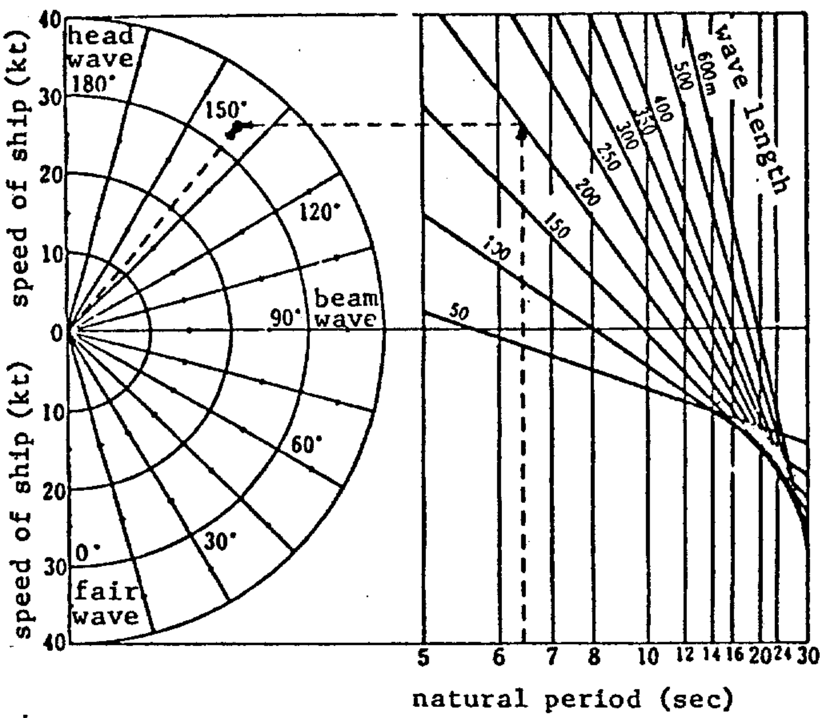


Fig. 92 Synchronism of Ship Motion in Regular Waves

7.1.2. Approximate Calculation Method of Pitching Motion

(1) Approximate calculation formula on natural period of pitch
The calculation formula on the natural period of pitch T_θ is

$$T_\theta = 2\pi k'_{yy} / \sqrt{g \cdot GM_L},$$

where, k'_{yy} = Virtual radius of gyration about transverse axis
GM_L = Longitudinal metacentric height

Following formulas are given for approximate calculation.

i) $T_\theta = 0 \cdot 5\sqrt{L}$

ii) Tamiya's formula $T_\theta = 2 \cdot 01\sqrt{(0 \cdot 77\,C_w + 0 \cdot 26)(0 \cdot 92 + 0 \cdot 44\,B/d)\,d}$

iii) Tasai's formula $T_\theta = 29 \cdot 1\sqrt{\{1 + 0 \cdot 83(B/2d)\,C_p^2\}\,C_b d/(5 \cdot 55 C_w + 1)^2}$

iv) Iwai's formula $T_\theta = 0 \cdot 41\sqrt{\{1 + 0 \cdot 415(B/d)\,C_p^2\}\,L}$

v) Kempf's formula $T_\theta / T_\phi = \sqrt{BM/GM}$

T_ϕ = Natural period of roll

vi) Lewis' formula

$T_\theta / \sqrt{T_L} = C\sqrt{\{\Delta/(0 \cdot 1L)^3\}\ (L/B)}$

(Fig. 93)

where the unit is "sec" for T_θ and T_ϕ, "m" for L, B and d, and "ton" for Δ.

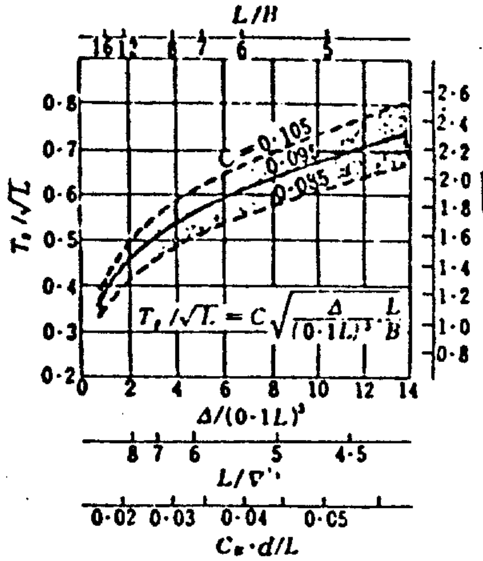


Fig. 93 Approx. Calculation on Natural Period of Pitch (by Lewis' formula)

(2) Approximate calculation formula on natural period of heave

The calculation formula on natural period of heave T_z is

$$T_z = 2\pi\sqrt{\nabla'/(g A_w)},$$

where, ∇' = Virtual volume of displacement

A_w = Water plane area

Following formulas are given for approximate calculation.

i) $T_z = \sqrt{(\nabla + 0 \cdot 24 B^2 L)/A_w}$

ii) $T_z = 2 \cdot 7\sqrt{d}$

iii) Tasai's formula $T_z = 2 \cdot 01\sqrt{\{C_{vp} + 0 \cdot 4(B/d) \cdot C_b\}\ d}$

where the unit is "sec" for T_z, "m" for L, B and d, "m3" for ∇ and "m2" for A_w.

(3) Approximate calculation method on amplitude of pitch

The following approximate calculation methods are used for the amplitude of motions.

i) Iwai's method

The approximate calculation formula on pitch amplitude for medium and small sized mixed boats is obtained neglecting the high dimensional terms and combination and then the amplitude of pitch is approximately obtained when the principal particulars of the ship are given.

ii) Moor-Murdey method

Moor-Murdey shows the method of calculating the pitch amplitude and heave amplitude by using principal particulars, Beaufort wind scale and the regression curves which have already been obtained from the model test results of general cargo ships with block coefficient of 0.55 - 0.88

7.1.3. Approximate Calculation Formula on Roll

(1) Period of roll T_ϕ (sec)

(a) In ordinary case $T_\phi = 2\pi k_{xx}/\sqrt{g\,GM} = 2{\cdot}01 k_{xx}/\sqrt{GM}$

(b) In case GM is nearly zero or small

$$T_\phi = \frac{602}{\phi}\frac{k_{xx}}{\sqrt{g\left(BM-\frac{1}{3}GM\right)}} = \frac{192}{\phi}\frac{k_{xx}}{\sqrt{BM-\frac{1}{3}GM}}$$

where, k_{xx} = Virtual radius of gyration about longitudinal axis through center of gravity (m)
ϕ = Angle of roll (deg.)

(2) Approximate formula on the radius of gyration

(a) $k_{xx} = cB$

c is nearly in the following range according to the type of ships.

Cargo boat	fully loaded	0.32 - 0.35	Passenger boat	0.38 - 0.43
	light	0.37 - 0.40	Fishing boat	0.38 - 0.44
Tanker	fully loaded	0.35 - 0.39	Battleship	0.34 - 0.38
	light	0.37 - 0.47	Cruiser	0.39 - 0.42

(b) Kato's formula

$$\left(\frac{k_{xx}}{B}\right)^2 = f\left[C_b \cdot C_u + 1{\cdot}10\,C_u(1-C_b)\left(\frac{H}{d}-2{\cdot}20\right)+\left(\frac{H}{B}\right)^2\right]$$

where, B = Maximum breadth of underwater ship body
C_u = Area coefficient of upper deck (for overall length of upper deck)
H (Effective depth) = $D+(1/L_{pp})\times\Sigma$ (Profile area of superstructures and deck houses)
f is coefficient shown below.

Passenger boat, Mixed boat, Cargo boat	0.125	Whale catcher boat	0.177
Tanker	0.133	Battleship	0.177
Skipjack and tuna fishing boat	0.200	Cruiser, Destroyer	0.172

For a passenger boat, a mixed boat and a cargo boat, the calculation is done rather easily by the following formula.

$$\left(\frac{k_{xx}}{B}\right)^2 = 0{\cdot}125\left(\frac{H}{B}\right)^2 + 0{\cdot}020\frac{H}{d_0}\left(1+3{\cdot}7\frac{d_0-d}{d_0}\right)+0{\cdot}027$$

where, d_0 = Full load draft
d = Optional draft

(3) Damping coefficient

The curve in which the abscissas are mean angles of roll ϕ_m and the ordinates are decrements of roll in each swing $\Delta\phi_m$ is called the curve of extinction. In the small range of roll angle, the curve is approximately shown as follows:

$$\Delta\phi_m = a\phi_m + b\phi_m^2 \quad \text{or} \quad \Delta\phi_m = N\phi_m^2$$

where a, b and N are called damping coefficients and shown their approximations in Table 86 for each kind of ship.

Table 86 Damping Coefficients

	N_{20}	a	b		N_{15}	N_{10}
Small passenger boat	0.015	0.050	0.0125	Large passenger boat		0.020
Small cargo boat	0.017	0.030	0.0155	Large cargo boat	0.019	
Fishing boat	0.019	0.100	0.0140	Large tanker	0.017	
Whale catcher boat	0.010	0.060	0.0070	N_{20}, N_{15}, and N_{10} are N for $\theta_m = 20°$, 15° and 10° respectively.		
Small warship	0.018	0.065	0.0150			

On the other hand, the following approximate formula is presented by Watanabe and Inoue.

$$N = \frac{n\,L\,d}{\Delta \cdot GM\,T_\phi^2}\left[l^3 \left(1 + \frac{d^2}{4l^2}\right) + \frac{fB^4}{64d} \right]$$

$$n = 0{\cdot}03 + 0{\cdot}78\,C_b \cdot d/L + 1{\cdot}5\,\sigma A_b/L^2 \quad \text{(for 10° of roll angle)}$$

$$= 0{\cdot}02 + 1{\cdot}1\,C_b \cdot d/L + \sigma A_b/L^2 \quad \text{(for 20° of roll angle)}$$

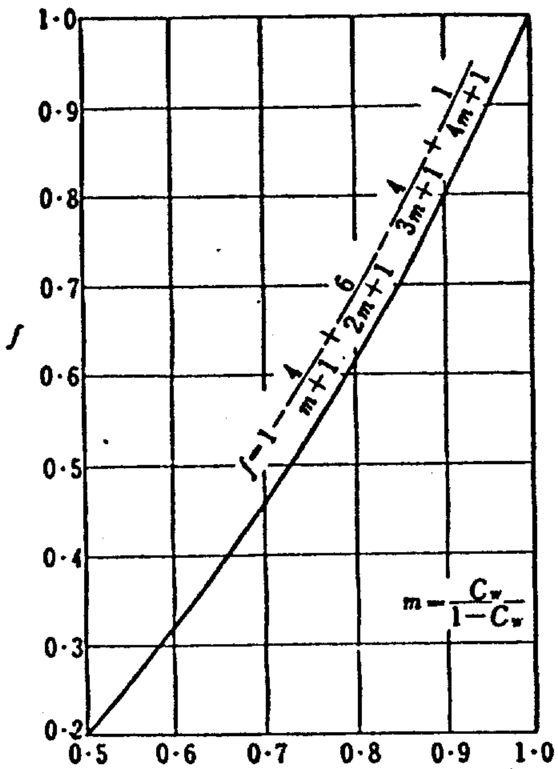
where, $l = KG - d/2$,
f = Function of C_b (Fig. 94)
σ = Function of C_b and aspect ratio β of bilge keel (Fig. 95)
A_b = One side area of bilge keel at either ship side

The logarithmic damping coefficient, δ, the logarithm of the ratio of the adjacent roll amplitude, is approximately given

$$\delta = \Delta\phi_m / \phi_m = a + b\phi_m \quad \text{or} \quad \delta = N\phi_m$$

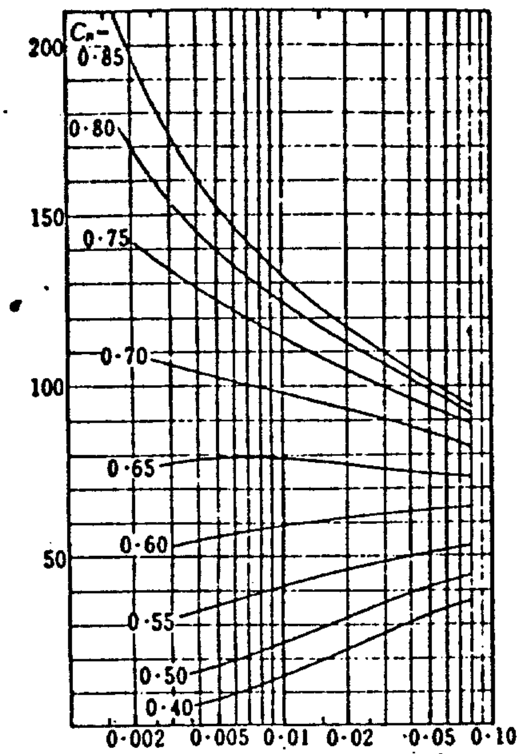
As the equation of rolling motion is non-linear with the above-mentioned damping coefficients and difficult to be solved, it is shown linearly as $\ddot{\phi} + a_e\dot{\phi} + \omega_\phi^2\phi = 0$ with the equivalent damping coefficient a_e. The relation between a_e and damping coefficient is calculated in general from energy loss in one cycle. In a linear equation, the following formula is obtained from $a_e = \omega_\phi\delta/\pi$.

$$a_e = \omega_\phi(a + b\phi_m)/\pi \quad \text{or} \quad a_e = \omega_\phi N\phi_m/\pi$$



waterplane coefficient C_w

Fig. 94 Waterplane Coefficient



aspect ratio of bilge keel β

Fig. 95 Aspect Ratio of Bilge Keel

When a ship is going ahead, the damping coefficient is generally larger than that when it stops (ship speed = 0). Takahashi's approximate formula is represented as an example which includes ship speed effect to a_e

$$a_e = a_{e0}\{1+0\cdot8(1-e^{-10F_n})\}$$

a_{e0} = Equivalent damping coefficient at ship speed = 0

(4) Reduction of roll angle due to resistance

The number of roll n necessary for the reduction of roll angle from ϕ_0 to ϕ_n is shown as follows:

When $\Delta\phi_m = a\phi_m + b\phi_m^2$ (curve of extinction)

$$n = \frac{2\cdot303}{a}\log_{10}\frac{\phi_0(a+b\phi_n)}{\phi_n(a+b\phi_0)}$$

When $\Delta\phi_m = N\phi_m^2$ (curve of extinction)

$$n = \frac{1}{N}\left(\frac{1}{\phi_m}-\frac{1}{\phi_0}\right)$$

(5) Approximate formula of amplitude

(a) Rolling in regular waves

The forced roll amplitude ϕ_r of the ship which is rolling regularly against beam seas with wave length L_w and wave height H_w is

$$\phi_r = \frac{\gamma \Theta_w}{\sqrt{\left(1-\frac{T_\phi^2}{T_w^2}\right)^2 + 4\left(\frac{a+b\phi_r}{\pi}\cdot\frac{T_\phi}{T_w}\right)^{2}}} \quad \text{(deg)}$$

or

$$\phi_r = \frac{\gamma \Theta_w}{\sqrt{\left(1-\frac{T_\phi^2}{T_w^2}\right)^2 + 4\left(\frac{N\phi_r}{\pi}\cdot\frac{T_\phi}{T_w}\right)^{2}}} \quad \text{(deg)}$$

where, T_w (Wave period) $= \sqrt{2\pi L_w/g} = 0.8007\sqrt{L_w}$

Θ_w (Maximum wave inclination angle) $= 360^\circ (H_w/2)/L_w$

γ = Effective inclination coefficient of wave

In case that the ship is of normal form and its centre of gravity is not excessively high or low, for waves which are almost in synchronism the effective inclination coefficient γ is shown approximately as follows:

$\gamma = 0.73+0.60(OG/d)$ (OG is negative to center of gravity under water level)

or $\gamma = 0.74(KG/d)^{[illegible]}$ (0.85)

While ϕ_r in the foregoing formula can be obtained by repeating successive approximation.

When the period of the ship is equal to the wave period, i.e. in synchronism $T_\phi = T_w$, the forced rolling angle ϕ_{syn} becomes maximum and is shown as

$$\phi_{syn} = -\frac{a}{2b}+\sqrt{\frac{a^2}{4b^2}+\frac{\pi\gamma\Theta_w}{2b}}$$

$$= \sqrt{\pi\gamma\Theta_w/(2N)}$$

(b) Rolling in irregular waves

The maximum angle of roll during 200 times of roll in irregular waves becomes about 0.7 times the rolling angle in regular waves. Then the possible maximum angle of roll ϕ_{max} becomes

$$\phi_{max} = 0.7\,\phi_{syn} = 0.88\sqrt{\frac{\gamma\Theta_w}{N}} = \sqrt{138.5\frac{\gamma}{N}\cdot\frac{H_w}{L_w}}$$

With regard to the maximum angle of roll in irregular waves, the calculation method of the statistical probability analysis by wave spectra is developed by Iwai and the others, and also the method of calculating effective wave inclination coefficient by Mizuno.

(6) Allowable limits of rolling period etc. in viewpoint of comfortableness on board

(a) Kempf's formula $T_\phi\sqrt{g/B} \geq 8$

(b) Watanabe's formula $GM \leqq B/12$

(c) Tomi's formula $a\omega_e < 1.0\,m/sec^2$ (a = Oscillating acceleration, ω_e = Circular frequency of encounter)

or $GM < 0.256(k_{xx}/B)^2 \cdot B^{4/3}$ (Unit: m)

7.1.4. Method of Oscillation Reduction

(1) Categories and comparison of anti-rolling systems (Table 87)

Table 87

Type	External type			Internal type				
	Passive type		Active type	Passive type		Active type		
	Bilge keel	Fixed fin	Auto. fin	Anti-rolling tank	Weight transfer	Anti-rolling tank	Gyroscope	Weight transfer
Decrease of roll	35%	no data	90%	60 - 70%	no data	no data	45%	no data
Effect at low speed	effective	ineffective	ineffective	effective	effective	effective	effective	effective
Loss of deadweight	negligible	negligible	1% of displt.	1 - 4% of displt.	same extent as anti rolling tank	same extent as passive type of tank	2% of displt.	same extent as anti rolling tank
Decrease of static stability	no	no	no	yes	yes	yes*	no	yes*
Increase of advance resistance	a little	a little	yes in working	no	no	no	no	no
Necessity of auxiliary power	0	0	small	0	0	large	large	large
Space occupied inside ship	0	0	smaller than water tank	medial	smaller than water tank	medial	large	medial
Continuous space athwartships	un-necessary	unnecessary	unnecessary	usually necessary	necessary	necessary	un-necessary	necessary
Possibility of damage by collision	probable	more probable	unprobable in retreat	unprobable	unprobable	unprobable	un-probable	unprobable
Price	low	medial	high	medial	high	high	very high	high

* The reduction of static stability is considered due to the necessary margin for the possibility of concentrated weight to one side.

(2) Passive type anti-rolling tank

Defining that K_s is the product of displacement and GM, M_o the amplitude of anti-rolling moment, J_s the apparent moment of inertia, ε the phase lag between the roll angle of a ship and the wave inclination angle, B_s the damping coefficient of roll, θ_w the wave inclination angle, ω_s and ω the circular frequency of oscillation and wave motion respectively, and K_t the product of moment of inertia of liquid surface and specific gravity of liquid in the anti-rolling tank, and by assuming $\omega_s^2 = K_s/J_s$, $\zeta_s = B_s/(\omega_s \cdot J_s)$, $C = M_o/K_t$, $\lambda = K_t/K_s$, $e = \omega/\omega_s$ the motion equation of the ship and anti-rolling tank is

$$\ddot{\phi} + \left(\zeta_s + \frac{C\sin\varepsilon}{e}\lambda\right)\omega_s\dot{\phi} + (1 - \lambda C\cos\varepsilon)\,\omega_s^2\phi = \omega_s^2\theta_w$$

Taking ϕ_o and θ_w to be the maximum amplitude of ϕ and θ_w respectively, the magnification coefficient μ is shown as follows;

$$\mu = \left|\frac{\phi_o}{\theta_w}\right| = 1/\sqrt{(1 - e^2 - \lambda C\cos\varepsilon)^2 + e^2\left(\zeta_s + \frac{C\sin\varepsilon}{e}\lambda\right)^2}$$

The anti-rolling tank gives effect to the damping of ship's roll in the form of $(C\sin\varepsilon)\lambda/e$ and relates to the circular frequency of oscillation in the form of $\lambda C\cos\varepsilon$. These relations are shown in Fig. 96. The anti-rolling moment M_o is obtained from each of the motion equations of the ship and the anti-rolling tank or the method of forced oscillation.
The form of passive type anti-rolling tank is shown in Fig. 97 and their characteristics are described below.

(a) Frahm type (Fig. 97 (a))
This is the type of air connection between the tops of the vertical legs of the U-tube, the water damping in the tanks is controllable by adjusting the air valves on the air pipes and the resistance of water tubes. The oscillation of the ship excites that of the water in the tanks. The optimal adjustment of the natural frequency and the water damping in the water tanks cause the roll-damping effect by giving a phase difference of 90 deg. between the ship and the water in the tanks.

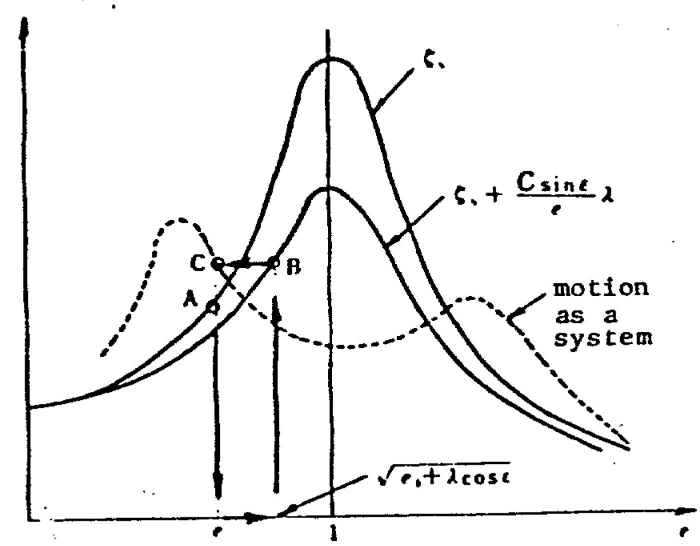
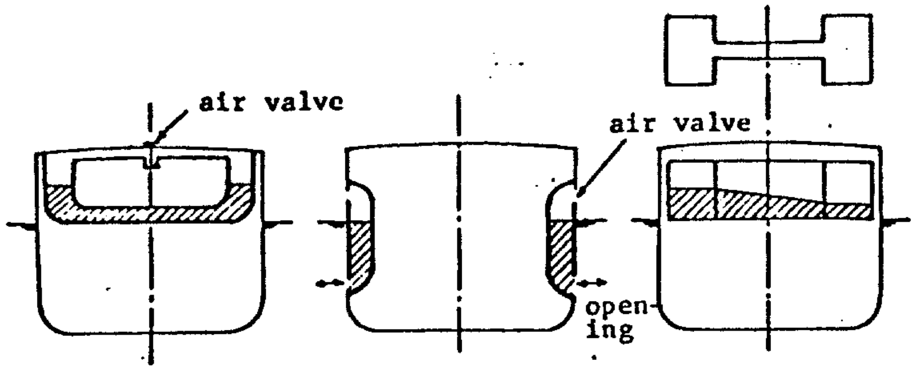


Fig. 96 Anti-rolling characteristics of Ship - Tank

(b) Foerster open type (Fig. 97 (b))
As the tanks are open at the bottom to the sea and vented at the top, the water flow is restricted. At the oscillation of the ship, the different water level in the tanks of both sides gives the roll damping effect due to the restricted flow of water in the tanks.

(c) Flume type (Fig. 97 (c))
This is the complete open channel type, anti-rolling principle of which is the same as the above (a). The damping in the tanks is caused by free water surface effect in the tanks and eddy making resistance at the corner of water channel.



(a) Frahm type (b) Foerster open type (c) Flume type

Fig. 97 Form of passive type anti-rolling tank

In (a) and (c), the energy of oscillation of the ship is absorbed by the water in the tanks and diffused by the damping in the tanks, hence the large anti-rolling effect can be expected by giving the large damping to a large quantity of water. On comparing (a) and (c), (c) is superior in the fact that the larger damping is introduced by a comparatively small quantity of water and that the natural frequency is easily adjusted by the level control of water in the tanks. However (a) is superior in the easiness of the damping adjustment, and the operation start and stop. Not having the natural frequency, (b) is different from (a) and (c), and the phase lag to the exciting force is mainly produced by adjusting the area of the openings.

(3) Fin stabilizer

The fin stabilizer, which is intended to gain the anti-rolling moment by the lift produced on the fin, consists of three parts in a broad way, i.e. the fin, the drive unit for the fin and the detection controller. The control methods of the manufacturers are characterized respectively. As an example, the control diagram of Sperry-type is shown in Fig. 98.

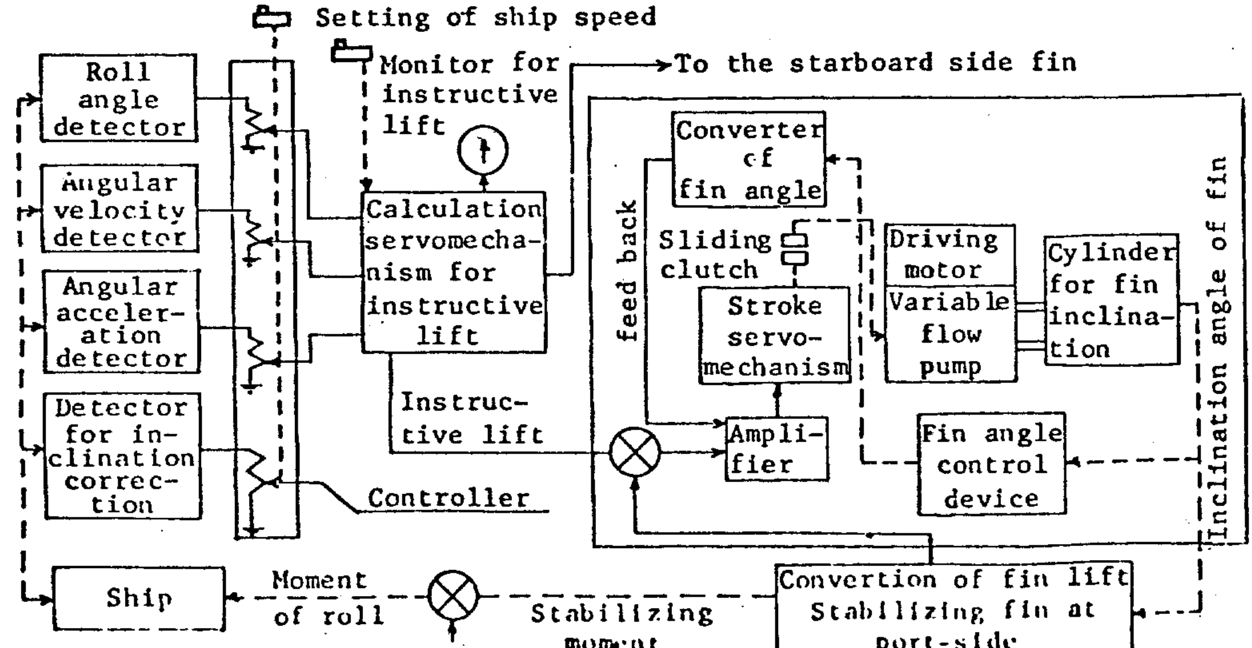


Fig. 98 Block diagram of fin stabilizer

The feed-back control of fin angle β is carried out in proportion to ϕ, $\dot{\phi}$ and $\ddot{\phi}$. Assuming that the lift on the fin is in proportion to the fin angle, the motion equation of the ship having the fin stabilizer is shown as follows;

$$J_s\ddot{\phi} + B_s\dot{\phi} + K_s\phi = K_s\theta_w + P\beta$$
$$\beta = K_1\ddot{\phi} + K_2\dot{\phi} + K_3\phi \qquad\qquad P = \rho ARV^2\, dC_L/d\beta$$

where A is the total projected area of fin, R the distance between the center of roll and the fin, V ship speed and ρ specific gravity of sea water. $dC_L/d\beta$ is the gradient of lift coefficient of fin as shown below.

$$\frac{dC_L}{d\beta} = \frac{m}{1 + m(1+\tau)/(\pi\lambda_e)}, \qquad \lambda_e = \frac{4}{3}\cdot\frac{b}{c}$$

(b : Breadth of fin, c : Chord length of fin)

$$\tau = 0.019\lambda + 0.067, \qquad m = 0.7\times 2\pi \qquad (\lambda : \text{Aspect ratio})$$

The other symbols are same as those stipulated in (2) Passive type of anti-rolling tank. In a general case, the fin control is obtained sufficiently by taking only K_2 into account.

The fin area is decided by the lift L_2 of fin necessary to the anti-rolling moment of the fin stabilizer acting against the stability force of the ship body and the maximum lift L_1 which can be produced by each sized fin of the manufacturer's standard specification. As an example of L_1, the fin stabilizer of the Sperry type is shown in Table 88. L_2 is calculated by the following formula.

$$L_2 = \frac{\Delta\cdot G_oM\sin\theta_e}{B + OR}$$

θ_e : Inclination angle of effective wave (usually 5°)

OR : Span length of fin

The relation between L_1 and L_2 is obtained empirically and varied in the respective navigation routes and cargoes. The actual results of the ships with the fin stabilizer are shown in Fig. 99.

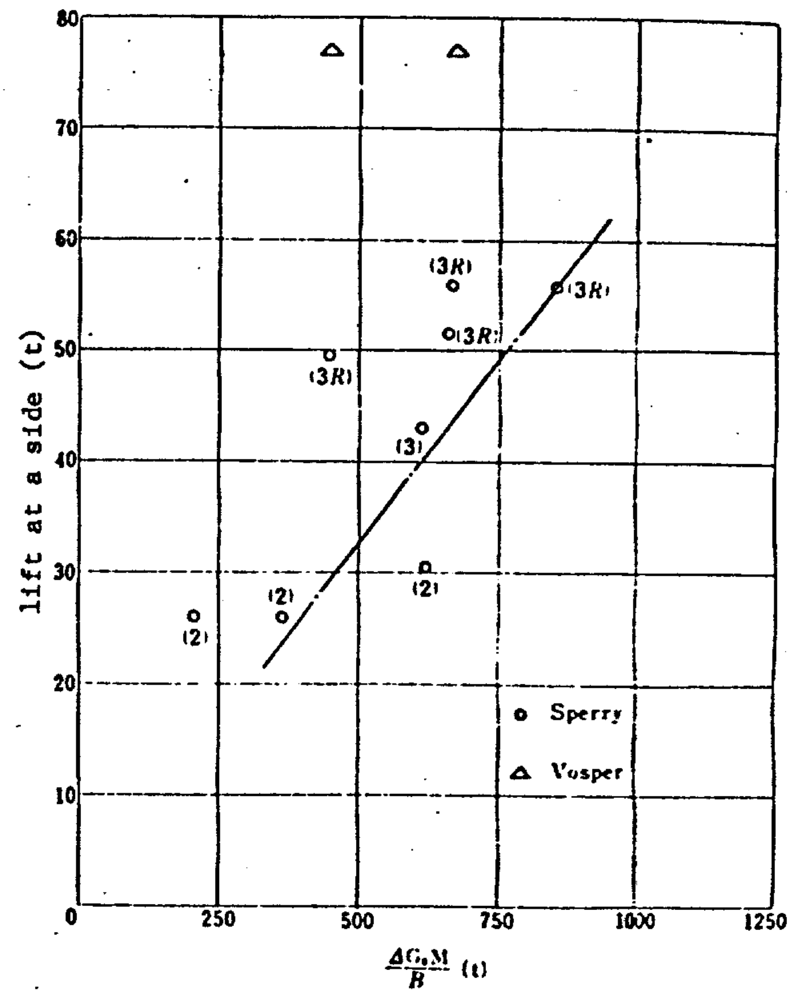


Fig. 99 Actual results of ships with fin stabilizer

Note) The symbols in parentheses show the fin types. (Refer to Table 88)

Table 88 Particulars of Stabilizer

Type		Symmetrical fin form, With flap totally fitted on rear edge of fin, Flap angle = 1.5 x Main fin angle, Housing type to be folded backward, Lift control system				
		1	2	3	3 *R*	4
Size of fin (m)		2.44 x 1.07	3.05 x 1.52	3.66 x 1.68	3.66 x 1.83	4.27 x 2.13
Max. lift (t)		20.3	30.5	43.7	55.9	91.4
Max. lift to each speed (t)	15 kt	11.4	20.3	26.8	29.3	40.0
	16	13.0	23.2	30.6	33.4	45.4
	17	14.6	26.2	34.6	37.7	51.3
	18	16.5	29.4	38.7	42.3	57.5
	19	18.3	30.5 (32.7)	43.2	47.1	64.1
	20	20.3	30.5	43.7 (47.9)	52.2	71.1
	21	20.3 (22.4)	30.5	43.7	55.9 (57.5)	78.2
	22	20.3	30.5	43.7	55.9	85.9
	23	20.3	30.5	43.7	55.9	91.4 (94.0)
	Remarks	Figures in ( ) show calculation values.				

7.2. Statistical Prediction on Ship Response

7.2.1. Statistical Prediction Method (Refer to Chapter I, 2.10)

(1) Short term prediction
Assuming that the probability distribution of ship response in time series in confused sea is the normal distribution and the probability distribution of extreme value (the maximum or minimum value) is subject to Rayleigh distribution (this assumption is applied hereinafter), the variance of ship response σ' or the cumulative energy density E is applied as parameter of short term distribution. The relation between E and σ is

$$\sqrt{E} = \sqrt{2}\,\sigma$$

(a) Ship response in confused seas
The relation between the course of ship ψ, the direction of wave μ and the angle of attack χ is shown in Fig. 100. When the response amplitude operations (*RAO*) of frequency of ship response in long-crested regular waves and the wave spectrum $f(\omega, \alpha)$ in irregular seas in the short term are given, the function of energy density is obtained by the method of energy spectrum to which the linear overlapping theory is applied. The *RAO* of ship response is obtained by theoretical calculations or model tests.

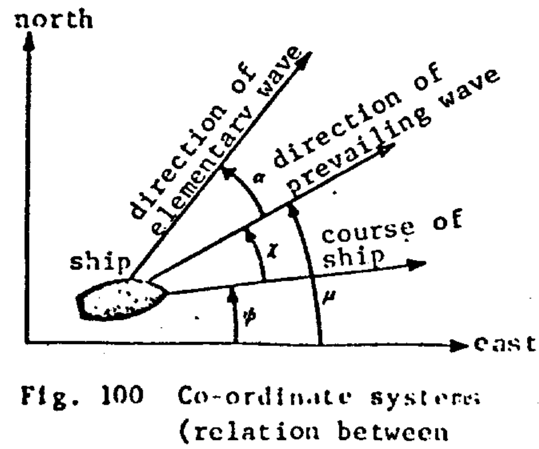


Fig. 100 Co-ordinate systems (relation between course and waves)

The two dimensional wave spectrum $f(\omega, \alpha)$ is shown in general by the product of one dimensional wave spectrum $f(\omega)$ and the direction distribution function of elementary wave $g(\alpha)$ as described below.

$$f(\omega, \alpha) = f(\omega) \times g(\alpha)$$

$$g(\alpha) = 1 \quad \text{(long-crested irregular waves)}$$

$$\left.\begin{array}{ll} = \frac{\pi}{2}\cos^2\alpha , & |\alpha| \leq \frac{\pi}{2} \\ = 0 & \frac{\pi}{2} < |\alpha| \leq \pi \end{array}\right| \text{(short-crested irregular waves)}$$

As an example the ISSC spectrum etc. may be used for one dimensional wave spectrum. (Refer to Chapter VI, 1.3)
The energy density function of ship response is shown as

$$[S(\omega, \chi, \alpha)]^2 d\omega d\alpha = [RAO(\omega, \chi + \alpha)]^2 [f(\omega, \alpha)]^2 d\omega d\alpha$$

The variance of ship response is shown as

$$[\sigma_s(\chi)]^2 = \int_{-\pi}^{\pi} \int_0^{\infty} [S(\omega, \chi, \alpha)]^2 \, d\omega d\alpha$$

(b) Short term prediction of ship response
The various expected values in irregular seas of short term are shown by the standard deviation values σ. (Refer to Table 18, Chapter I, 2.10)
The extreme value X of ship response x exceeds a certain value x_1 in the probability q as shown in the following formula

$$q(X > x_1) = \exp(-x_1^2/2\sigma^2)$$

and the time rate to $x > x_1$ is

$$p(x > x_1) = \frac{1}{2}\left\{1 - \frac{2}{\sqrt{\pi}}\int_0^{x_1/\sqrt{2}\sigma} \exp(-\xi^2) d\xi\right\}$$

The significant wave height $H_s(q_1)$ which shows the limit to which the probability q of a constant value x_1 being exceeded goes beyond a certain value q_1 is described as follows.

$$H_s(q_1) = \frac{x_1}{\sqrt{2\log_e(1/q_1)}} \frac{1}{\sigma/H_{1/3}}$$

(2) Long term prediction

(a) Long term prediction on uncommon values of ship response
Regarding the acceleration of oscillation, the stress on a ship body and bending moment caused by wave load, the long term prediction is applied for the prediction of uncommon values which rarely occur through a ship's life. When the probability density function of wave occurrence in long term $p(H_{1/3}, \bar{T}_0)$ (refer to Chapter VI, 1.3) is given, the long term cumulative probability Q_{x1} with which the ship response of the ship navigating along a constant course in the sea region exceeds x_1, is obtained as the function of the angle of attack χ as follows;

$$Q_{x1}(\chi) = \int_0^{\infty} \int_0^{\infty} \exp(-x_1^2/2\sigma^2) \, p(H_{1/3}, \bar{T}_0) \, dH_{1/3} d\bar{T}_0$$

Assuming that the wave occurrence probability in long term of the angle of attack is uniformly distributed,

$$Q_{x1} = \frac{1}{2\pi}\int_0^{2\pi} Q_{x1}(\chi)\, d\chi$$

(b) Long term prediction on occurrence frequency of critical condition
This prediction is applied to the long range probability with which the frequency of occurrence of the submergence, slamming and propeller racing exceed a certain value. The wave occurrence frequency in long term $p(H_{1/3},\ \bar{T}_0)$ being given, the response x of the ship navigating keeping a course with the angle of attack χ to the wave exceeds a certain critical level with the probability q . The long term cumulative probability, with which the navigation condition in which q exceeds a certain level q_1 is encountered, is shown as the function of χ as follows;

$$Q_{q1}(\chi) = \int_0^\infty \int_{H_s}^\infty p\,(H_{1/3},\ \bar{T}_0)\, dH_{1/3}\, d\bar{T}_0$$

However, on condition that the ship's speed is constant, H_s is referred to 7.1.1 (1)(b) and the long term occurrence frequency of the angle of attack χ is distributed uniformly between 0 and 2π , the following formula is given.

$$Q_{q1} = \frac{1}{2\pi}\int_0^{2\pi} Q_{q1}\ (\chi)\, d\chi$$

7.2.2. Statistical Distribution of Ship Response

(1) Ship response in confused seas .
The calculation example of significant double amplitude of oscillation (container ships) in confused seas is shown in Fig. 101 (pitch) and Fig. 102 (roll). The acceleration by oscillation is shown in Fig. 103 (vertical acceleration at bow) and Fig. 104 (transverse acceleration at center of gravity).

(2) Short term distribution

(a) Slamming
The following two items are usually considered as the occurrence condition of slamming.

1) Exposure of the ship's bottom at bow
2) Relative speed v_{rs} at the time when the ship's bottom at bow hits water surface again exceeds threshold velocity v_{cr}

The item 2) is dependent on ship's form, ship's speed, etc. and the formula $v_{cr} = 0{\cdot}09\sqrt{gL}$ (Ochi's formula) is often used and also the values by Tasai and Ferdinande are introduced as those of analysed experimental results. The calculation example on the limit of slamming occurrence is shown in Fig. 106.

Note) The calculation examples of SR 108 container ships in Fig. 101 - Fig. 115 are those for the ships with $L = 175$m.

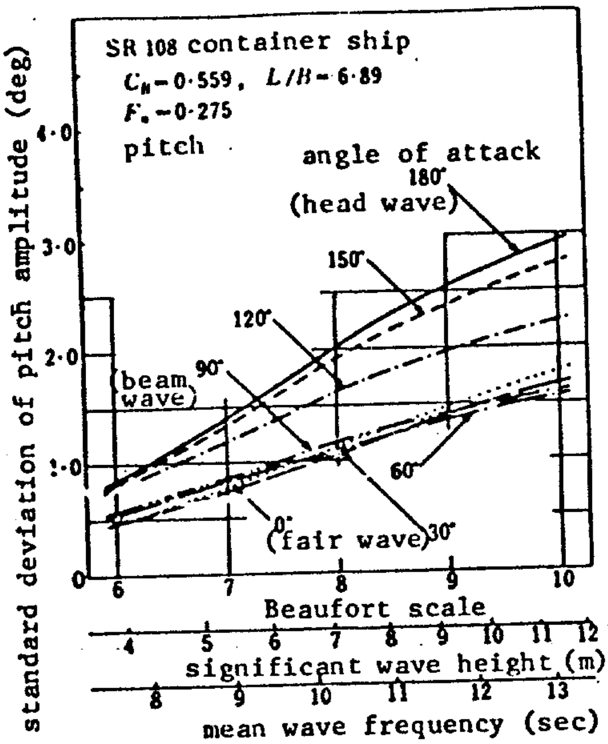


Fig. 101 Standard deviation of ship response in confused seas (pitch)

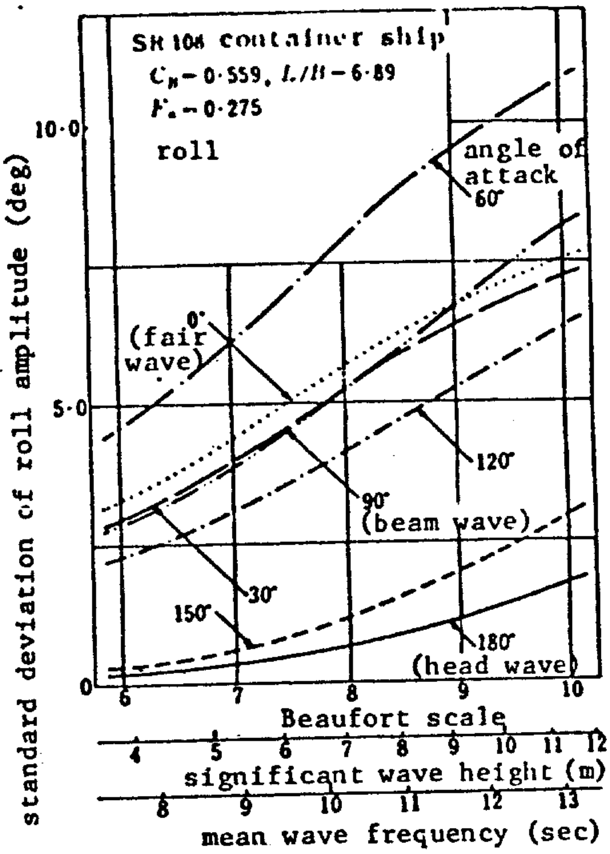


Fig. 102 Standard deviation of ship response in confused seas (roll)

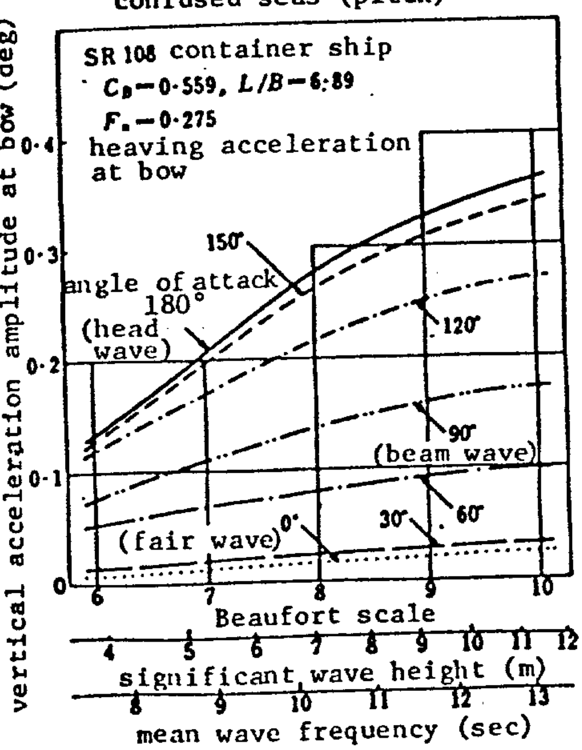


Fig. 103 Standard deviation of ship response in confused seas (vertical acceleration at bow)

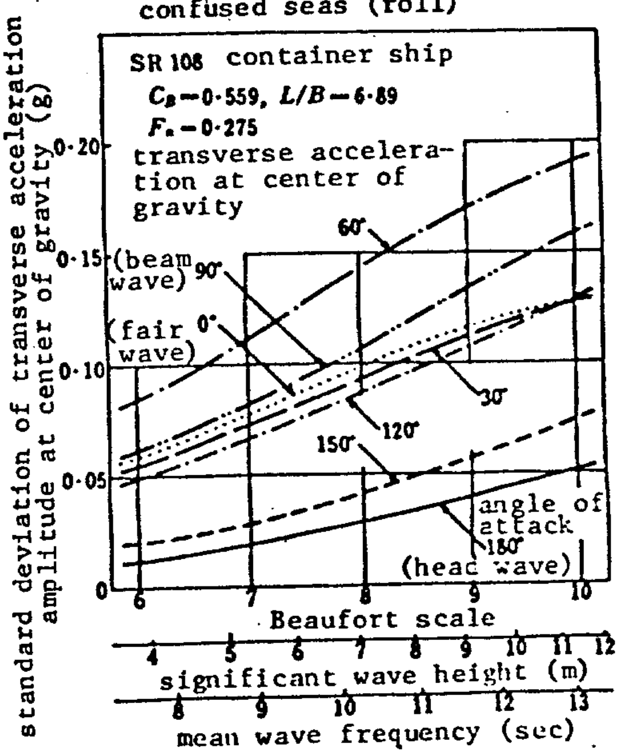


Fig. 104 Standard deviation of ship response in confused seas (transverse acceleration at center of gravity)

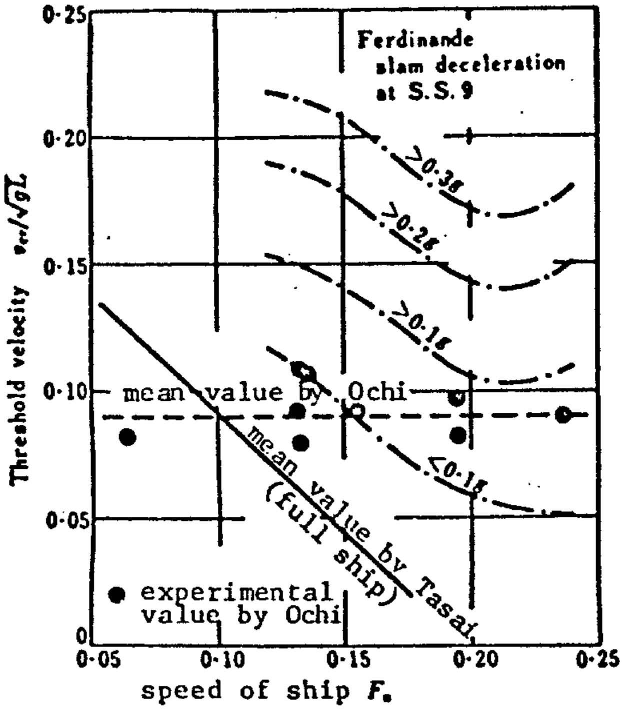


Fig. 105 Occurrence limit of slamming threshold velocity

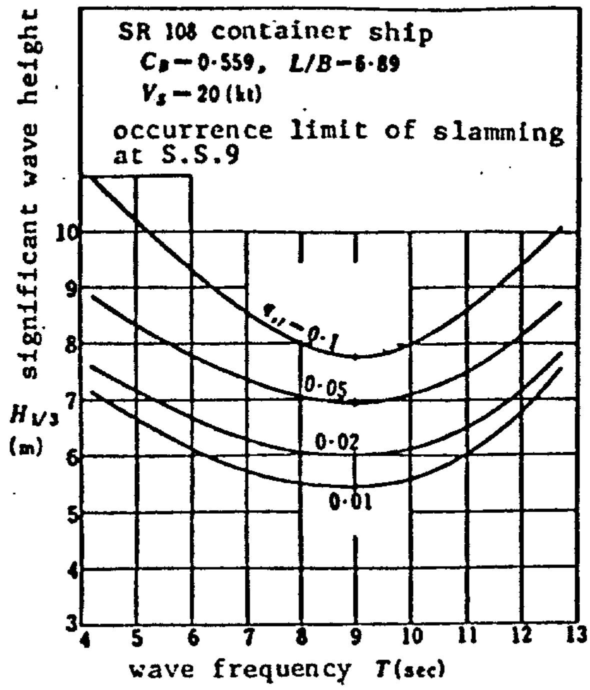


Fig. 106 Occurrence limit of slamming

(b) Submergence of sea water

The condition that the relative motion amplitude z_{rl} exceeds the bow freeboard f is defined as the submergence of sea water. The effective freeboard f_e for navigating condition in calm sea is desirous to be used as the bow freeboard. f_e is obtained by subtracting the statical swell-up ζ_s of bow seas from f. Regarding ζ_s, Tasaki's experimental formula about large tanker is introduced below.

$$\zeta_s = 0{\cdot}75 \frac{BL}{L_E} F_n^2$$

L_E : Length of water plane entrance

In case of navigating in seas, the revised z_{rd} to the dynamical swell-up of wave surface by relative motion had better be applied instead of z_{rl}. The experimental formula by Tasaki is shown as follows;

$$z_{rd} = z_{rl} \cdot \frac{4(C_B - 0{\cdot}45)}{3} \left(\frac{\omega_e L}{g}\right)^{1 \cdot 1}$$

$$0{\cdot}16 < F_n < 0{\cdot}29, \quad 1{\cdot}6 < \frac{\omega_e^2 L}{g} < 2{\cdot}6$$

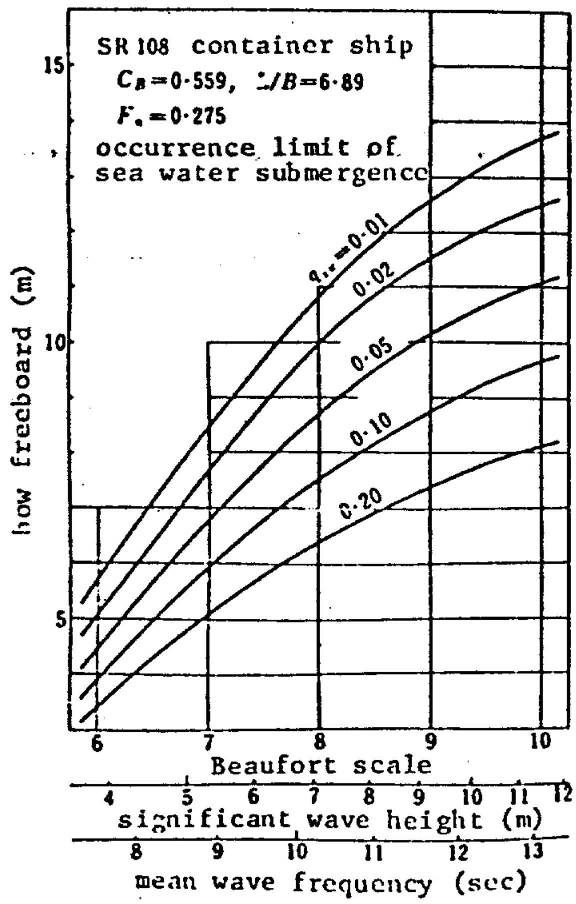


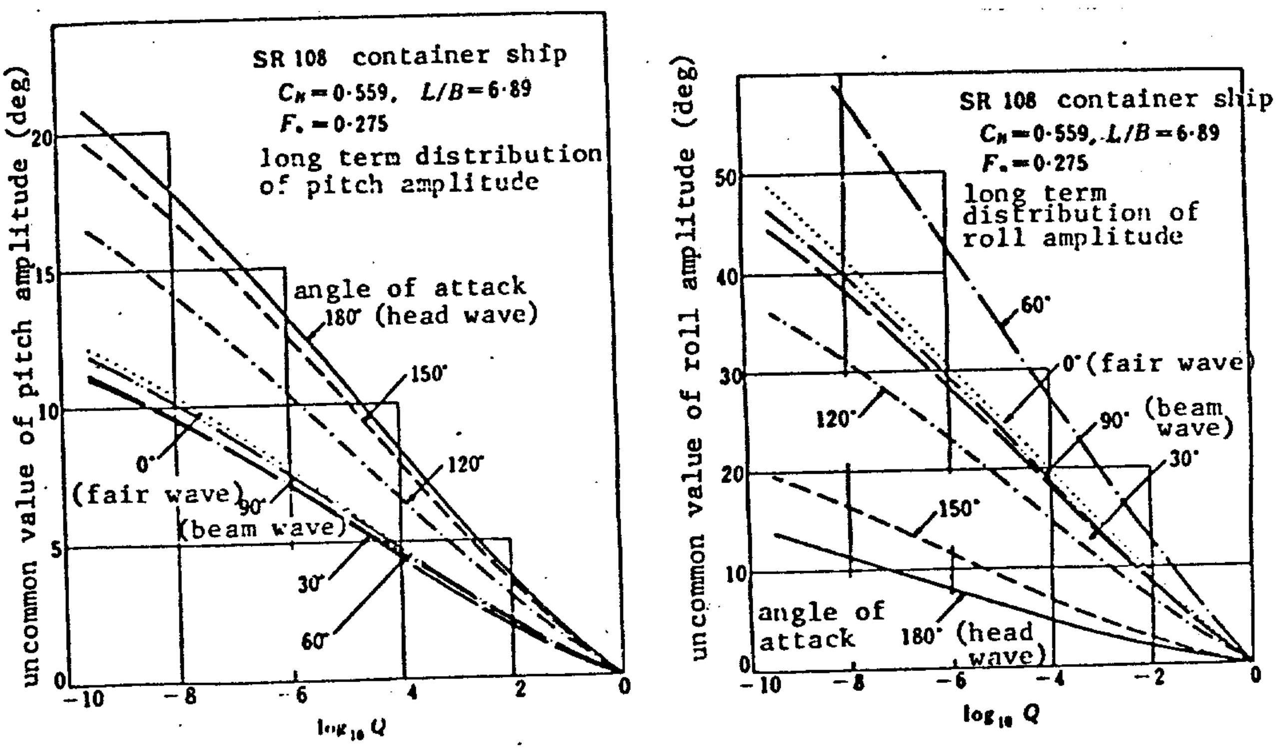
Fig. 107 Occurrence limit of sea water submergence

The relation between the occurrence limit of sea water submergence and the bow freeboard to be obtained by the calculation is shown in Fig. 107.

(3) Long term distribution
To obtain the long term distribution of ship response, the data on seas over a long term are required. The observation data on the North Atlantic and others (refer to Chapter VI, 1.3.4) are often used for a long term prediction.

(a) Uncommon values of ship response
The prediction of uncommon values on pitch amplitude and roll amplitude, and on vertical acceleration at bow and transverse acceleration at center of gravity are exemplified in Fig. 108 and Fig. 109 respectively.

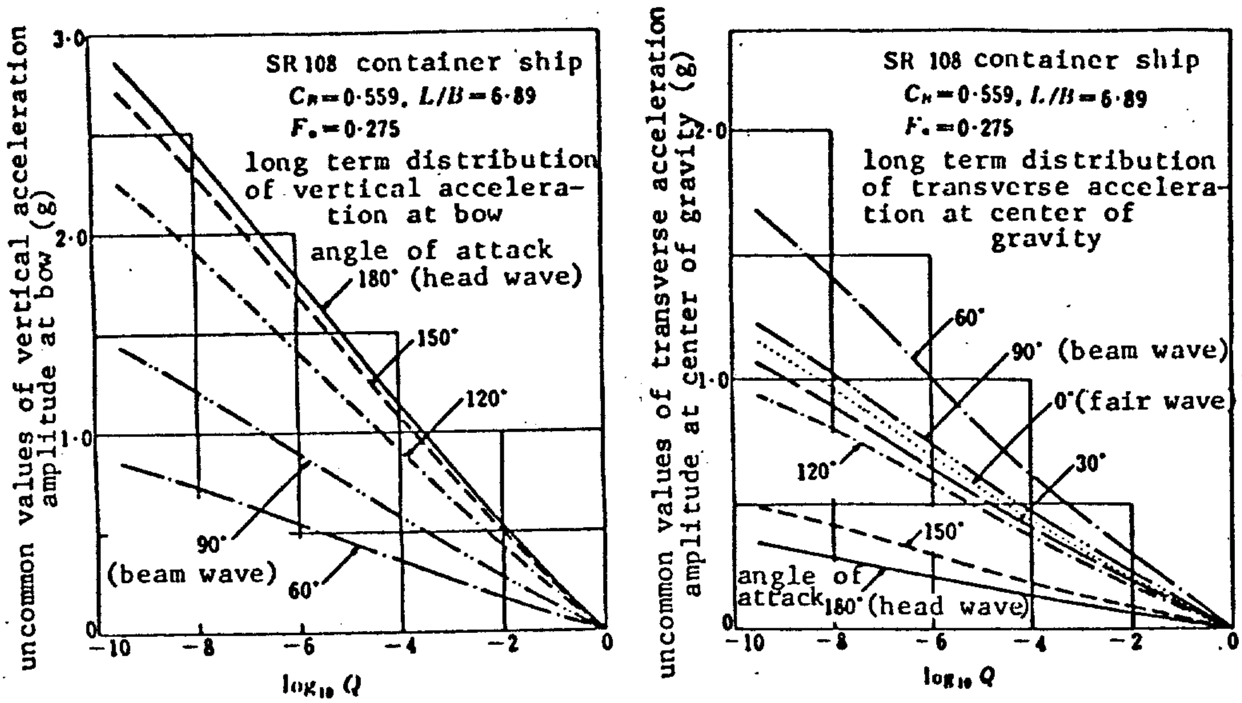
(b) Limitation for the deceleration to be required
Lewis represents the formula $q_{sl} = 0{\cdot}01$ as the occurrence probability of slamming in the limitation in which the deceleration is not required. The calculation example of long term cumulative probability of slamming to $q_{sl} \geq 0{\cdot}01$ is shown with a parameter of F_n to ship length in Fig. 110. Lewis also represents $q_{sw} = 0{\cdot}02$ as the occurrence probability of sea water submergence in the limitation in which the deceleration is not required.
Fig. 111 is the calculation example in which the long term cumulative probability of sea water submergence encountered to the navigating conditions of $q_{sw} \geq 0{\cdot}1$ is shown as a function of ship length.



(1) Uncommon value of pitch amplitude

(2) Uncommon value of roll amplitude

Fig. 108 Long term distribution of ship response



(1) Uncommon values of vertical acceleration at bow

(2) Transverse acceleration at center of gravity

Fig. 109 Long term distribution of ship response

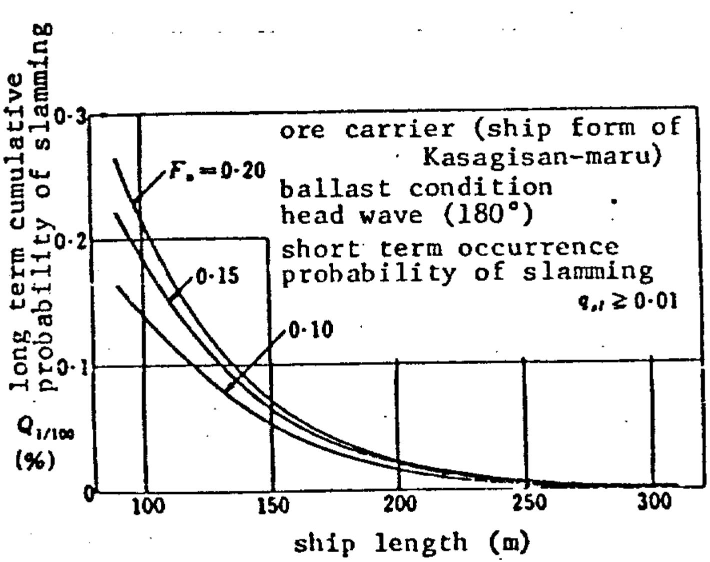


Fig. 110 Long term distribution of ship response (Long term occurrence probability of slamming)

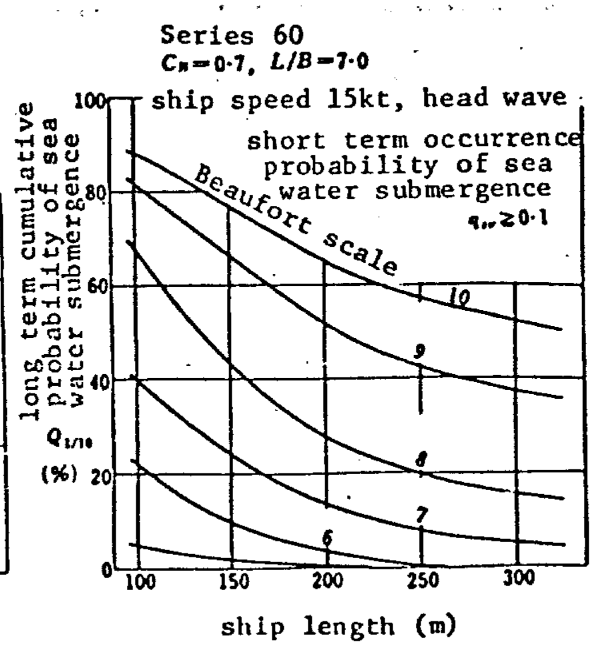


Fig. 111 Long term distribution of ship response (Long term occurrence probability of sea water submergence)

7.3. Resistance Increase and Propulsive Performance in Seas

7.3.1. Resistance Increase in Regular Seas

The modification method based on Maruo's theory and the approximate calculation method based on the strip method are introduced as the method which are used widely to obtain the resistance increase R_{AW} in regular seas theoretically. (Fig. 112)

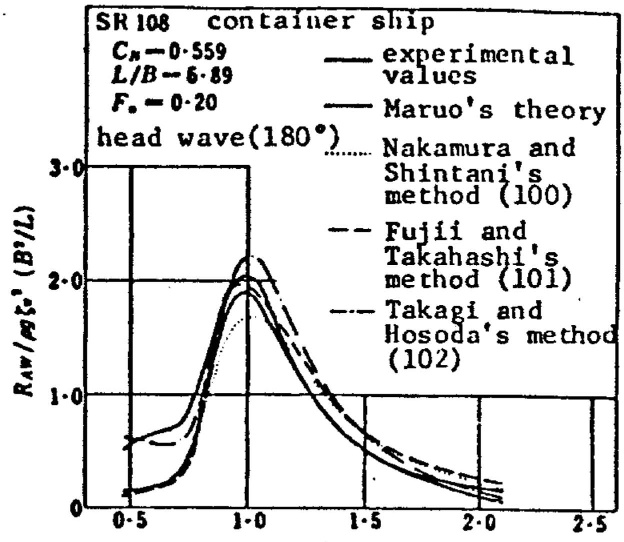


Fig. 112 Example of calculation of resistance increase in regular seas (in head wave)

7.3.2. Resistance Increase in Confused Seas

Using the response amplitude operators of resistance increase in the long-crested regular waves, on the assumption that the resistance increase is in proportion to the square of wave height, the short term prediction method of 7.2.1 is applied to the calculation of the mean increase of resistance $\overline{R_{AW}}(\chi)$ in confused seas.

$$\overline{R_{AW}}(\chi) = 2\int_0^{2\pi}\int_0^{\infty} R'_{AW}(\omega, \chi+\alpha)\,[f(\omega,\alpha)]^2\, d\omega\, d\alpha$$

where $R'_{AW}(\omega, \chi+\alpha)$ is (resistance increase in confused seas)/(wave height)^2.

7.3.3. Resistance Increase by Wind

The resistance of wind pressure is

$$R_a = \frac{1}{2}\rho_a k(\theta) C_a A_T V_a^2$$

where ρ_a is air density, θ relative wind direction, V_a relative wind velocity, A_T front projective area of ship body above water line.
With χ of the angle between the direction to bow and the wind direction and U of the wind velocity, V_a is

$$V_a^2 = U^2 + V^2 - 2UV\cos\chi, \quad \theta = \tan^{-1}\frac{\sin\chi}{V/U - \cos\chi}$$

C_a is the resistance coefficient of front wind pressure, $k(\theta)$ is the influence coefficient of wind direction. The examples of the above coefficients obtained from the experiment in a wind tunnel are shown in Fig. 113 and Fig. 114. Besides, Isherwood method shown with regression curves by analysing many experimental data is introduced.
The rate of resistance increase by wind is smaller than that by wave under rough sea conditions but the rate becomes rather large under calm sea conditions. (Fig. 115)

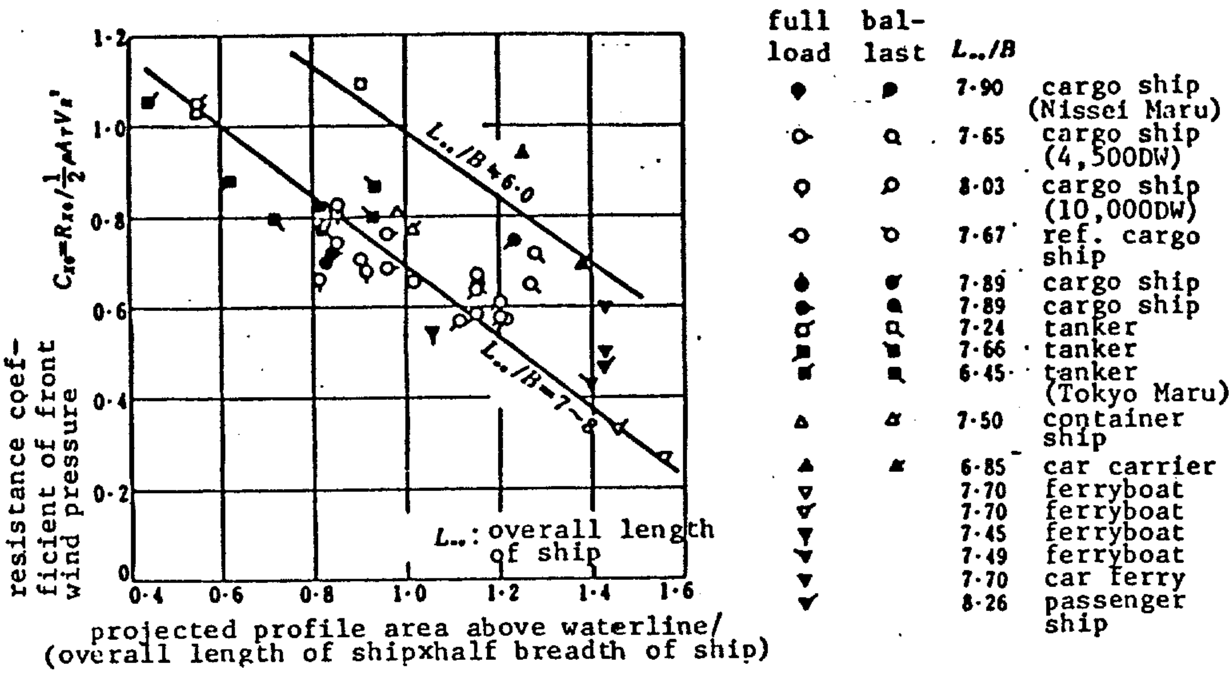


Fig. 113 Resistance coefficient of front wind pressure

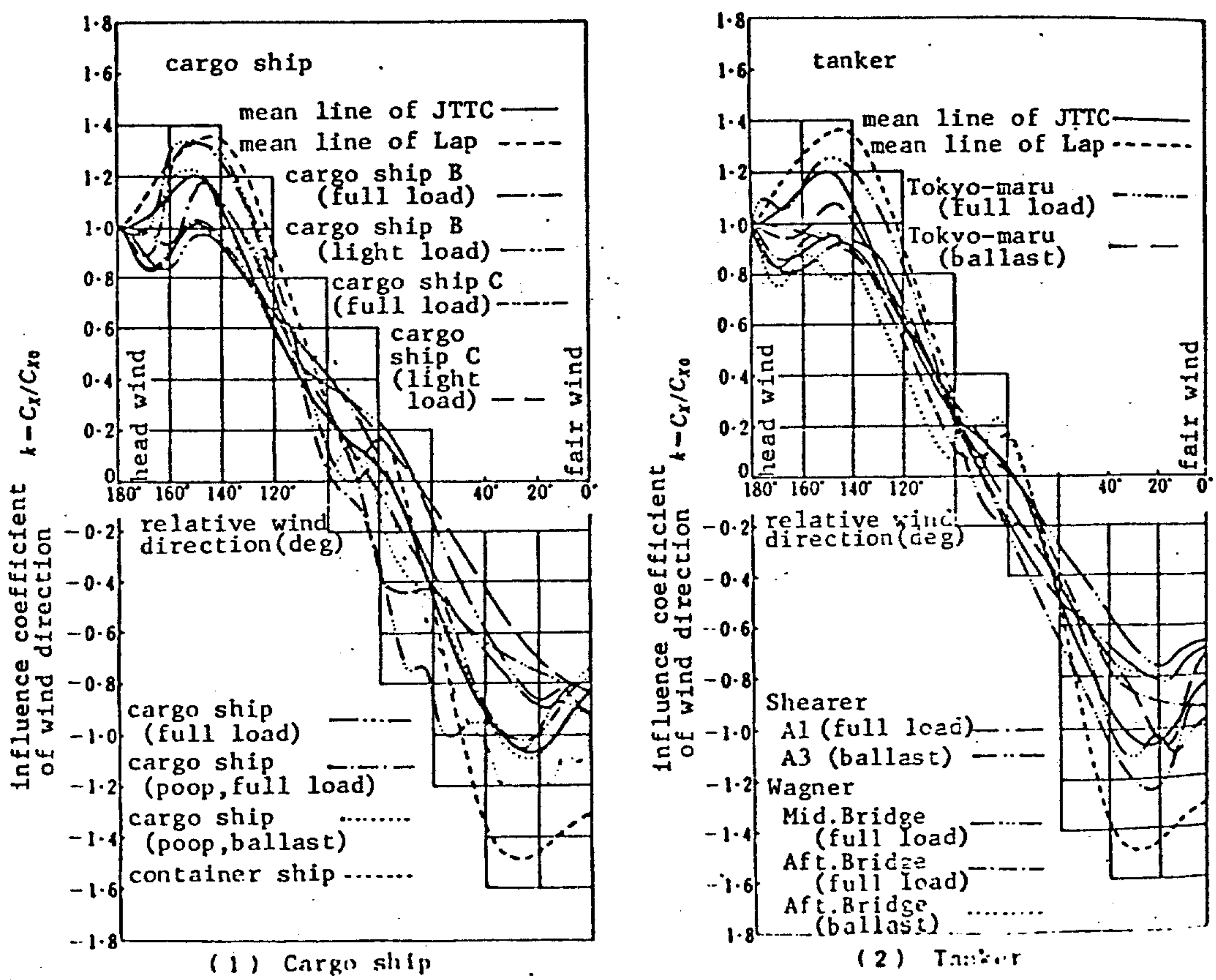


Fig. 114 Influence coefficient of wind direction

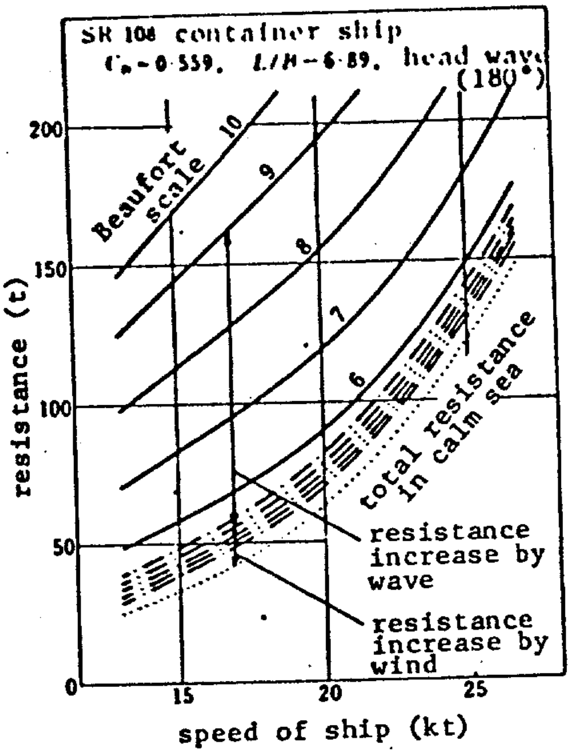


Fig. 115 Resistance increase by wind and wave

7.3.4. Propulsive Performance, Increase of Horse Power and Lowering of Ship Speed in Seas

(1) Propulsive performance
It is reported that the mean values in time series on $(1-t)$, $(1-w)$ and η_R under head seas are not so different from those under calm sea, but the open propeller efficiency η_0 and propulsive efficiency η decrease considerably.

(2) Increase of horse power
According to Miyamoto's method by which the thrust increase ΔT in head seas can be obtained,

$$\Delta T = 0.009\,446\, B H_{1/3}^2 (T_e\sqrt{g/L})^2\, C_B^{3/2} \sqrt{B/d}\, \frac{f(F_n)(\omega_e/\omega_m)^4}{\{1+0.11(\omega_e/\omega_m)^4\}^2} \quad (t)$$

$$f(F_n) = 2.10 - 26.8(F_n - 0.287)^2$$

$$\omega_e/\omega_m = \frac{12.09}{T_w\sqrt{g/L}\left\{1+\frac{0.875}{F_n}\left(\sqrt{1+\frac{25.13F_n}{T_e\sqrt{g/L}}}-1\right)\right\}}, \quad \omega_e = 2\pi/T_w$$

where $H_{1/3}$ is significant wave height, T_w mean wave period and T_e natural period of pitch. In addition to this method, there is Moor - Murdey's method by regression analysis to a lot of experimental results.

(3) Lowering of ship speed
Aertssen's formula by which the lowering rate of ship speed can be estimated from test results analyzed on actual ships is

$$100\frac{\Delta V}{V} = \frac{m}{L} + n \quad (\%)$$

where m and n are shown below in Table 89. Actual values of the lowering rate of ship speed are shwon in Fig. 116.

Table 89 Values of m and n

Beaufort scale	Significant wave height (m)	Frontal head seas		Oblique head seas		Beam seas		Following seas	
		m	n	m	n	m	n	m	n
5	3.0	900	2	700	2	350	1	100	0
6	4.2	1,300	6	1,000	5	500	3	200	1
7	5.8	2,100	11	1,400	8	700	5	400	2
8	7.4	3,600	18	2,300	12	1,000	7	700	3

As the limit of intentional speed reduction (navigation limit), Lewis and Aertssen's proposals (Table 90) have been introduced. On the other hand, Yonekura has proposed the navigation limit based on the examination on the structure and fatigue strength (Fig. 117).

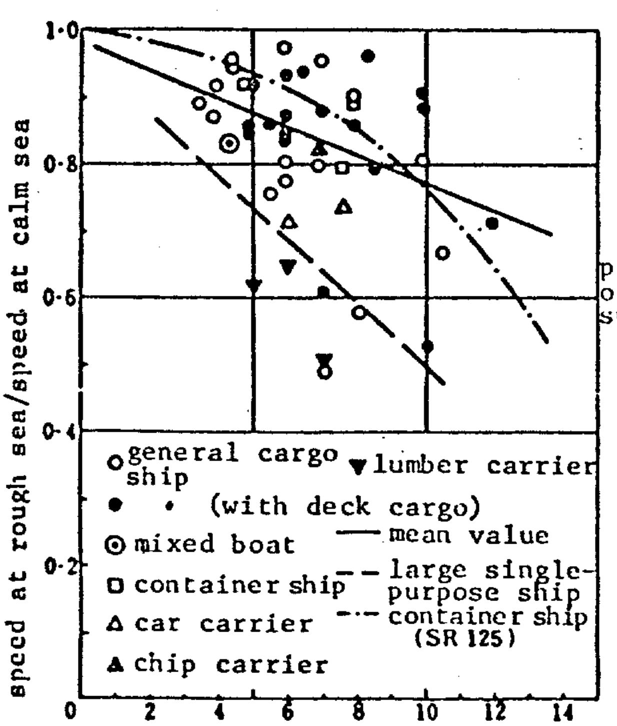


Fig. 116 Actual results of ship speed lowering in seas

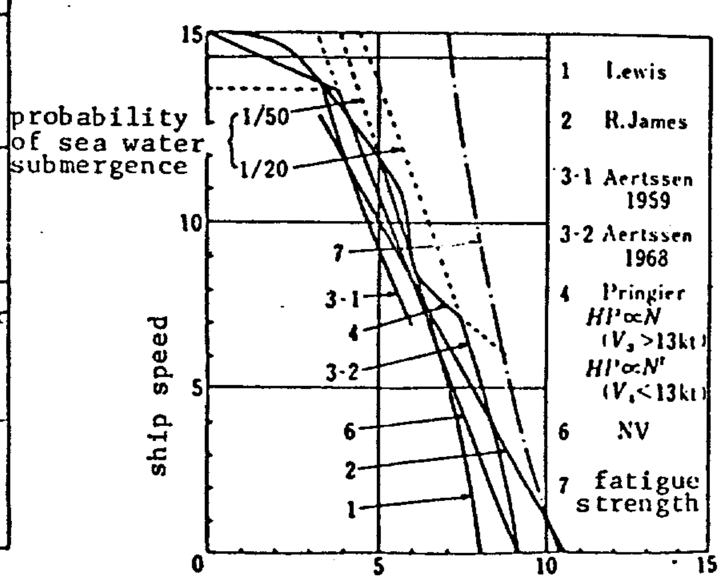


Fig. 117 Navigation limit

Table 90 Navigation Limit

		Tanker	Bulk carrier	General cargo ship	Ferry boat	Trawler
E. V. Lewis	Sea water submergence	1/ 50				
	Slamming	1/100				
	Acceleration	Passenger cabin 0.2 g,	Crew's living quarter or working area 0.4 g,		Probability 1/25	
G. Aertssen	Sea water submergence	5/100	5/100	5/100	5/100	5/100
	Slamming	3/100	3/100	4/100	5/100	6/100
	σ Whipping stress (kg/mm^2)	2.0	2.0	0.6	0.4	0.9
	Vertical acceleration at bow	0.5 g	0.5 g	0.9 g	1.0 g	1.4 g

Note) The limits for the sea water submergence and slamming are shown in probability (number of occurrence/number of oscillation).

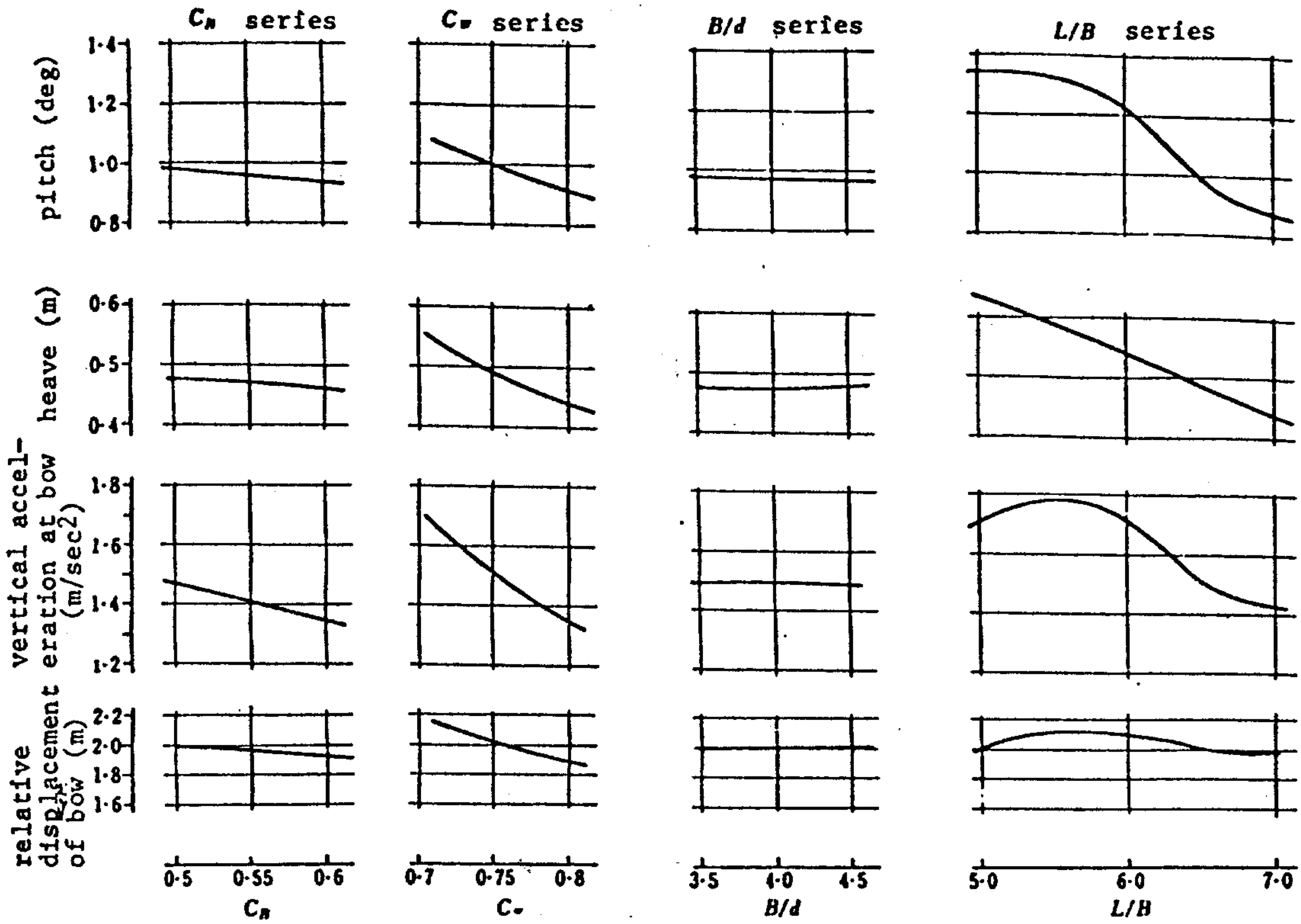
7.4. Effect on Seaworthiness by Ship's Form

7.4.1. Effect by Principal Dimensions

According to the calculation results (Fig. 118) based on the strip method by which Takarada and others calculated the ship motion in confused seas changing the ratio of principal dimensions of car ferry form, the effect to ship motion is most remarkable in L/B and C_w, secondaly in C_b and least in B/d. The pitch, heave and the relative displacement of bow to seas and vertical acceleration are smaller to the bigger L/B, C_w and C_b respectively. The trend of change is shown in Fig. 118 for the principal dimensions ratio but it should be noted that the displacement is not constant except in C_w series.

According to the results of model tests by Tasai and others for the ship's form of single screw high speed container carrier with constant displacement and either L/B of 6.8 or 8, the oscillation and vertical acceleration are smaller to the bigger L/B.

By the test results for the ship's form of series 60, Vossers and others show that the oscillation is smaller to the bigger L/d with the constant L, B, C_b and the variable d in the longer wave in length than the ship length. With the constant L, d, C_b and the variable B, L/B effect is small and less remarkable than that of L/d. Fig. 119 shows that with the constant L, B, d and the variable C_b the heave and pitch are not much effected by C_b but the relative displacement of the bow to the wave is smaller to the bigger C_b.



L−140·0m, B−21·5m
d−5·2m, C_B=0·50∼0·60

L−140·0m, B−21·5m
d−5·2m, C_B−0·50
C_W=0·712∼0·805

L−140·0m, B−21·5m
d−4·78∼6·14m, C_B−0·50

L−107·5∼150·5m, B−21·5m
d−5·2m, C_B−0·50

(Froude number = 0.25, Beaufort scale 7, in frontal head seas)

Fig. 118 Change of pitch by the ratio of principal dimensions of car ferry form (standard deviation)

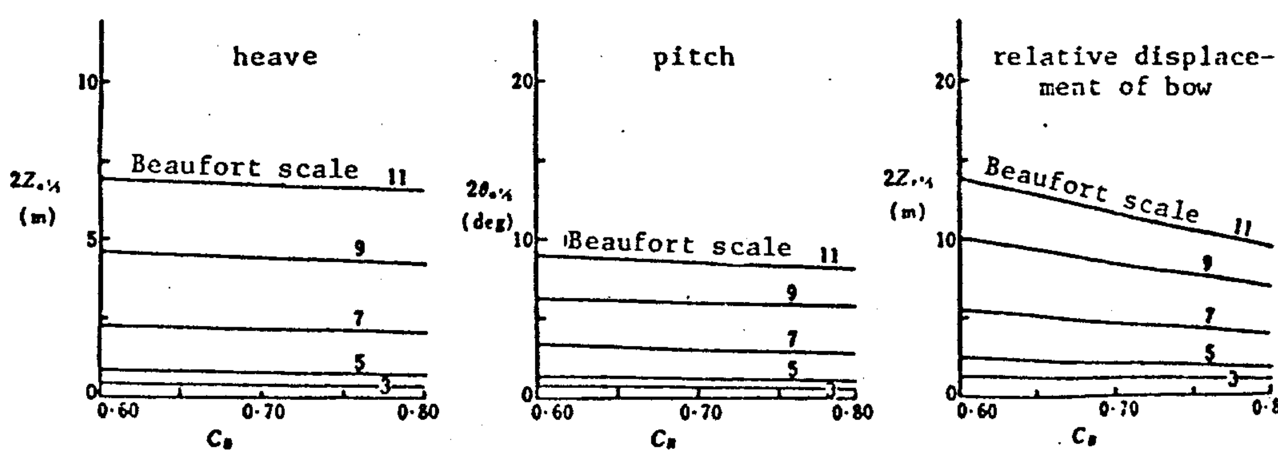


Fig. 119 C_B's effect on vertical motion
(L = 200m, V_s = 17.2kt, angle of encounter to wave = 170°)

7.4.2. Effect by the Shape of Frame Line

Swaan and others made experiments on the ship's form of series 60 (C_B = 0.70) by varying the shape of frame line in the fore part of ship body only. The experimental results show that the ship motion in V-shape frame line is smaller than that in U-shape in the longer wave in length than the ship length, the relative displacement of the bow to wave is smaller in U-shape frame line than in ordinary V-shape and the increase of horse power by waves is larger in the closer to V-shape in full load condition and also larger in excessive U-shape than V-shape in ballast condition. Yourkov calculated the vertical motion on the ships with C_B = 0.60, 0.70, 0.80 by the strip method maintaining the aft part of ship body identical and varying the extent of UV shape in the frame line of the fore part of ship body. The results show that the heave is smaller in V-shape, the pitch is smaller in V-shape in long wave and in short wave it is same as in U-shape or rather larger than in U-shape. However, it is generally resulted that the vertical motion is smaller in V-shape (Fig. 120) and such difference comes from the larger damping in V-shape. The difference between V-shape and U-shape is larger in smaller C_B and smaller in larger C_B.

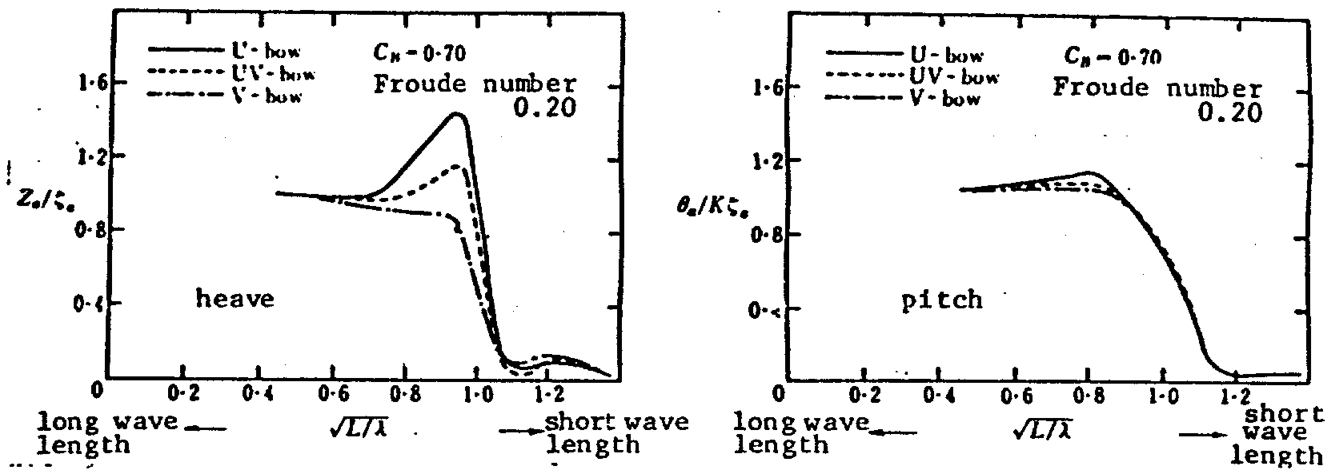


Fig. 120 Effect on vertical motion by the shape of frame line

In the ship form of car ferry described in the preceding article, the variation of C_B is corresponding to that of the shape of frame line. The fact that the ship motion is smaller in the larger C_B, means that the frame line of V-shape is more effective in this ship form too.

7.4.3. Effect by Flaring and Freeboard

According to the experimental results that Newton has got from the model test on the high speed warships in waves, the larger flare and freeboard bring about the effectiveness of less deck wetness with the less effect on the ship motion.
Swaan and others have also shown such experimental results in the variations of flare for the ship form of series 60 that the extent of flare gives more advantage to deck wetness with less effect on the ship motion. Fujii and others have obtained such results from the model test to be made to examine the relation between the flare and the panting at bow in the full ship that the closer to the vertical position the stem is, the more advantage can be obtained. This fact has been confirmed in the investigation on the damage example of actual ships in the Structural Committee of the Society of Naval Architects of West Japan. In this investigation, it is reported that the larger the radius of curvature on horizontal plane of the bow shell near the upper deck is the higher the damage rate becomes.

7.4.4. Effect by Longitudinal Radius of Gyration

Swaan and others made self-propulsion test in confused seas by the ship form of series 60 with $C_b = 0{\cdot}60$ varying longitudinal radius of gyration k_{yy} from 0.21 to 0.27. The test results (Fig. 121) show that the heave does not give much effect on the longitudinal radius of gyration but the increase of longitudinal radius of gyration causes the increase of the pitch and the relative displacement of the bow to wave, which is disadvantageous to deck wetness. In addition, the lowering of ship speed becomes greater but the vertical acceleration at bow becomes smaller.

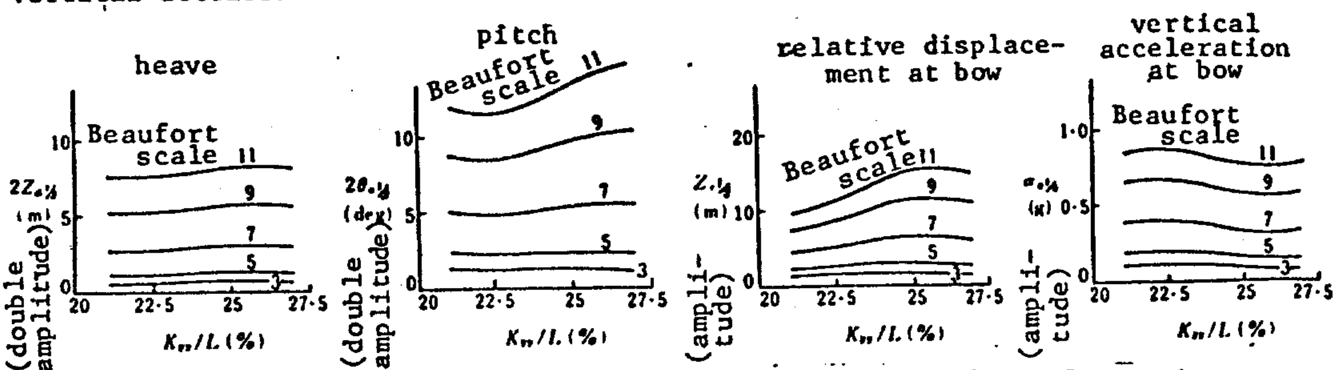


Fig. 121 Effect on vertical motion by longitudinal radius of gyration (L = 150m, V_s = 14.9kt, angle of encounter to wave = 150 deg.)

Vessers and others have got such results from the self-propulsion test in regular waves for the ship form of Victory-type with $C_b = 0{\cdot}69$ that the greater longitudinal radius of gyration brings about the greater lowering of ship speed.

7.4.5. Effect by Bulbous Bow

According to the experimental results on the ship form of series 60 with $C_b = 0{\cdot}65$ by Gerritsma, the bulbous bow with its cross-sectional area of 10-15 percent to the area of midship section brings about the smaller pitch and the greater heave and horse power increase by waves. Concerning the single screw high speed container ships, Tasai and others examined the effect of small bulbous bow (the corss-sectional area of 2 percent to the area of midship section) being usually used on this type of vessels and have obtained the experimental results that the adoption of the bulbous bow is unfavorable to the sea water submergence and induces the greater panting pressure to the bow bottom because of the larger swell of wave and the decrease of effective freeboard by the bulbous bow, while the oscillation performance and the horse power increase by waves are not much effected. Wahab has reached the same conclusion as Gerritsma and Tasai from the model test for high speed liners. But his conclusion is different from Tasai's in regard to the horse power increase by waves due to the adoption of the bigger bulb (17.2%) and same as Gerritsma in the point that the adoption of the bulb brings about the greater horse power increase in waves (Fig. 122). On the effect on the seaworthiness for the ship's form of high speed warship by the large sized bulbous bow (25 - 65%), Takezawa has obtained such results from an investigation that the adoption of the bulbous bow tends to decrease the oscillation but to increase the horse power by waves.

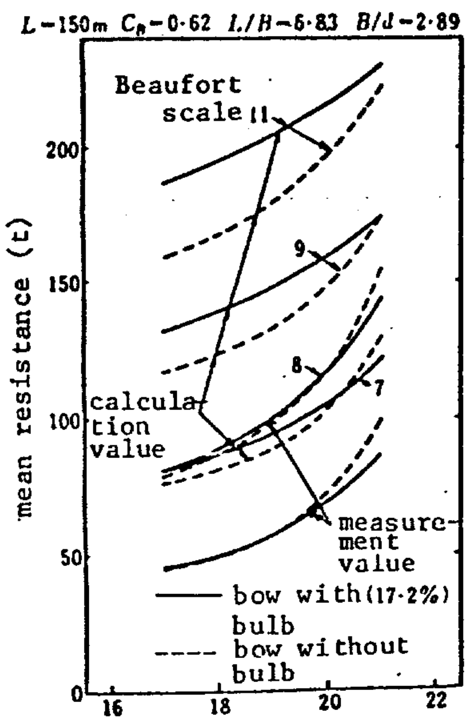


Fig. 122 Effect by bow on mean resistance in irregular long crest waves

8. RUDDER

8.1. Force and Torque Acting to Rudder

8.1.1. Calculation Formulas to be Generally Applied to Rudder Design

V_r = Flow velocity to rudder (m/sec), V_r' = Flow velocity to rudder (kt),
α = Angle of attack (deg.), P_n = Normal force to rudder (kg)
T = Torque (kg-m), h = Height of rudder (m),
c = Breadth of rudder (m)
a = Distance between leading edge of rudder and center line of rudder stock (m)
t = Thickness of rudder (m)
x = Distance between leading edge of rudder and center of normal force (m)
A_R = Movable part area of rudder (m²) (Fig. 123)

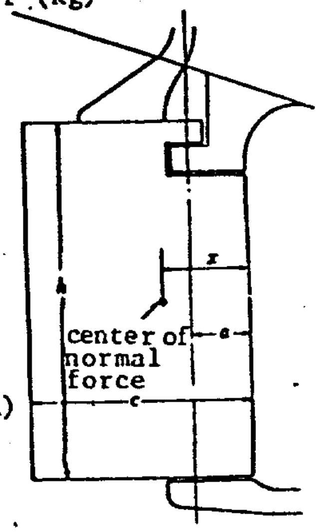


Fig. 123

(1) Normal force and center of pressure

(a) Beaufoy's and Jössel's formula

$P_n = 58{\cdot}8 A_R V_r^2 \sin\alpha = 15{\cdot}6 A_R V_r'^2 \sin\alpha$ (Beaufoy's formula)

$x/c = 0{\cdot}195 + 0{\cdot}305 \sin\alpha$ (Jössel's formula)

(b) Akasaki's formula

$P_n = 1{\cdot}025 A_R V_r^2 \{1 - 0{\cdot}6(t/c_e)\}$ (Pₙ)

where, c_e = Effective breadth of rudder (Fig. 125), (Pₙ) is normal force at $V_r = 1$m/sec, $A_R = 1$m², $t/c_e = 0$ and obtained from Fig. 124.

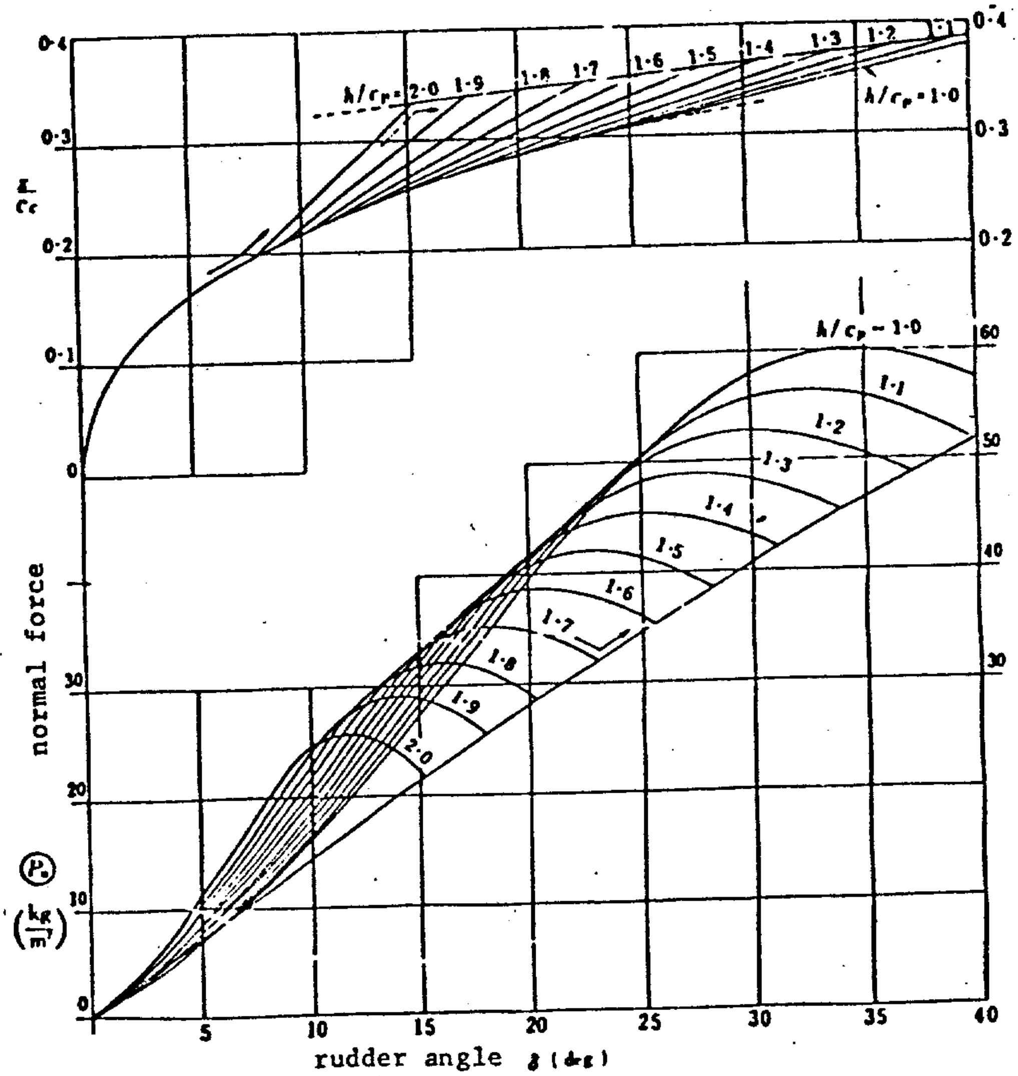
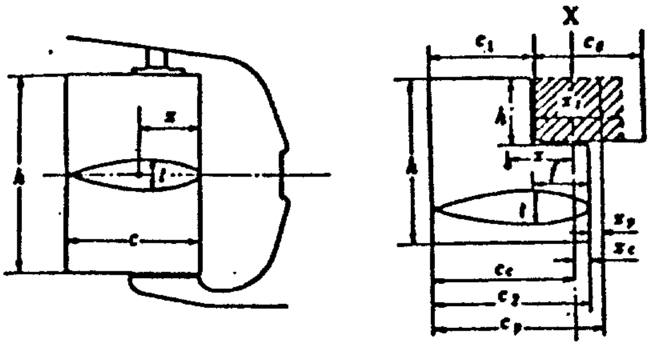


Fig. 124 x/c_e or (Pₙ) ~ Rudder Angle Curves



$c = c_p = c_e$
in the case of balanced rudder

in the case of semi-balanced rudder

x_1 : Length of dead wood part having effects on rudder

$$c_p = c_2 + x_p$$
$$c_e = c_1 - x_e$$

The provisional leading edge of rudder X—X is obtained as follows.

$$\begin{cases} x_e = \dfrac{f c_1 h'}{c_1 h' + c_2 (h - h')} \\ x_1 = \dfrac{(c_1 + c_2)}{2} \times \dfrac{h'}{h} \times \dfrac{c_2}{c_1} \\ x_p = (x_1 - f) \times \dfrac{h'}{h} \end{cases}$$

Fig. 125 Illustration of c, c_p, c_e etc.

The center of normal force is obtained from $x/c_e \sim$ rudder angle curves in Fig. 124, but refer to Fig. 125 as to c_e.

(2) Torque $T = P_n(x - a)$

(3) Flow velocity to rudder V_r
The flow velocity to the rudder is accelerated by the race of the propeller. In general, the V_r to be used in the rudder torque calculation is about 1.15 times the trial speed for single screw, single rudder ship and twin screw, twin rudder ship and about 1.10 times for twin screw, single rudder ship.

8.1.2. Various Factors Having Effects on Rudder Performance
The formulas in 8.1.1 are usually applied to rudder design, but the following factors, which have great effects on the forces acting to the rudder, should be properly considered.

(1) Aspect ratio $\lambda = h/c$
The effect of aspect ratio on lift coefficient C_L (refer to Fig. 126) of the symmetrical airfoil of Göttingen type is shown in Fig. 127. It is well understood that the larger the aspect ratio is, the larger the rate of lift increase becomes for the increase of angle of attack, and on the other hand, the larger the aspect ratio is, the more, the possibility of stall appears at small angle of attack. However, most of actual rudders working in the race of the propeller may be considered not to stall even at the large angle of attack as much as 35 to 40 degrees. Therefore, the rudder with large aspect ratio is actually favourable in spite of the results in Fig. 127 (refer to 8.1.1 (2)).

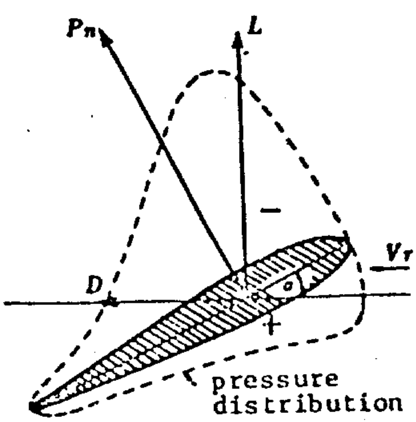


Fig. 126

Life coefficient $C_L = \dfrac{L}{\frac{\rho}{2} A V_r^2}$

Drag coefficient $C_D = \dfrac{D}{\frac{\rho}{2} A V_r^2}$

Normal force coefficient $C_n = \dfrac{P_n}{\frac{\rho}{2} A V_r^2}$

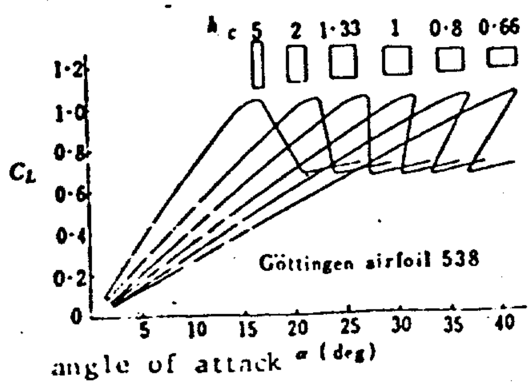


Fig. 127 Effect of Aspect Ratio on Lift Coefficient

It is also noted that the rudder with larger aspect ratio has less rudder torque against the large normal force.

(2) Race of propeller and wake of hull

The race of the propeller increases the flow velocity to the rudder and the rudder force. This effect is larger to the larger slip ratio of the propeller. The wake decreases the rudder force. These effects are shown by the following formulas according to Okada and Fujii's results. In case of the pretty large slip ratio like that of recent large vessels, C_N tends to increase at the larger rate than $s^{1.4}$. (Refer to 8.3.2)

$$C_N = \frac{P_N}{\rho A_R V_s^2 / 2} = (1-w)^2 (1 + 3 \cdot 6 s^{1.4}) \frac{6 \cdot 1 \lambda}{\lambda + 2 \cdot 2} \sin \alpha$$

where V_s = Ship speed (m/sec), λ = Aspect ratio
s = Real ship ratio = $1 - (1-w)V_s/(nP)$.
P = Propeller pitch (m), n = Revolutions per second
w = Wake factor

(3) Yawing motion

At the beginning of the turning, since the ship is drifted out of the turning circle, the center of pressure moves forward with the decrease of angle of attack to the rudder and rudder force. At the same time, the lowering of speed by the turning decreases the rudder force directly, while it increases the rudder force indirectly through the increase of propeller slip and shifts the center of pressure forward. As the wake at the turning motion is quite different from that at the straight advance, it also has great effects on the rudder force and the center of pressure. Due to these factors, the rudder force at the turning, especially the rudder torque, shows the complicated phenomenon and the values are frequently different considerably from those calculated by the preceding formulas. At present the formulas in 8.1.1 are generally used as the comparative criteria.

(4) Air drawing

The drawing of air occurs at the large rudder angle when the top of the rudder is at or near the surface of the water and causes the decrease of normal force and the increase of rudder torque. In addition, abrupt changes for both of the normal force and the rudder torque are sometimes induced.

(5) Camber ratio t/c

According to the experimental results by the wind tunnel of NACA, for the rudder with small camber ratio, the drag force increases and the lift force decreases in the large angle of attack, and the airfoil with small camber ratio tends to stall at small angle. But, if the camber ratio is too large, the performance becomes bad due to the increase of the drag force at small angle of attack. However, since the stall cannot occur in the race of the propeller, it is concluded that the effect on the rudder performances is small as far as the camber ratio is not so large (refer to 8.3.3 (3)).

8.2. Type of Rudder (Fig. 128)

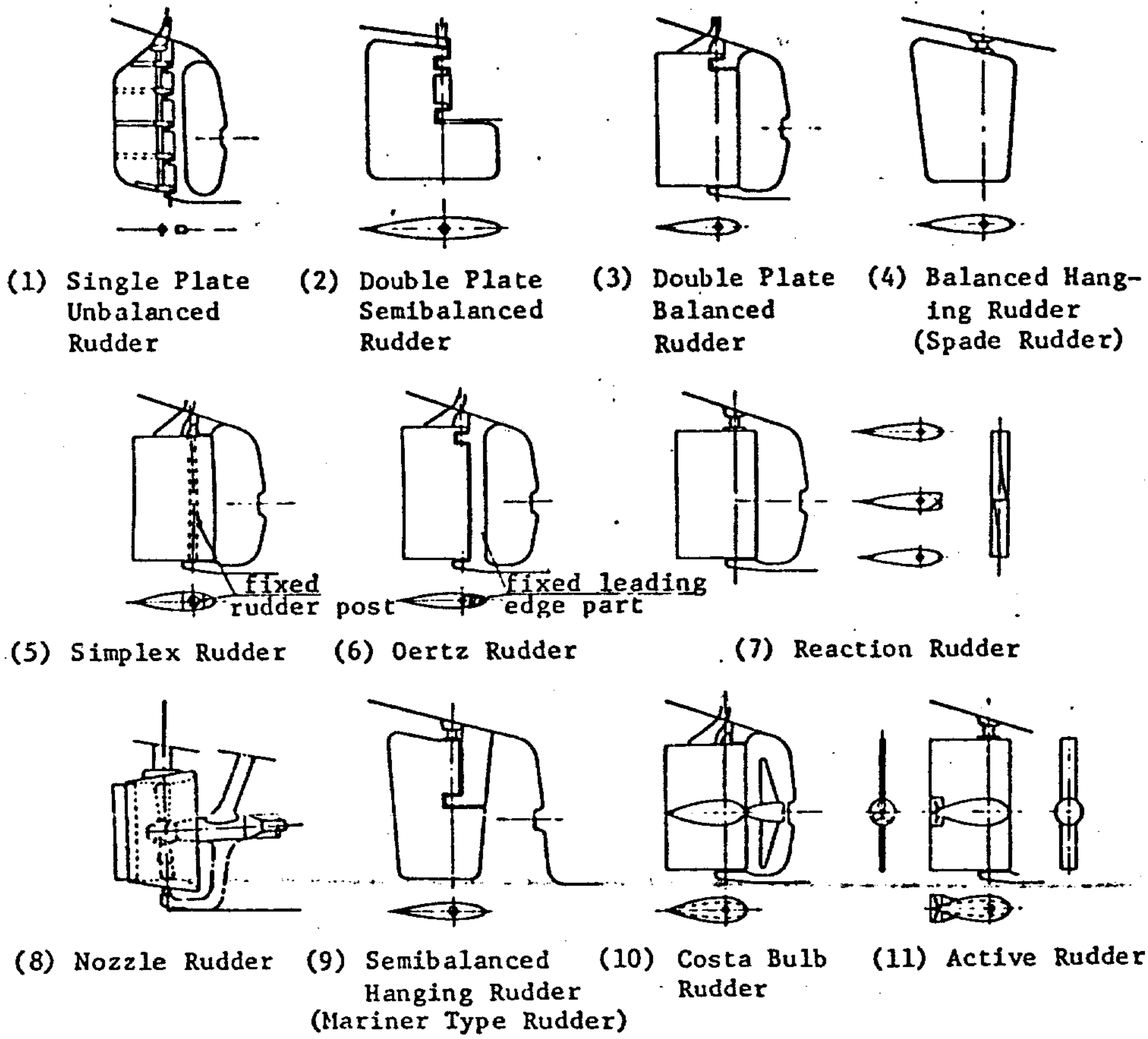


Fig. 128 Type of Rudder

The double plate balanced rudders are widely used. The reaction rudder which collects the revolving energy held in the propeller race and increases the propulsion efficiency can provide 1 - 2 percentage of saving in propulsion horse power with the twisted fore end part of rudder (Fig. 128 (7) and Fig. 134 (2)). The active rudder, having a small propeller driven by a small submersible electric motor, is employed on a ship like a fishing boat or a launch which especially requires the small turning radius and the excellent manoeuvrability at slight speed. Many rudders of this type employ the steering gears with maximum rudder angle of 45 to 90 degrees at both sides. The nozzle rudder, giving a larger tug thrust and a more effective manoeuvrability at slight speed, is appreciated for the harbour tugboat use.

8.3. Design of Rudder

8.3.1. Determination of Rudder Area (Refer to 8.3.3 (4))

(1) Method from actual values of existing ships

Rudder area is estimated from rudder area ratio Ld/A_R (A_R is the rudder area of the movable part) of the same kind of ships having similar length.

In such full ships as tankers, the actual values of Ld/A_r are apt to decrease as the parameter $C_b/(L/B)$, which denotes the fullness of the ship, increases. These values are shown on Fig. 129.

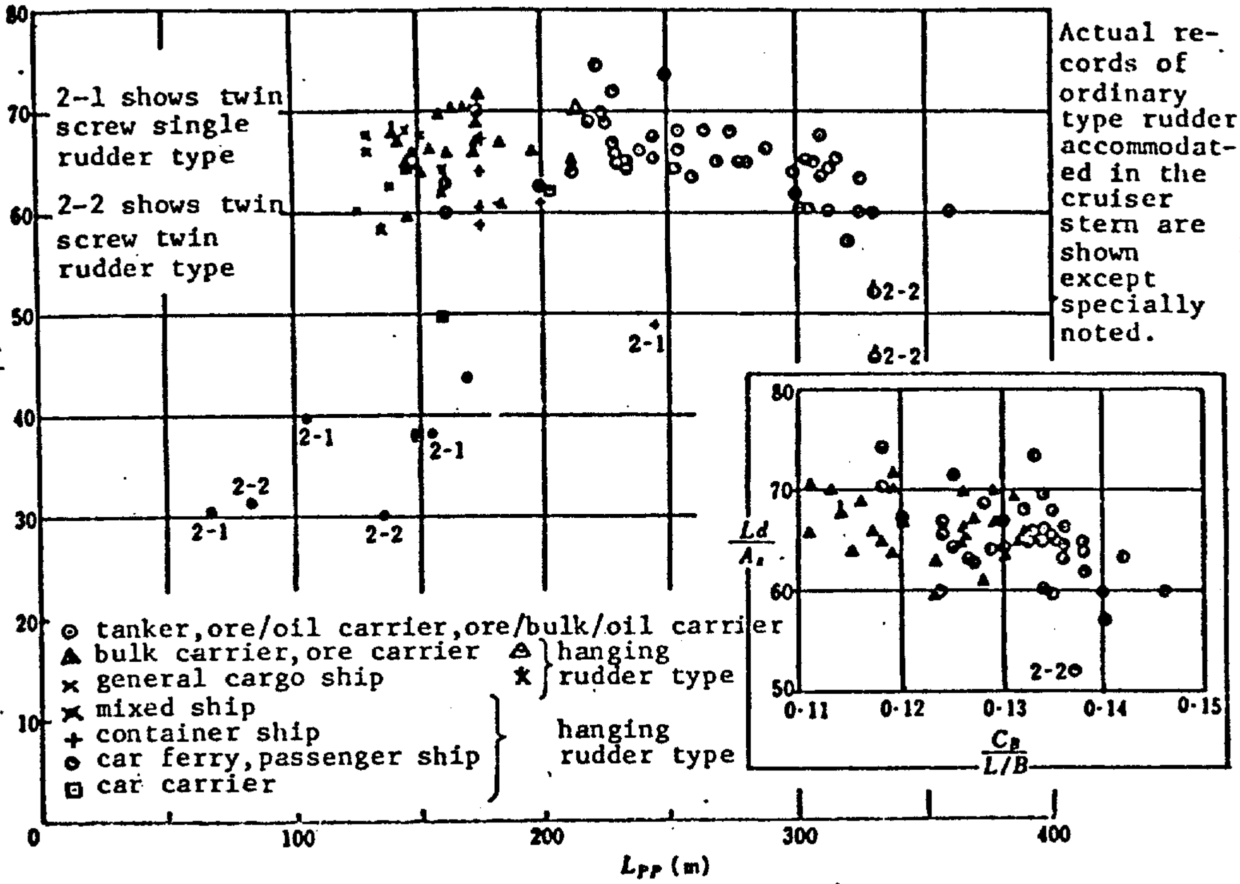


Fig. 129

(2) Murahashi's chart (Fig. 130)
This chart is available for general cargo ships, bulk carriers, tankers, etc. But, in case of full ships having $L/B < 6 \sim 6{\cdot}5$, and $C_b > 0{\cdot}8$, it is desirable to calculate rudder area ratio by the method mentioned in (3).

(3) Yamada's chart (Figs. 131 and 132)
This chart is mainly for large full ships with single screw, single rudder and cruiser stern such as tankers. The greater value required from the course stability (Fig. 131) or the turning ability (Fig. 132) is adopted as the rudder area ratio of the intended ship. But, actually, it is necessary to take into account that stern form, rudder form and arrangement of rudder and propeller give much influence on course stability and turning ability of the ship in addition to the ratio of hull dimensions and block coefficient.

(4) Chart for ships with large profile area affected by wind (Fig. 133)
This chart is decided so that the ship can be operated under the condition that (wind speed)/(ship speed) is 4.5 and below and actual results are also taken into consideration in this chart. This chart is available for ships with large profile area affected by wind such as car ferries and car carriers. The chart shown in Fig. 133 is for ships with single screw and single rudder. And corrections for rudder area are necessary to the extent of 1.5 times for ships with twin screws and single rudder and 0.9

times for those with twin screws and twin rudders, considering the flow speed to the rudder.

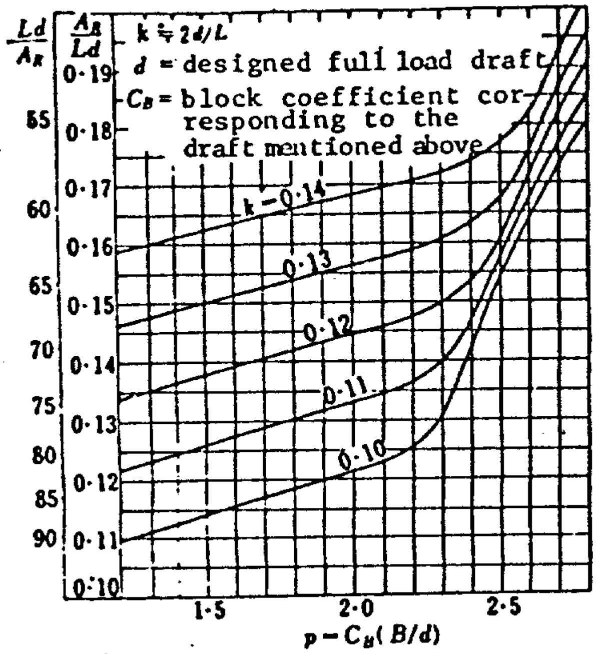


Fig. 130 Determination Chart of the Rudder Area

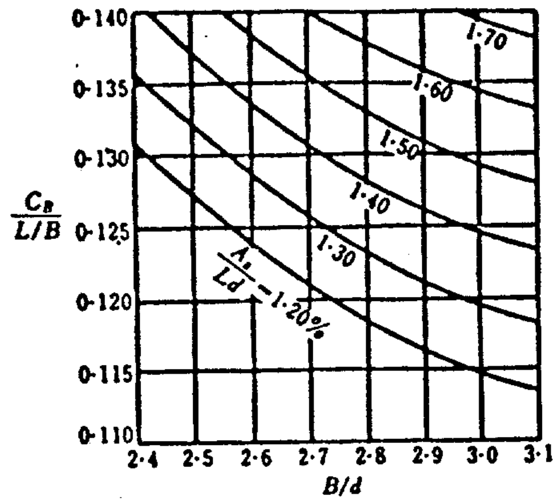


Fig. 131 Standard Rudder Area Ratio required from Course Stability

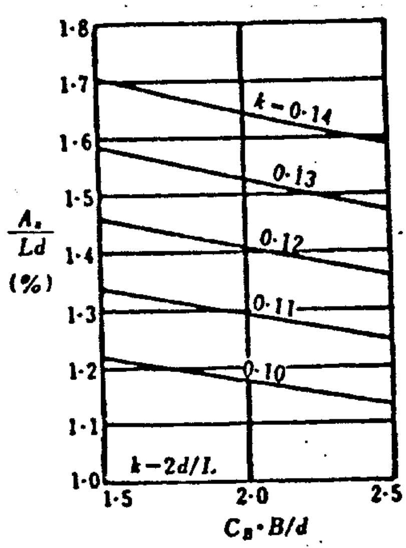


Fig. 132 Standard Rudder Area Ratio required from Turning Ability

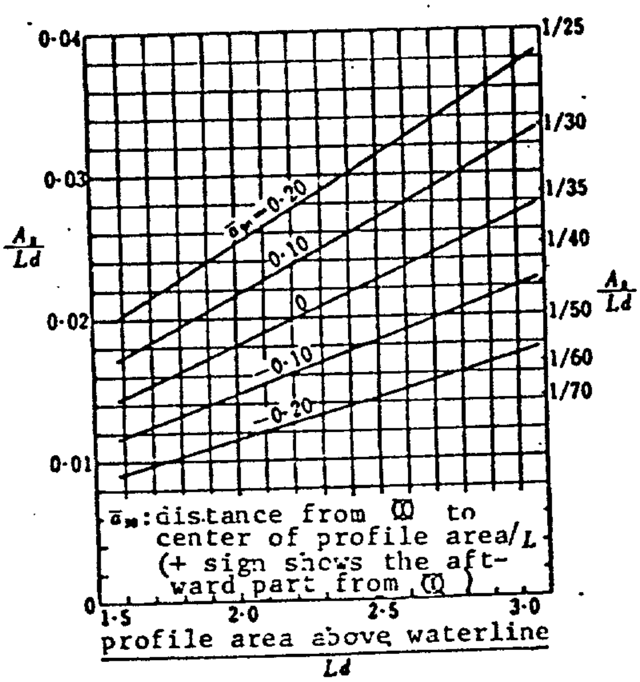


Fig. 133 Determination Chart of Rudder Area for Ships with Large Profile Area

8.3.2. Arrangement of Rudder

The effect of arrangement of rudder and propeller shall be taken into consideration in the final stage of determining the rudder area. The smaller the clearance between the rudder and the propeller is, the better effect of the rudder will be obtained, but the more unfavorable effect will be given to the hull vibration (refer to 10.4 (5), table 93). The influence of the combination of propeller and rudder on the effect on rudder is presented by Baker and Bottomley as shown on Table 91.

Table 91

Combination of propeller and rudder		Effect* on rudder	V_r/V	Increase ratio of effect on rudder by Dead wood
No. of propellers	No. of rudders			
1	1	0.9 - 1.0	0.95 - 1.0	1
2	1 (Adjacent to dead wood)	0.7 - 0.8	0.65 - 0.7	1.6 - 18
2	1 (Distant from dead wood)	0.4 - 0.5	0.65 - 0.70	1
2	1 (Hanging rudder, fine ship and cut up stern)	0.9	0.95	1
2	2	1.0 - 1.1	1.0 - 1.05	1

$$* \text{ Effect on rudder} = \frac{\text{Normal force of rudder fitted at stern}}{\text{Normal force of rudder itself}} = \left(\frac{V_r}{V}\right)^2 \times \text{(Increase ratio by dead wood)}$$

8.3.3. Dimensions of the Rudder

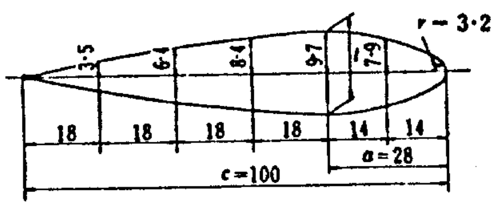
(1) Aspect ratio
From the point of torque saving of steering gear, aspect ratio should be as large as possible within the range that stall and air drawing of the rudder do not occur. But, actually, the height of the rudder is limited by the ship draft and also the rudder area ratio is determined by the kind of ship and ship length, so aspect ratio is in almost all cases decided by such factors. The aspect ratio of the rudder for large full ships such as tankers are usually between 1.3 and 1.7 and the bigger the ship becomes, the smaller the aspect ratio is apt to be. The aspect ratio of the rudder for car ferries and passanger ships having twin screws and single rudder is rather small and the values for some of such ships are between 0.7 and 1.1.

(2) Balance ratio
Balance ratio is the value of the forward part area of balanced or semi-balanced rudder divided by the total area of the said rudder. The balance angle (the angle at which torque becomes zero) calculated by Beaufoy, Jössel's formula is recommended to lie between 16 degrees and 17 degrees for large ships and 13 degrees and 15 degrees for small ships. Attention shall be especially given to the medium speed diesel engine ships with manually operated steering gears because the rudder with balance angle over 13 degrees makes it heavy and difficult to return rudder angle to normal position. In this case the calculation results of the torque at

35 degrees by Beaufoy, Jössel's formula is apparently big but in actual condition such torque never appears as small ships response quickly to the motion of the rudder, so balance ratio of the rudder for small ships is usually adopted within the range between 0.24 and 0.29. Though the calculated rudder torque at going astern by the formulas mentioned in 8.1.1 sometimes becomes considerably big, actually such a big torque never comes about, therefore, when balance ratio is decided it is not necessary to consider the rudder torque at going astern.

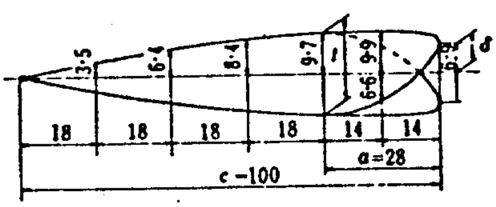
(3) Camber ratio t/c

Camber ratio cannot be very small from the structural point of view, but the smaller the ratio is, the smaller the resistance becomes. Usually, the value between 0.16 and 0.22 is taken as the ratio and smaller values for large ships and larger values for mariner type rudder within the range mentioned above. The position of the maximum thickness of the rudder usually coincides with that of the center of rudder pintle from the structural point of view (refer to Fig. 134).



(1) One example of stream-lined section used for the rudder. Sizes of each part are shown based on the breadth taken as 100.

$a/c = 0{\cdot}280$, $t/c = 0{\cdot}194$



(2) One example of the twist form of reaction rudder. Sizes of each part are shown based on the breadth taken as 100.

$a/c = 0{\cdot}280$, $t/c = 0{\cdot}194$

$\delta/c = 0{\cdot}069$

Note) $\delta/h = 0{\cdot}035 \sim 0{\cdot}050$

Fig. 134

(4) Regulations concerning dimensions, etc. of the rudder

Some classification societies give recommendations or requirements of their own on rudder area, rudder form etc.

(a) NV (Guidance) $A_r = dL\{1 + 25(B/L)^2\}/100$ (m^2)

i) L, B, d : Ship length, breadth and draft defined by the regulations (m)

ii) The value shall be increased for the ships operated frequently in harbors, canals and other narrow waterways.

iii) The area of the stream lined rudder horn and rudder post under the horizontal level of the upper surface of the trailing edge of the rudder may be included in the rudder area.

iv) The area of the rudder which is not just after the propeller shall be increased at least 30% of the area calculated by the above formula.

v) In addition to the above, some recommendations are made on balance ratio, the position of the maximum thickness of the rudder, etc.

(b) NK

Steering speed is regulated by the rudder area and the rudder form as follows:

For the ships having L/V of not less than 9 except passenger ships, the time required to put the rudder 35 degrees over to 30 degrees over may be extended within the limit calculated by the following formula in general.

$$7 \cdot 22 \frac{L}{V} \left| 1 - \frac{Ld}{A_e} \cdot \frac{BC_b}{L} / (13 \cdot 3 - r) \right| \quad \text{(sec)}$$

where, L, B, d and C_b are ship length (m), breadth (m), draft (m) and block coefficient respectively defined by the regulations.

V = Ship speed (knot)

$$A_e = \frac{A_R(0 \cdot 6 + 0 \cdot 4 D_p/h)}{0 \cdot 45 + 0 \cdot 675/\lambda} (m^2).$$

D_p = Propeller diameter (m)

h = Mean height of the rudder (m)

λ = Ratio of mean height to mean breadth of the rudder

r = The greater value of

$$3 \cdot 0 \left(\frac{B}{d} + 5 \right) \frac{Ld}{A_e} \times 10^{-3} \quad \text{or} \quad 4 \cdot 2 \left(\frac{L}{BC_b} \right)^2 \left(3 \frac{B}{d} - 1 \right) \frac{Ld}{A_e} \times 10^{-3}$$

9. TURNING AND MANOEUVRABILITY

9.1. Turning of Ship

9.1.1. Estimation of Turning Circle

Manoeuvrability of the ship at the large rudder angle can be represented by the turning circle. Estimation of turning circle can be made by using;

(1) Estimation chart based on the analysis of the results of the actual turning tests

(2) Series model test results

Further, if the test results of similar ships are available to refer, the turning circle of the ship in question can be estimated more accurately. Definition of the words on the turning course is shown on Fig. 135.

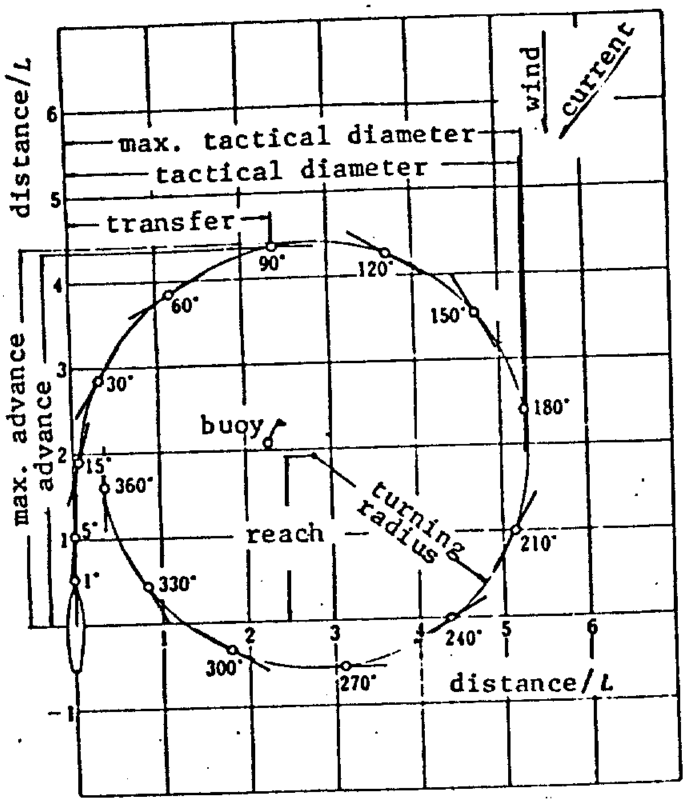


Fig. 135 Definition of Words on the Turning Course

(1) Estimation method by Hovgaard-Schoenherr-Takarada

This is the approximate estimation formula of turning circle derived from the actual test results. The steady turning radius R is given by;

$$R = K_1 \nabla / (A_R \cdot C_N \cos \delta)$$

and, putting D_{T1} instead of $2R$, the approximate estimation formula of tactical diameter is given as shown on Fig. 136,

where ∇ = Displacement volume (m^3)

A_R = Rudder area of movable part (m^2)

δ = Rudder angle (deg)

$C_N \cos\delta$ and K_1 = Values given by Fig. 136

Corrections due to trim and speed shall be made based on Fig. 137.
Actual tactical diameter is 10 - 20% larger than the steady turning diameter, and the fuller is the ship, the larger is the value apt to be.

(2) Estimation method from the results of series model tests

The approximate steady turning diameter can be estimated by obtaining the steady turning diameter of base ship ($L/B = 7{\cdot}3$, $B/d = 2{\cdot}5$) from Fig. 138 and making correction due to the effect of L/B given by Fig. 139.

turning diameter

$$D_r/L = K \left(\frac{Ld}{A_r}\right)\left(\frac{1}{C_B}\right)\left(1 + \frac{25 t}{L}\right)\left\{1 + 5.3\,(C_b - 0.40)\,(\ldots - 2.5)\right\}$$

δ = 35°

K = 0.21 ... single screw stern

0.025 - twin screw twin rudder

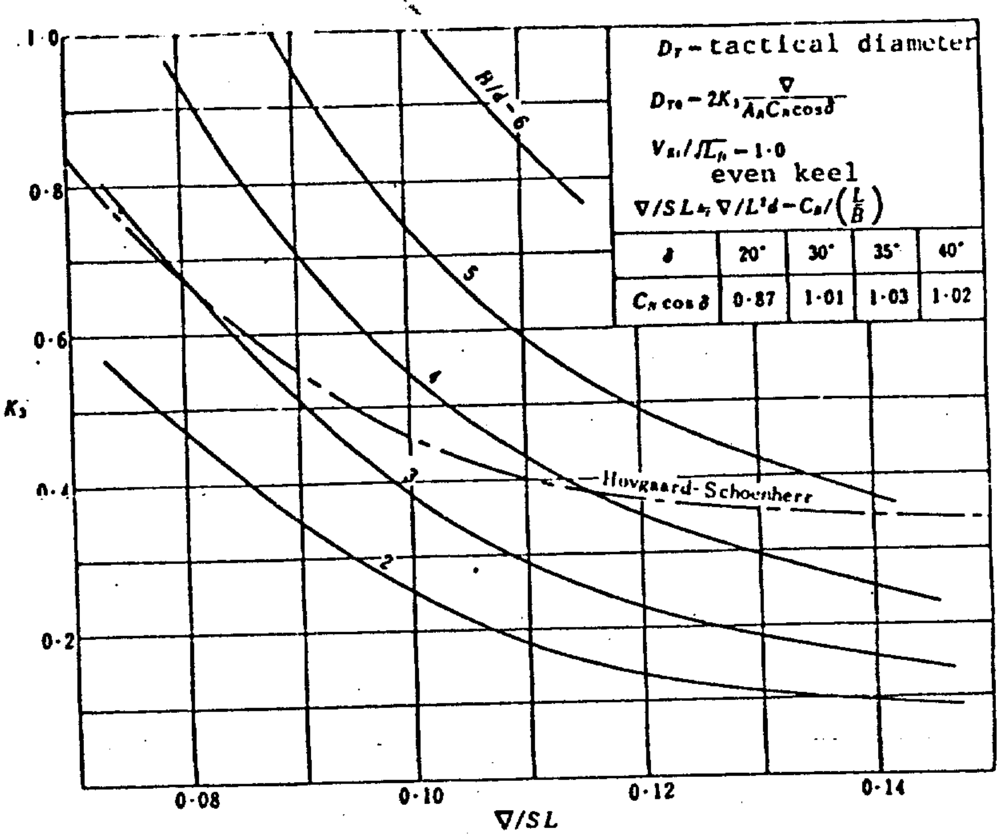


Fig. 136 Estimation Chart of Turning Circle

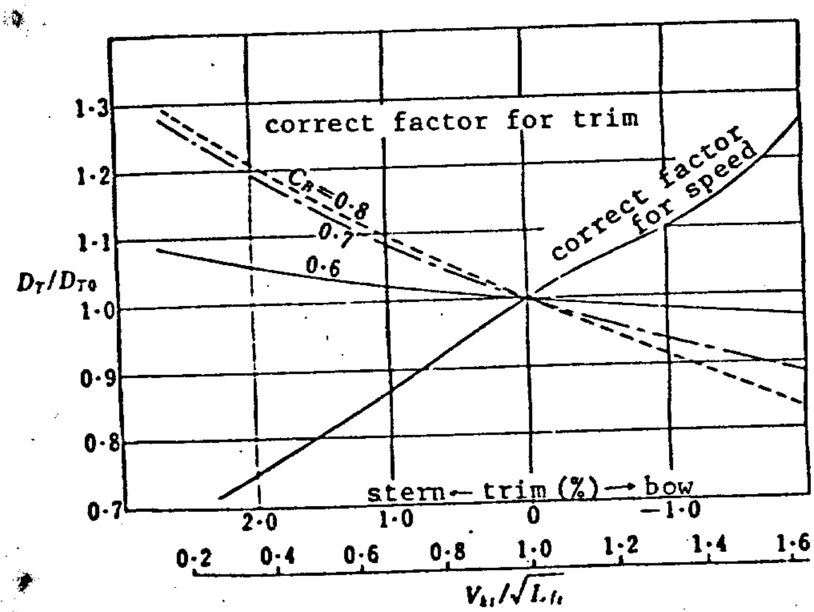


Fig. 137 Effect of Trim and Speed
on Turning Circle

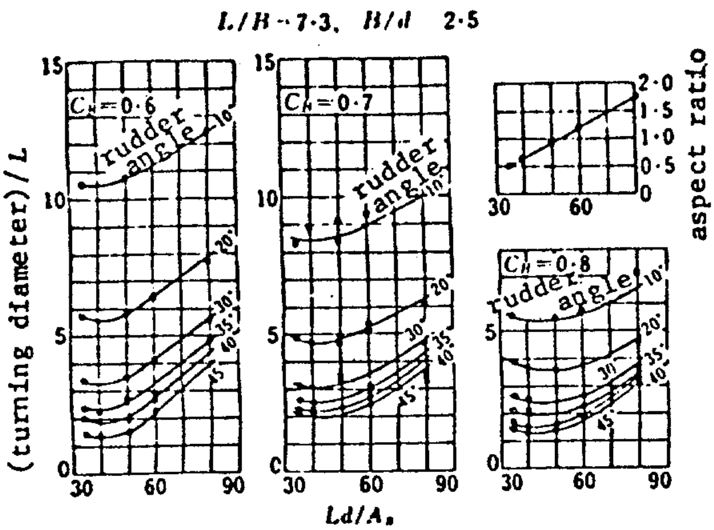


Fig. 138 Turning Diameter and Rudder Area Ratio

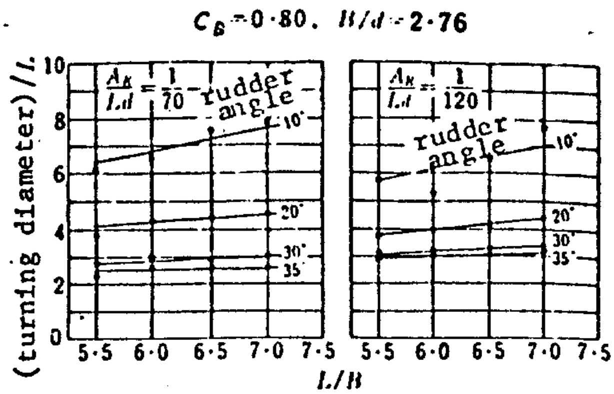


Fig. 139 Effect of L/B on Turning Diameter

9.1.2. Advance and Tactical Diameter of Actual Ships

It is common to record the advance and the tactical diameter (refer to Fig. 135) instead of steady turning radius in the report of sea trial results. The maximum advance and the maximum tactical diameter of actual ships are shown on Fig. 140 and Fig. 141 respectively.

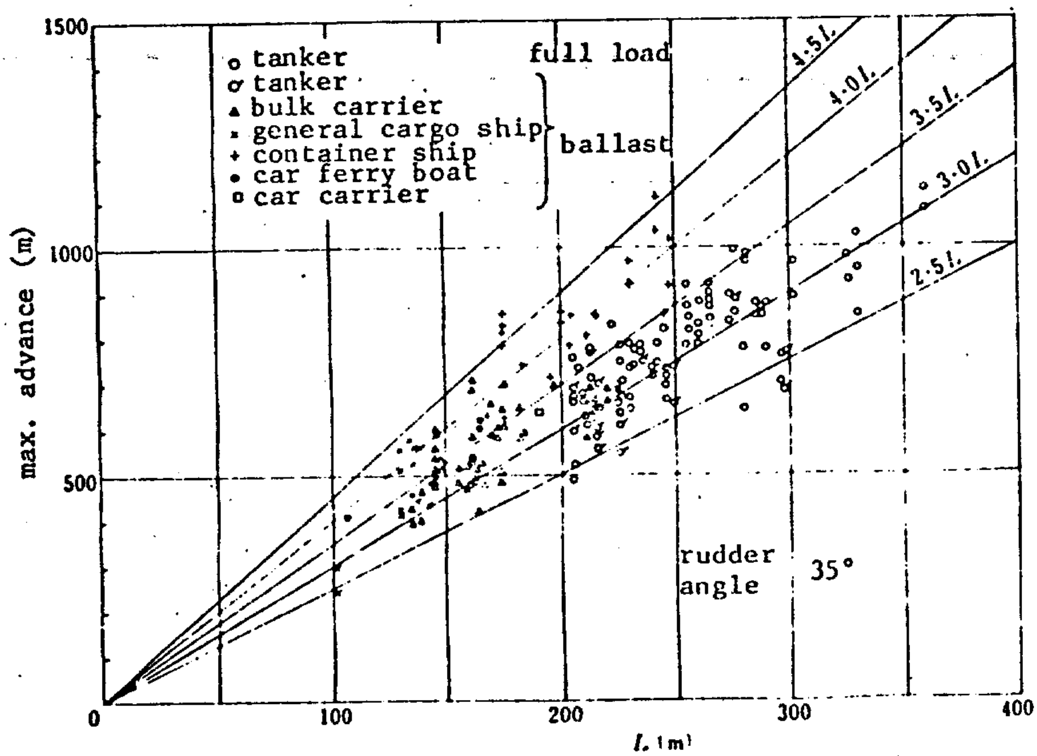


Fig. 140 Maximum Advance of Actual Ships

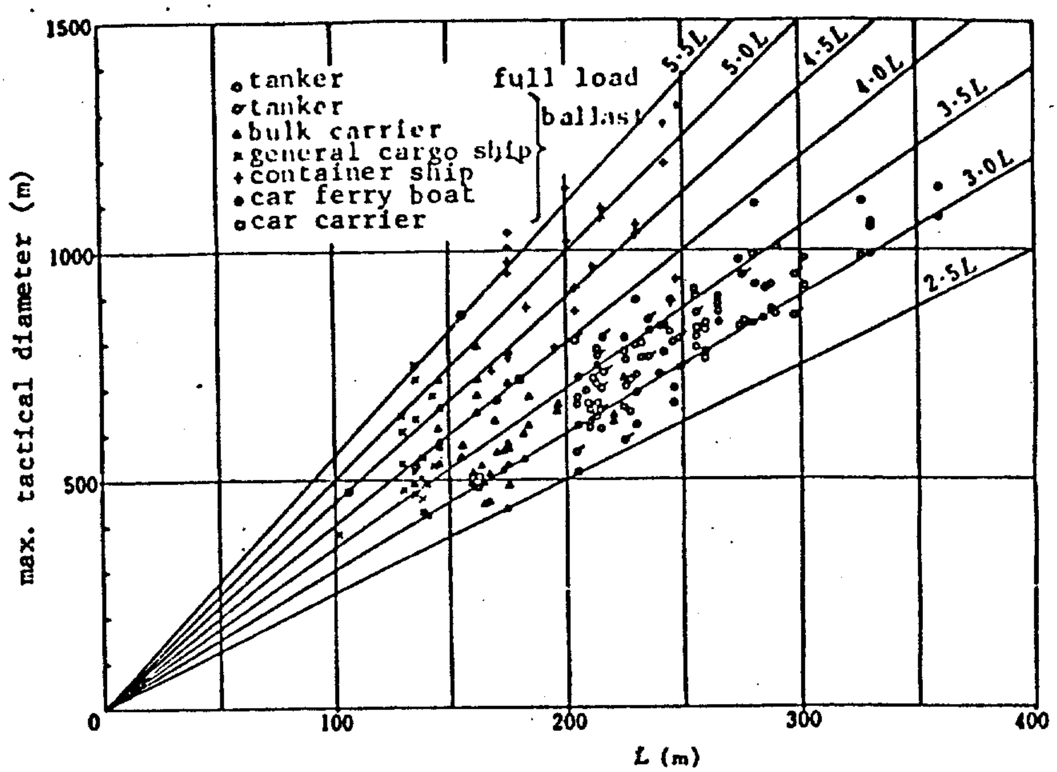


Fig. 141 Maximum Tactical Diameter of Actual Ships

9.1.3. Speed Reduction due to Turning

Davidson proposed the curve shown on Fig. 142 for this purpose but, actually it seems that V_T/V is below this curve in almost all cases. The speed of the ship becomes steady after the turns about 90 degrees at ballast condition and 180 - 270 degrees at full load condition.

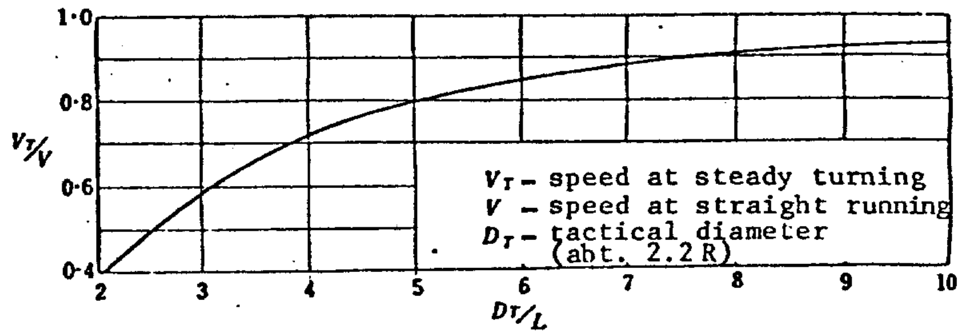


Fig. 142 Speed Reduction due to Turning

9.1.4. Heel Moment due to Turning

Initial inward heel moment = $P_n(OG+h')$ (t - m)

Steady outward heel moment = $\frac{\Delta}{g}\frac{V_T^2}{R}(OG+h)$ (t - m)

where, P_n = Normal force on rudder (t)
V_T = Ship speed at steady turning (m/sec)
R = Steady turning radius (m)
h' = Distance from waterline to the center of pressure of rudder (m)
h = Distance from waterline to the center of transverse resistance (m)
OG = Height of center of gravity above waterline (m)
Δ = Displacement (t)

The value of h/d is about 0.5 for general merchant ship.

9.2. Manoeuvrability

9.2.1. Three Essential Factors for Manoeuvrability

Manoeuvrability of the ship is composed of following three essential factors.

(1) Turning ability
This means the degree of steady turning and the greater is K -factor, which is the ratio of the angular velocity at steady turning and the rudder angle, the better is the turning ability.

(2) Response to steerage
This represents the ability of the ship as to how quickly she approaches the steady turning motion. The smaller is T , which is the time lag between the steering motion and the turning motion of the ship, the quicker is the response of the ship.

(3) Course stability
This is the ability of the ship as to how quickly she goes into the straight running without operation of the rudder after turning motion caused by the disturbance has occurred. The smaller is T , the better is the course stability. Accordingly, the response and the course stability are closely related each other and the ship which has excellent response and course stability is easily operated during navigation.

9.2.2. Equation of Ship Motion in Steerage and Manoeuvrability Factors

The ship motion in steerage is approximately represented by the following equation. By solving this equation, the ship motion at any rudder angle can be roughly estimated.

$$T\frac{d\dot{\psi}}{dt} + \dot{\psi} - K\delta(t)$$

where, $\dot{\psi}$ = Turning angular velocity
$\delta(t)$ = Rudder angle (function of time t)
K = Turning ability factor (1/sec)
T = A factor of response and course stability (sec) (Refer to 9.2.1.)

This linear equation gives a better approximation to comparatively fine vessels such as cargo ships, but the degree of approximation becomes low for such full ships as tankers compared with that for cargo ships due to the effect of non-linearity, so the degree is usually made high by taking the non-linear term into account as follows,

$$T\frac{d\dot{\psi}}{dt} + \dot{\psi} + \alpha\dot{\psi}^3 - K\delta(t)$$

where α is a constant representing the degree of non-linearity and is obtained from the turning test, etc. But the following data on the factors of equation of motion are for linear equation of motion.
K - and T -factor vary according to hull form, rudder area and rudder angle. These factors can be obtained from the result of zig-zag test or turning test (refer to 9.3). Usually, K - and T -factor are used as non-dimensional form of $K'-K/(V/L)$ and $T'-T\times(V/L)$, where V is the approach speed or mean speed during the test.
Turning resistance by using K' obtained from 10 degree zig-zag test is shown on Fig. 143 (for tankers) and Fig. 144 (for cargo ships). Generally, the larger are $C_b/(L/B)$ and B/d and the smaller is the rudder area ratio A_R/Ld , the smaller becomes turning resistance. The plotted points of actual turning resistance scatter in a wide range because it is affected

by not only hull dimension ratio and rudder area ratio but also stern frame line and arrangement around the rudder and propeller and because some experimental errors are contained. The mean lines in Fig. 143 are proposed by Yamada based on the analysis results. Relations between T' and K' obtained from various kinds of zig-zag tests are shown on Fig. 145. Once hull dimension ratio and rudder area ratio are settled, the approximate values of K' and T' can be obtained from Fig. 143 - Fig. 145. On the other hand, these charts are also utilized to estimate the hull dimension ratio and rudder area ratio to secure the turning resistance equivalent to that of similar ships which have the results of 10 degree zig-zag test.

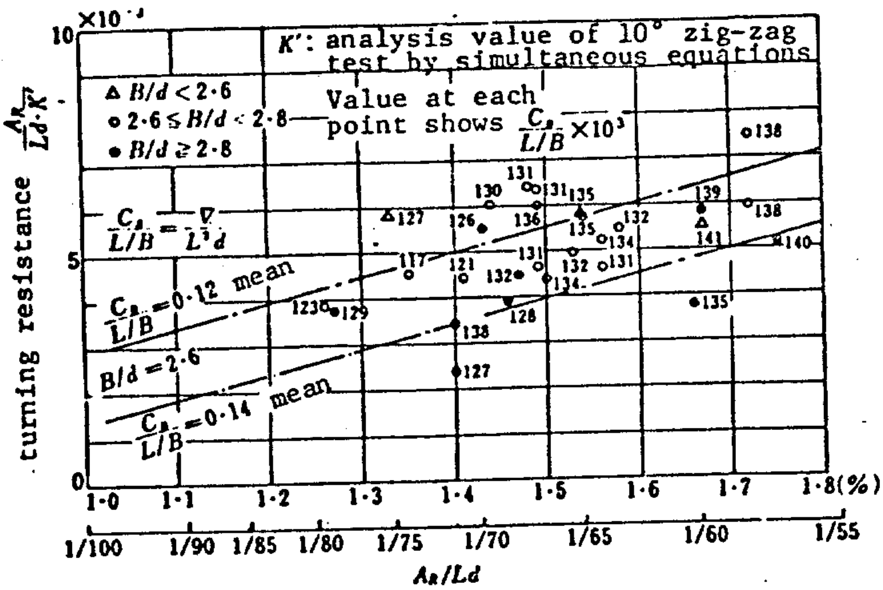


Fig. 143 Relation among Hull Form, Rudder Area Ratio and Turning Resistance (for Tankers).

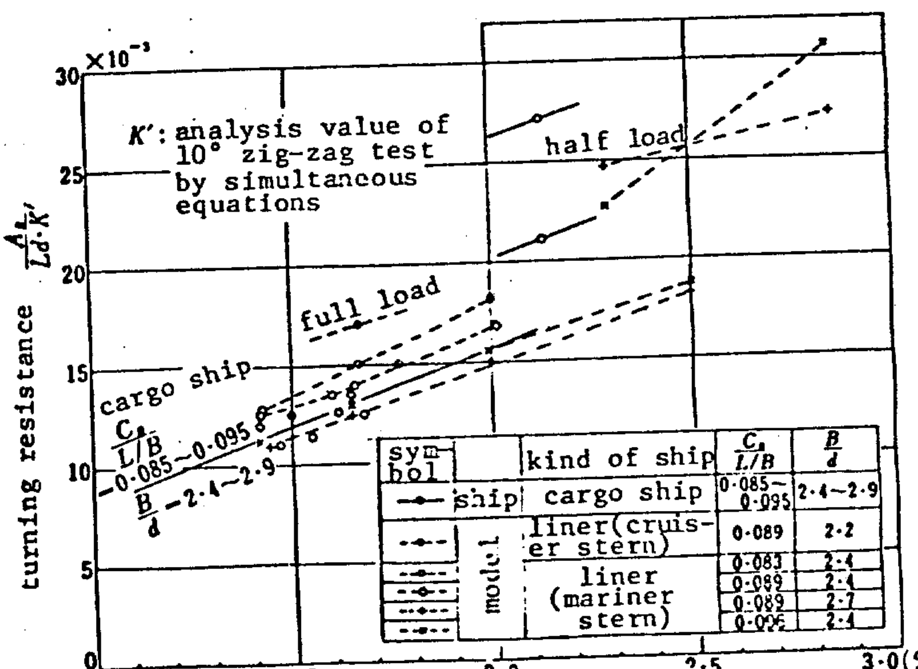


Fig. 144 Relation among Hull Form, Rudder Area Ratio and Turning Resistance (for Cargo Ships)

9.3. Test Methods of Ship Manoeuvrability

9.3.1. Turning Test

It is important to know the turning ability at the helm angle of 35 degrees because it shows the maximum turning ability of the ship in an emergency. More comprehensive data can be obtained if the tests are conducted for normally used rudder angles of 15 degrees, 10 degrees, etc., in addition to the above. The tests are generally carried out at the maximum continuous output or the normal output, and also they are sometimes executed at the lower speed with lower engine output. When the turning test at the rudder angle of over 35 degrees are requested, it is usually carried out at the maximum rudder angle.
As to the measurement at the test, following direct or indirect method is applied. One method is that the course and the turning angle of the ship, which is running around the aiming buoy thrown to the sea beforehand, are measured with the compass and the angle measurement boards aboard the ship and the other is that the course of the ship is calculated by value integration based on the measurement result of ship speed with the pressure log or with the small wood boards thrown to the sea. The test results are usually shown in the form of Fig. 135 (refer to 9.1.1).

9.3.2. Zig-zag Test

(1) Zig-zag test normally applied
This is very effective to know the manoeuvrability of the ship when she is in normal navigation. Turning angle is recorded on the time basis for the ship operation as shown on Fig. 147. The qualitative levels of the manoeuvrability of the ship can be obtained by reading the turning time lag T_L' and the overpassed angle ψ_s shown on Fig. 147. The larger T_L' does the ship have, the slower response in the steerage and worse course stability she has. The vessel having larger $\psi_s/(T_L'\delta_0)$ is better in her turning ability. K - and T-factors (refer to 9.2.2) which show the qualitative levels of the manoeuvrability can be obtained by the method reported to JTTC. Although typical rudder angle for this test is 10 degrees, it is recommended to carry out the additional tests at 5 degrees, 15 degrees, etc. Actual figures of T' and T_L' are shown on Fig. 148. T' can be approximately estimated from Fig. 145 by using T_L' obtained from Fig. 147 and K' can also be approximately estimated from Fig. 145 by using T' above.

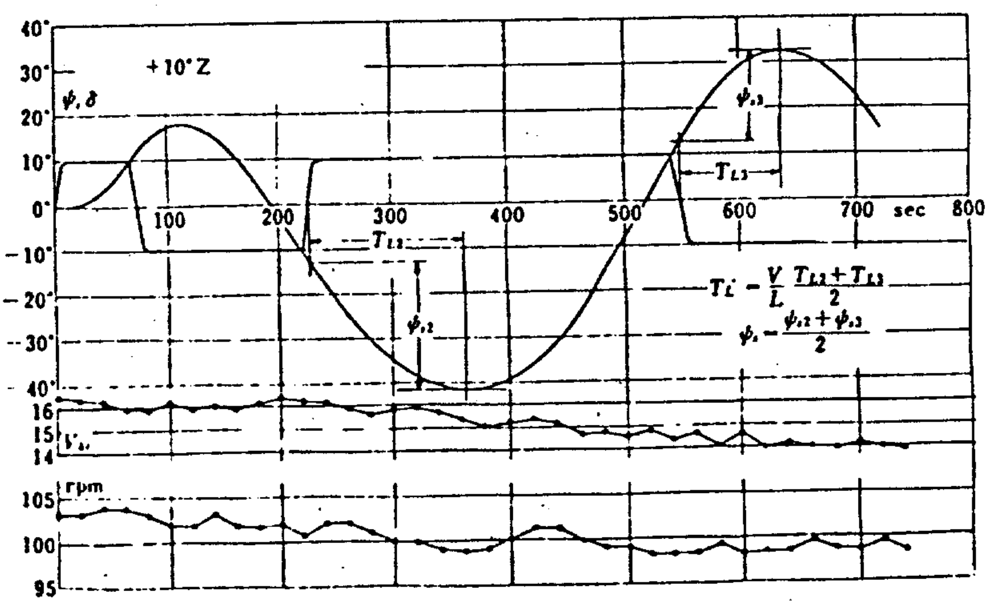


Fig. 147 Zig-zag Test

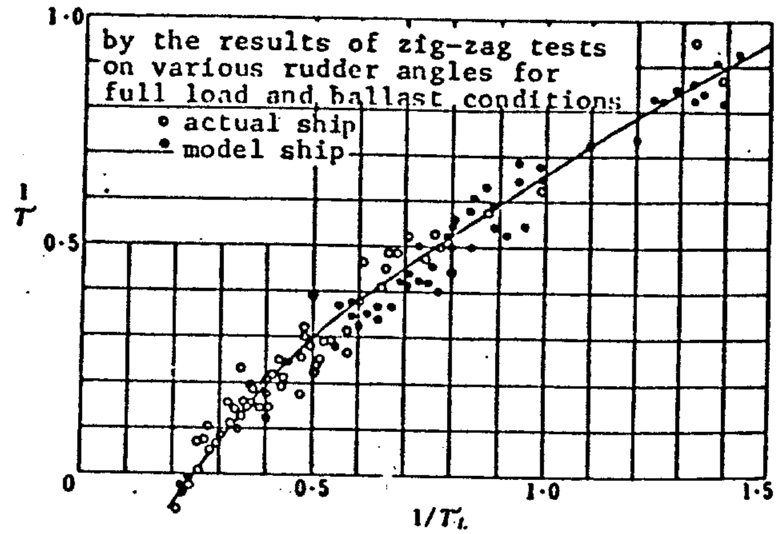


Fig. 148 $T' \sim T'_l$ Chart

According to JTTC Reports, it is said that the factors of ships with normal manoeuvrability obtained from 10 degree zig-zag test are;

$K' = 1{\cdot}5 \sim 2{\cdot}0$
$T' = 1{\cdot}5 \sim 2{\cdot}5$ For fully loaded cargo ships with average manoeuvrability ($L = 100 \sim 160$m)

$K' = 1{\cdot}7 \sim 3{\cdot}0$
$T' = 3 \sim 6$ For fully loaded tankers with average manoeuvrability ($L = 150 \sim 250$m)

But, K' and T' for very large tankers and industrial carriers in recent years with the length of 200 - 330 m are distributed up to 4 and 10 respectively at their full load conditions, which do not seem to give serious problems on their operations.

(2) Modified zig-zag test
The motion of the ship at the zig-zag test mentioned above is so much exaggerated compared with her course keeping motion in her normal operation that it is not always appropriate to apply K and T obtained by zig-zag test to the latter. This method is developed to improve the above defect, and the test is carried out by the same procedure as the normally applied zig-zag test except the combination of rudder angles and turning angles which are 10 degrees - 1 degree or 5 degrees - 1 degree. In addition to the above, such method as to turn the vessel in accordance with the turning angular velocity like 10 degrees - 0.3 degrees/sec instead of turning angle is applied (angular velocity basis zig-zag test).

9.3.3. New Course Test

The method proposed by RR - No.2 Standard Committee is one of the representative method. According to this method, the rudder is, at first, ordered to be placed at an angle of 15 degrees on one side and then, it is turned 15 degrees to the opposite side when the turning angle of the ship reaches 10 degrees. The test will be completed when the rudder is restored at midship after the turning motion is weakened and the ship become steady. Similar tests are also carried out for turning angles of 20 degrees and 30 degrees. The ship's course in the test is shown in the form of Fig. 149 after being obtained by the same method as described in the turning test. Furthermore, turn-over time and new course distance at the steady condition at the rudder angle of 15 degrees, which are very useful in actual operation of the ship, can be easily obtained by graphically showing new course angle - new course distance and new course angle - turning angle of the ship.

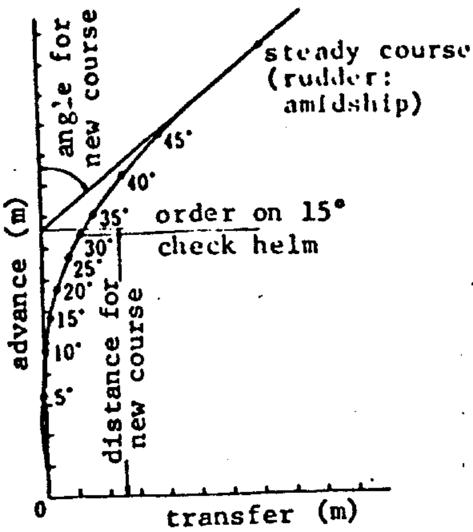


Fig. 149 New Course Test

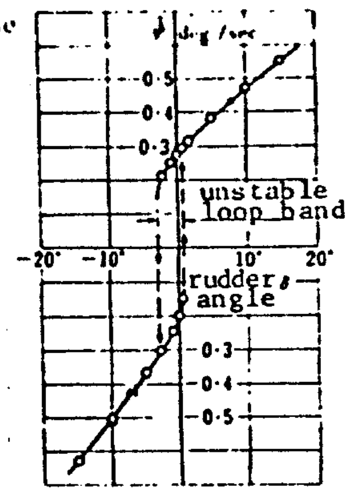


Fig. 150 Spiral Test

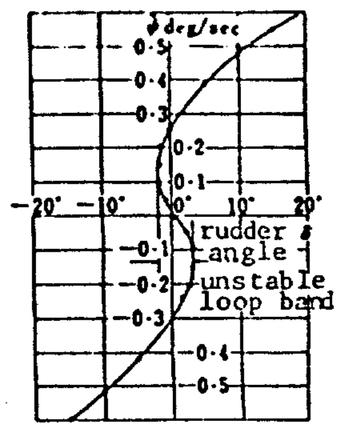


Fig. 151 Inverse Spiral Test

9.3.4. Spiral Test

This test is applied to the ships having inferior course stability to know the degree of their instability. The steady angular velocities $\dot{\psi}$ are measured for some rudder angles and $\dot{\psi} - \delta$ curve is obtained as shown on Fig. 150. It is very difficult to operate the ship having the unstable loop band over 20 degrees near the origin. This test takes so long time for large vessels that in recent years inverse spiral test in sometimes adopted instead of the spiral test.

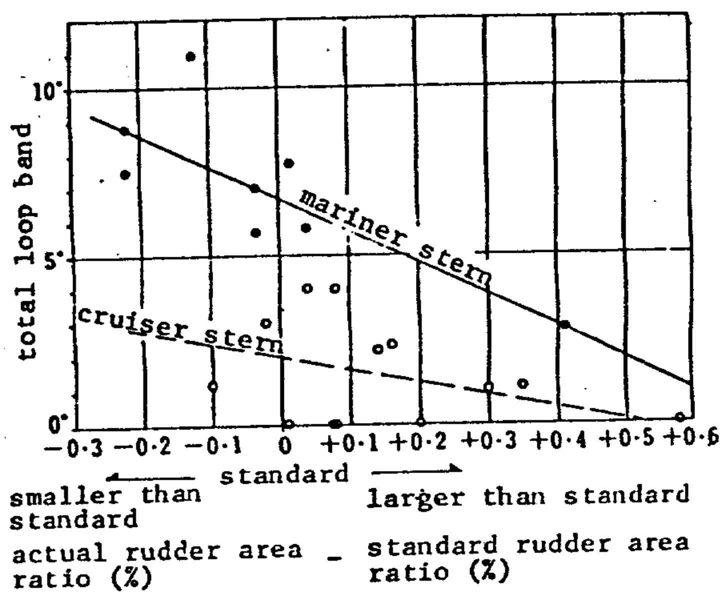


Fig. 152 Actual Results of Loop Band by Inverse Spiral Test

9.3.5. Inverse Spiral Test

Steering operation is continued to keep constant the turning angular velocity which is indicated with rate gyro angular velocity meter, and the mean rudder angle for appropriate period is graphically shown as that in the spiral test (Fig. 151).

As this test can be carried out even when the ship is within the unstable loop band, much more data can be obtained and the loop band can be estimated more accurately. The required time for this test is much reduced compared with that for spiral test.

Fig. 152 shows the actual values of the loop band obtained from the experimental result of the inverse spiral test for the large full ships (the standard rudder area ratio in the figure is obtained from Fig. 131).

9.4. Data on Ship Operation

9.4.1. Sinkage of Ship during Navigation

The smaller becomes the value of (water depth)/(draft) and the faster runs the ship, the bigger is the sinkage of the ship during navigation. Sinkage at the bow and change in trim for large tankers obtained both from model tests and actual experiences are shown on Fig. 153 and Fig. 154 respectively.

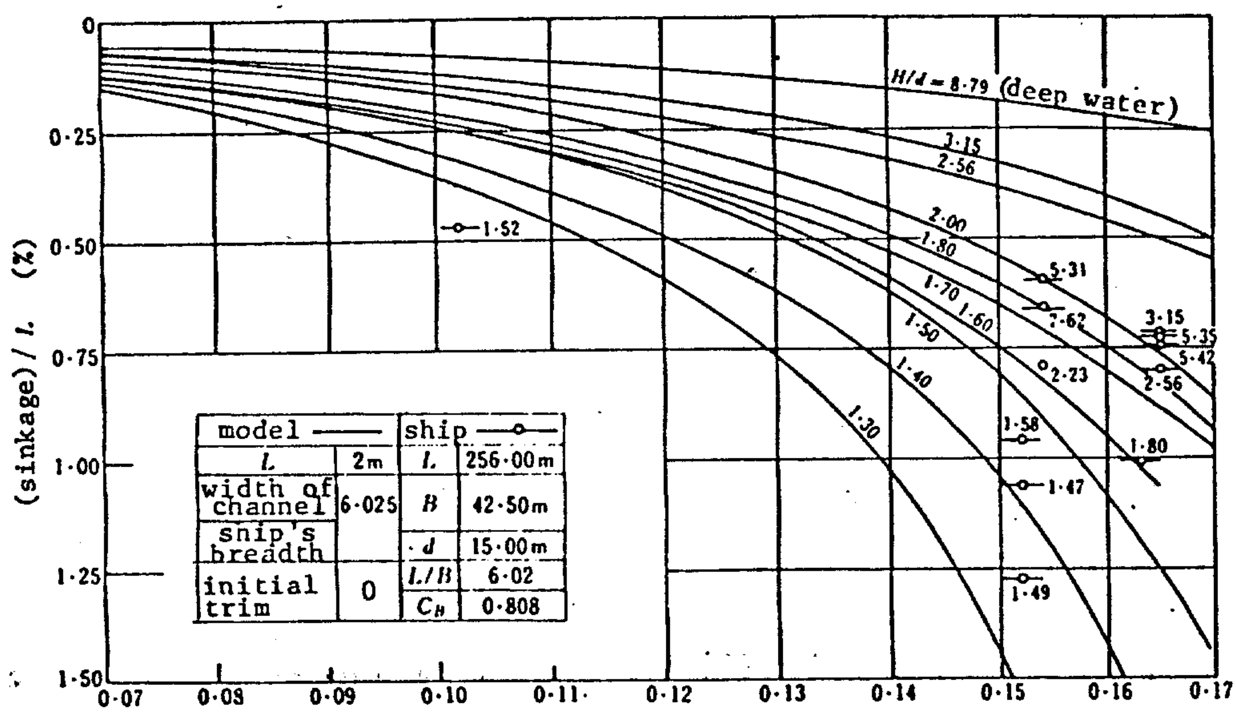


Fig. 153 Sinkage at Bow during Navigation
(Full Load Condition)

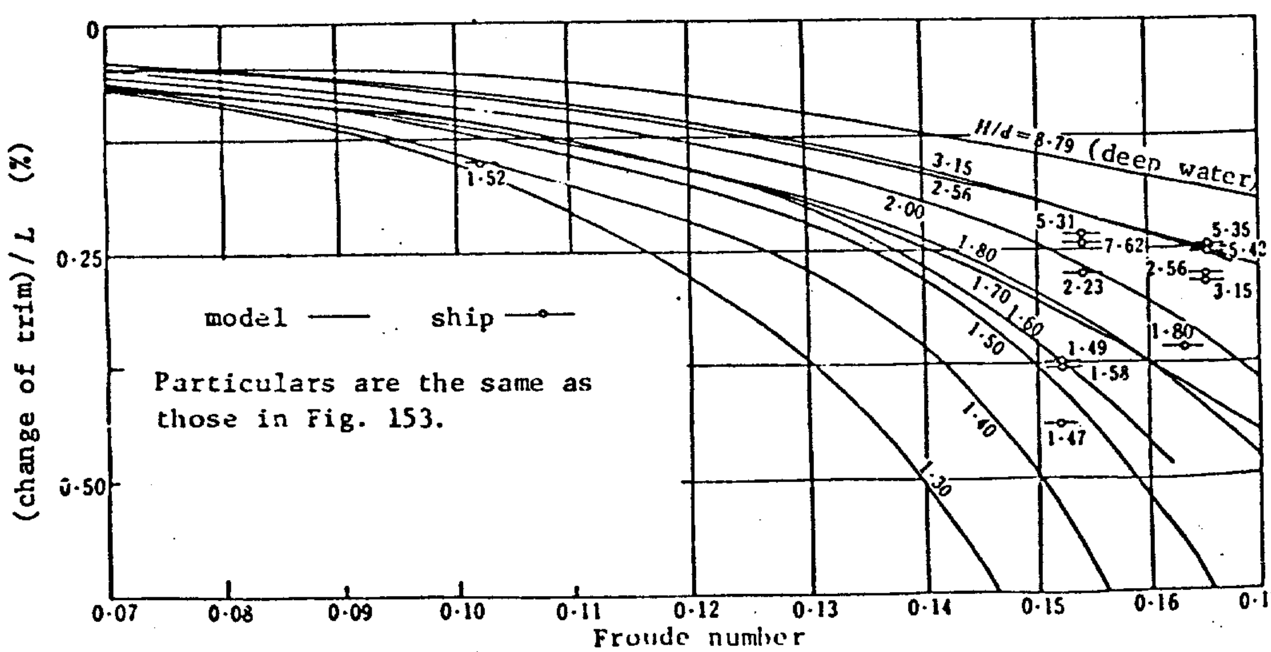


Fig. 154 Change in Trim during Navigation
(Full Load Condition)

9.4.2. Distance and Time to Ship's Stop

Distance and time to the ship's stop are governed by the initial speed, displacement and astern force due to the type of main engine, and attention shall also be given to the effect of time from the order of astern to engine stop and/or to the start of engine reversing. The actual results of distance and time in crash stop astern are shown on Fig. 155 and Fig. 156 respectively.

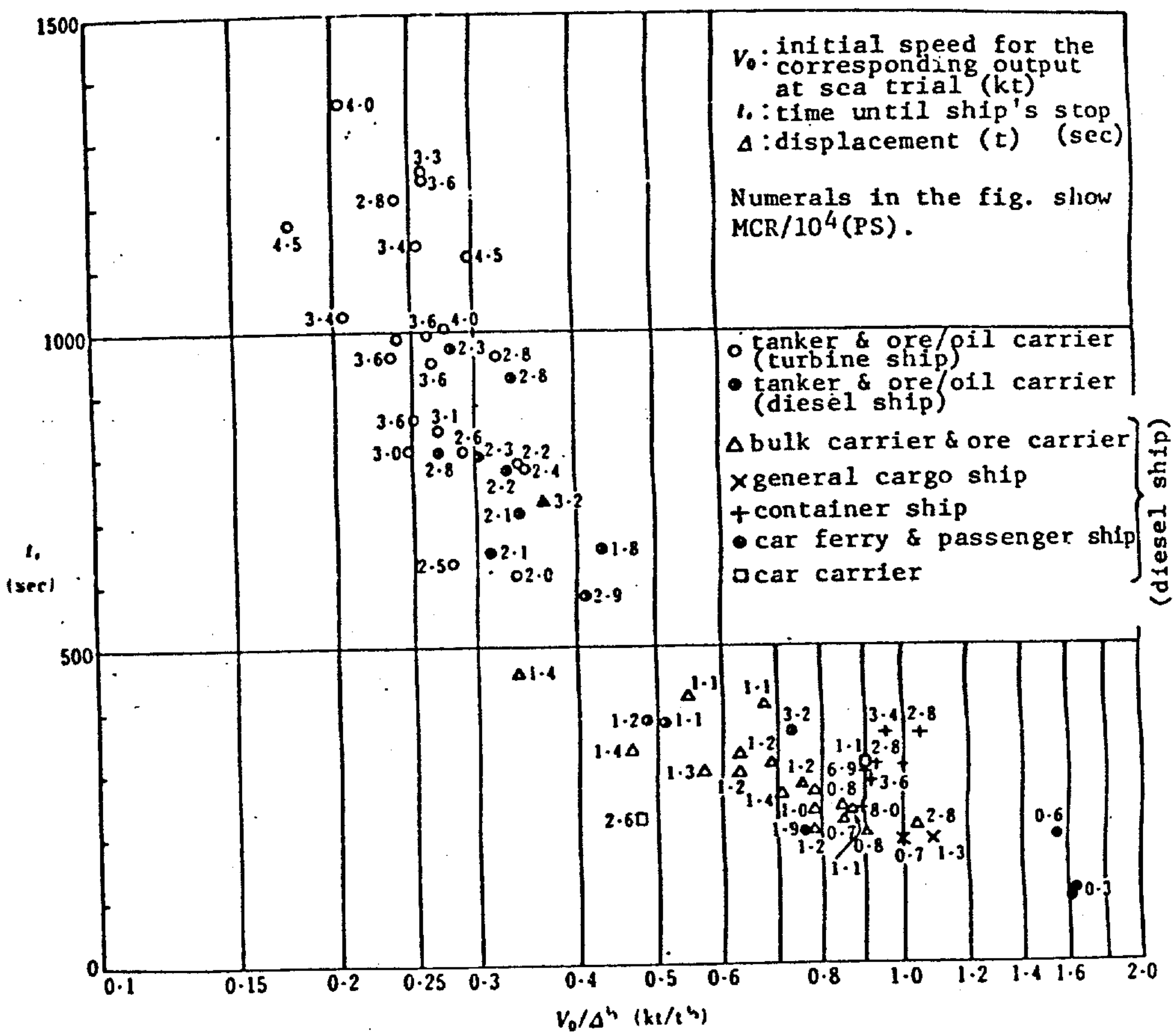


Fig. 155 Actual Results of Time in Crash Stop Astern

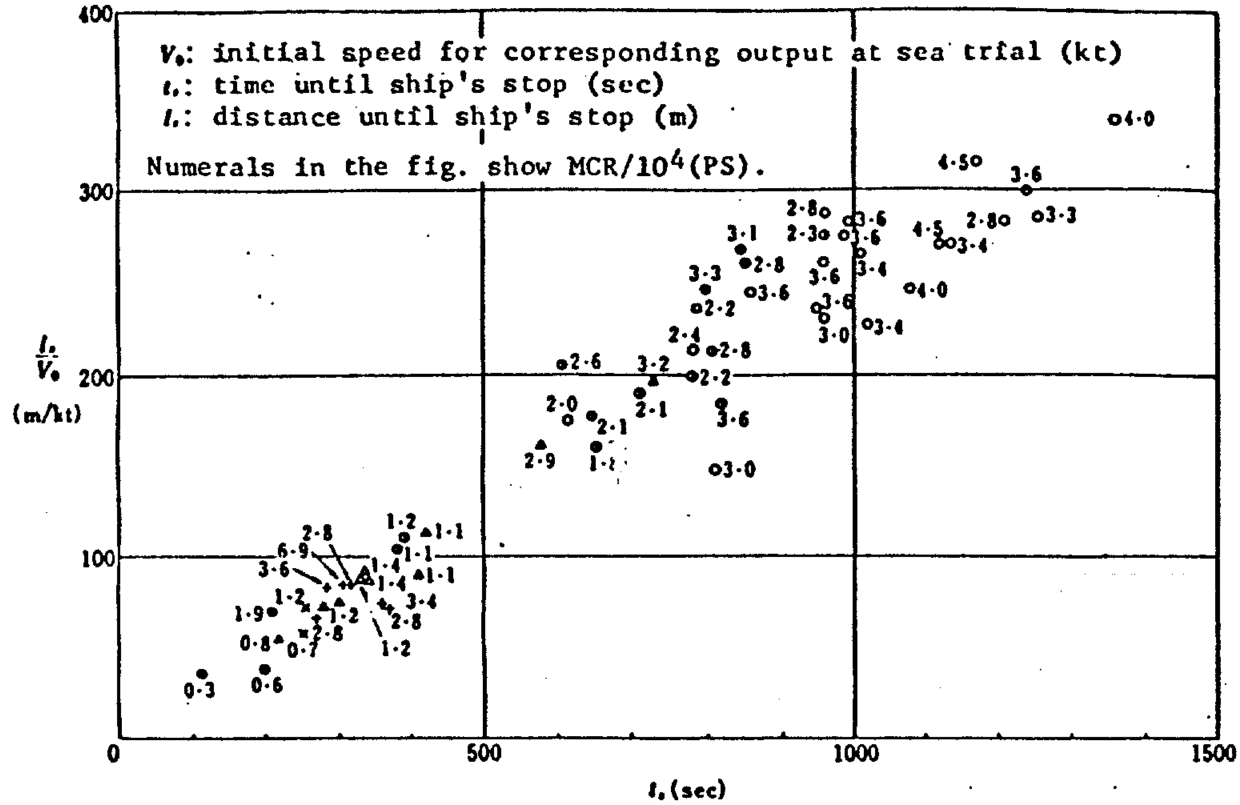


Fig. 156 Actual Results of Distance in Crash Stop Astern

9.5. Bow Thruster

Bow thrusters are mainly installed on passenger ships, ferries, and various kinds of working boats to improve their steering ability at low speed. Some examples of bow thrusters installed aboard the ship are shown on Fig. 157, and approximate values of propeller diameter, statical thrust and power can be obtained from Fig. 158.

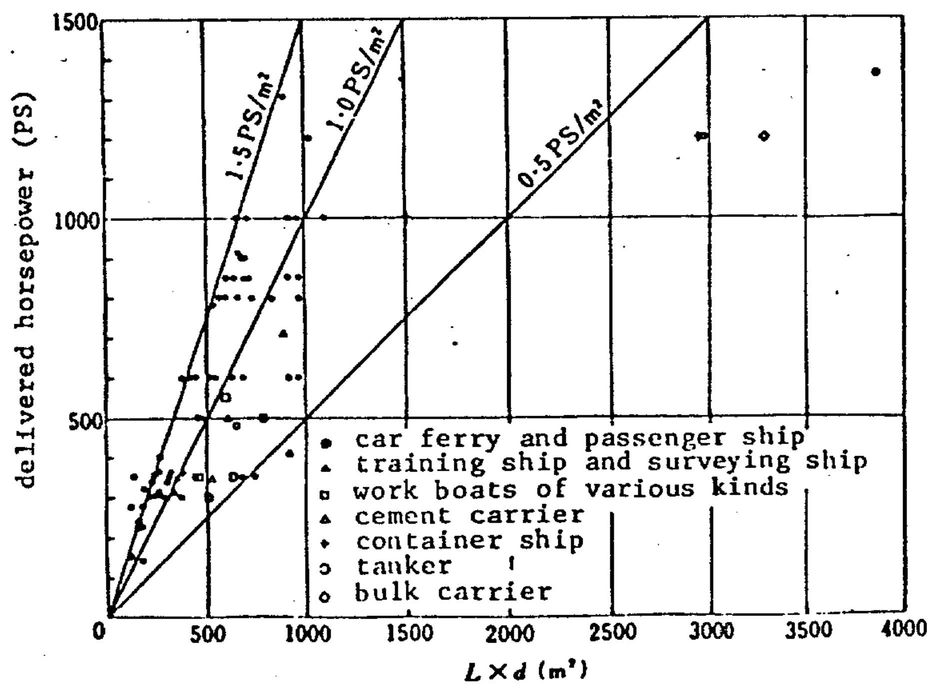


Fig. 157 Examples of Bow Thrusters Installed Aboard

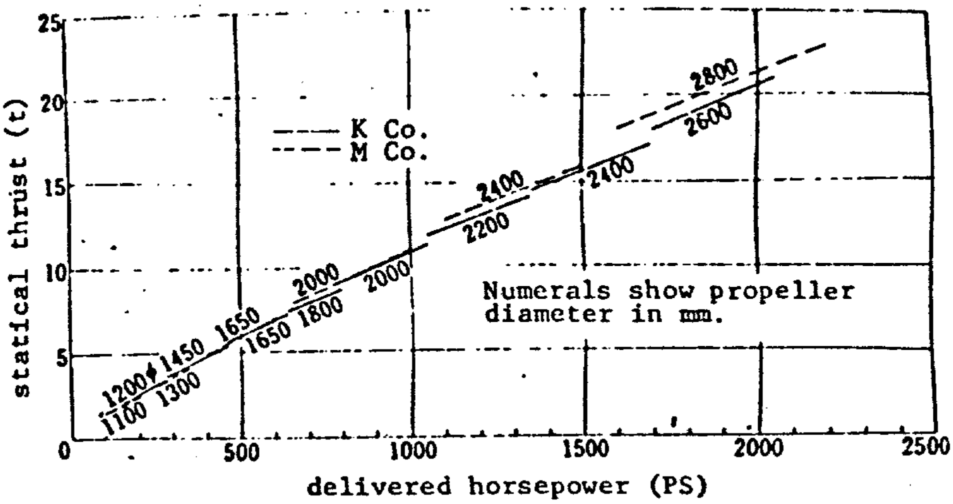


Fig. 158 Relation between Power and Thrust of Bow Thrusters

Hawkins' method is one of the representative ones to determine the power of the bow thruster. Fig. 159 shows the turning angular velocity $\dot{\psi}$ of the ship with a certain displacement based on the actual experiences. At first, suitable $\dot{\psi}$ corresponding to the displacement of the ship in question is decided so as to be placed within the belt zone. Next, the location of the bow thruster is decided to be placed as forward as possible. Finally, required thrust T is calculated from the formula shown on Fig. 160 by putting coefficient M in Fig. 160 and $\dot{\psi}$ above. Approximate required power can be obtained from Fig. 161 by assuming the duct area, that is, required power is given on the abscissa of the point where the straight line of T/A and belt zone meet.
Some reports on the model tests, model test results and determination methods of power are now available to refer in addition to the above.

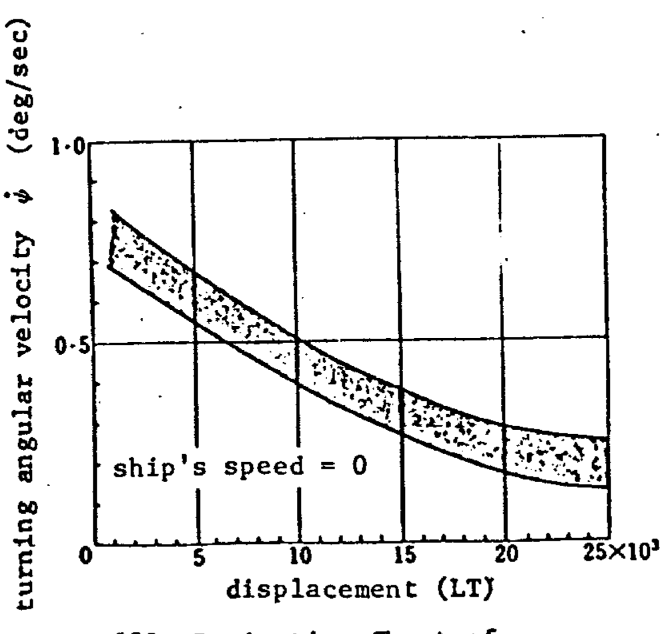


Fig. 159 Estimation Chart of Particulars of the Bow Thruster (1)

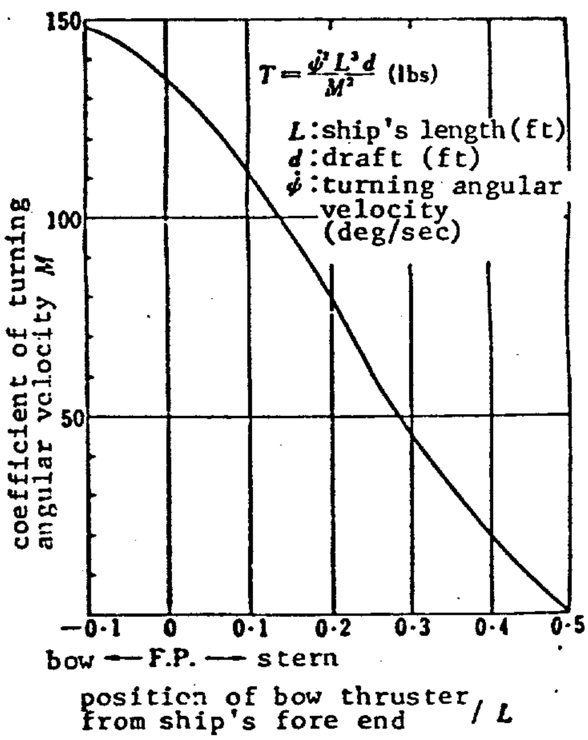


Fig. 160 Estimation Chart of Particulars of the Bow Thruster (2)

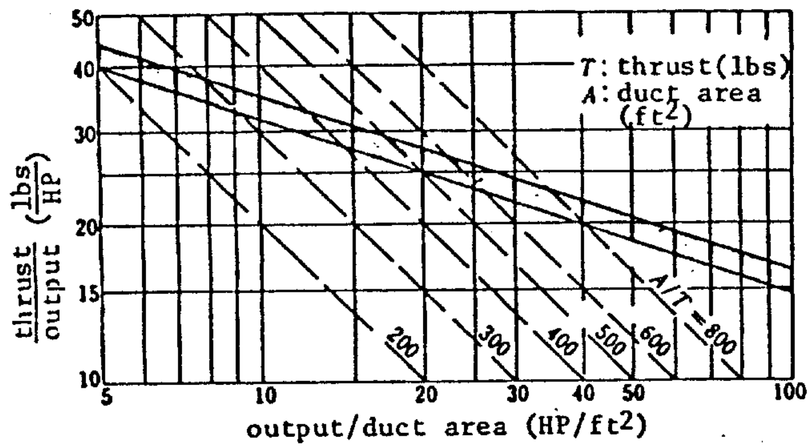


Fig. 161 Estimation Chart of Particulars of the Bow Thruster (3)

10. BASIC DESIGN

10.1. Items Necessary for Basic Design

(1) Basic items
Following items are indispensable for ship's basic design and are given by the customers in general;
Kind of ship, type of ship, deadweight, grade and numbers of passengers, kind of main engine, service speed.

(2) Additional items
Following items do not influence the principal dimensions, etc. so much as basic items, but these informations give the designers considerable advantages in clarifying the features of the ships which the customer wants to have.
Shipowner, nationality of the ship, liner or tramper, navigating route, navigating area, class of the ship, classification societies, the notation of the classification society, applied rules, gross tonnage.
Limitation for length, breadth, draft, etc., narrow waters in the routes, special features of wharves and ports.
Trial speed, cruising days without refueling, endurance.
Kind of cargoes, hold volume, numbers of decks, sizes and numbers of hatches.
Cargo gear, other miscellaneous outfits, contents of special equipment.
Complement.
Output of main engine, ratio of maximum continuous output and normal output and sea margin, numbers of propellers, location of engine room, fuel oil to be used, required quantity of fresh water and fuel oil.
Other special requirements.

10.2. Lightweight (LW) and Deadweight (DW)

(1) Lightweight (LW)
Lightweight is the weight of the ship at the completed condition of all works, after all the fittings, equipment and machinery are installed on board, that is, the total weight of hull steel, fittings and equipment and machinery (refer to 10.6.1).
Spares required by the rules are included in LW, but those in excess of and not required by the rules, inventories such as tablewares, blankets and daily necessaries are included in DW.
In the removable devices such as grain shifting board, fittings fixed to the hull such as sockets and ring plate are included in LW, whereas removable fittings such as pillars and divisional walls are included in DW.
Cooling fresh water and sea water, boiler water and lubricating oil in main engines, boilers, auxiliary machinery (for example, electric generators and prime movers, etc.) for propulsion of the ship and pipe lines which are directly connected to the above machinery are included in LW, but fresh water, sea water and lubricating oil used for other purposes than the above and all fuel oil are included in DW.

(2) Deadweight
The deadweight is the difference between the displacement of the ship at the assigned summer draft and the lightweight (refer to 1.3).

10.3. Data for Initial Design

10.3.1. Data for Determination of Principal Dimensions (Fig. 162 - 183)

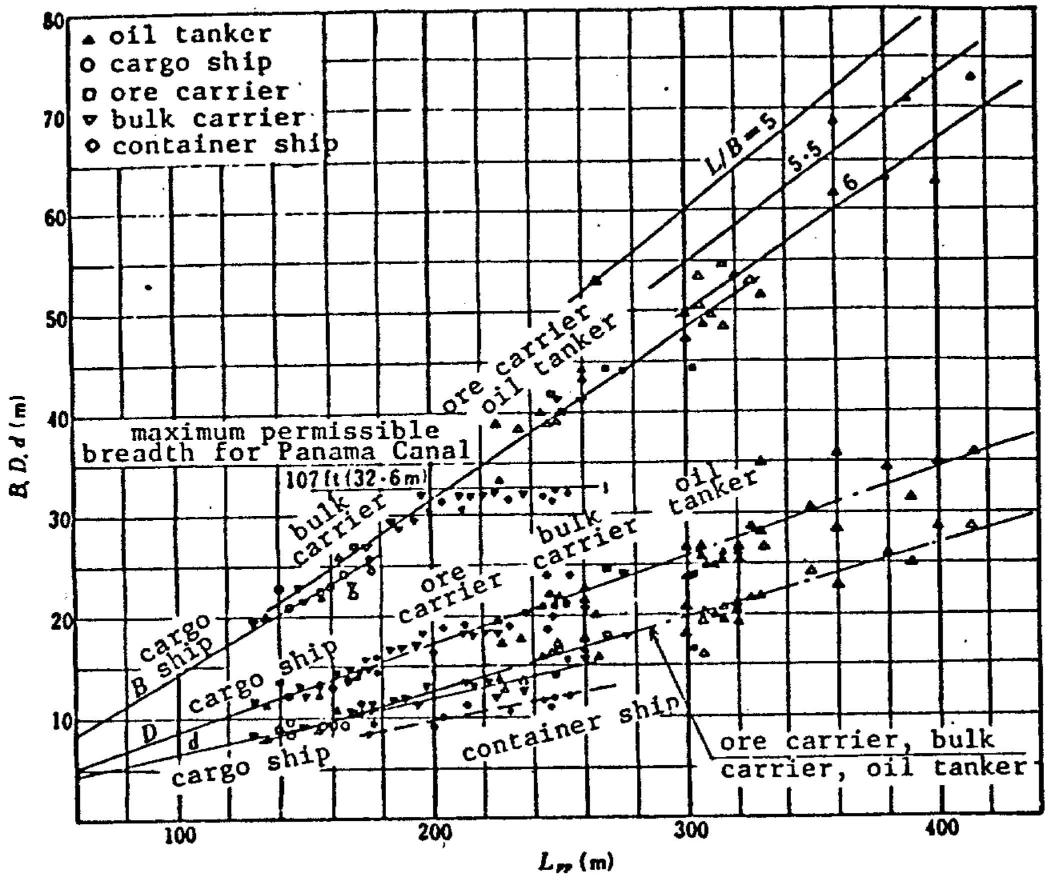


Fig. 162 $L_{pp} \sim B, D, d$

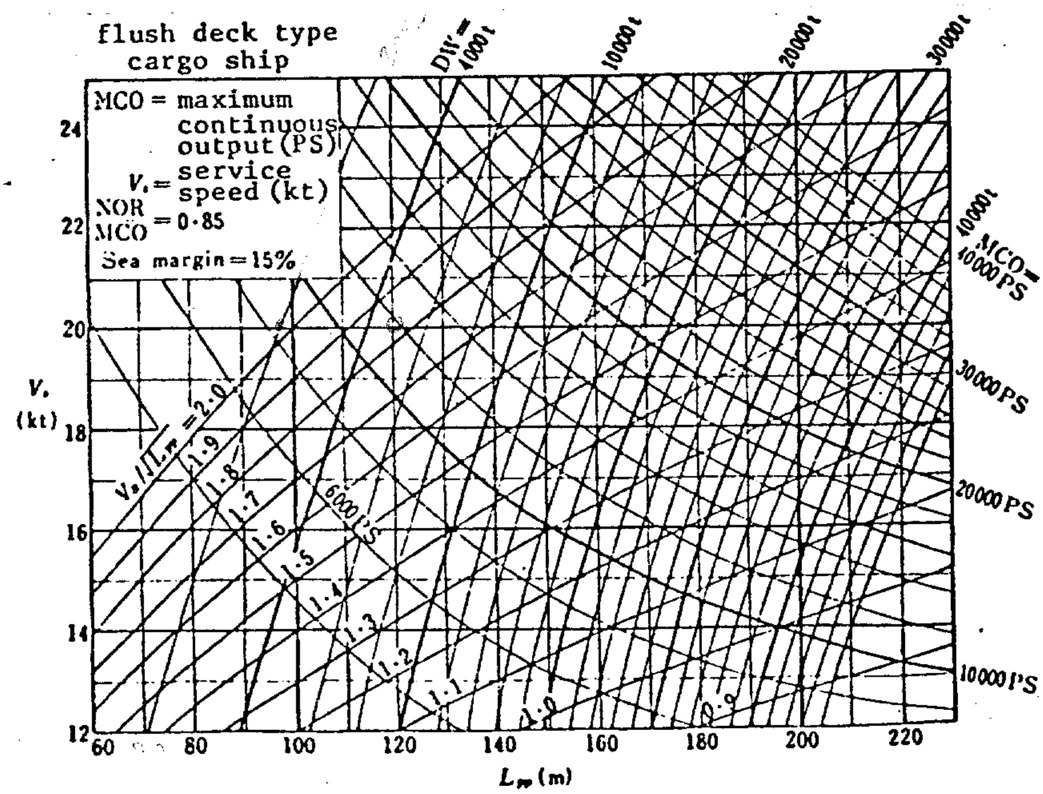


Fig. 163 Approximate Estimation Curve of $L_{pp} \sim V_s \sim$ DW $\sim$ MCO (1)

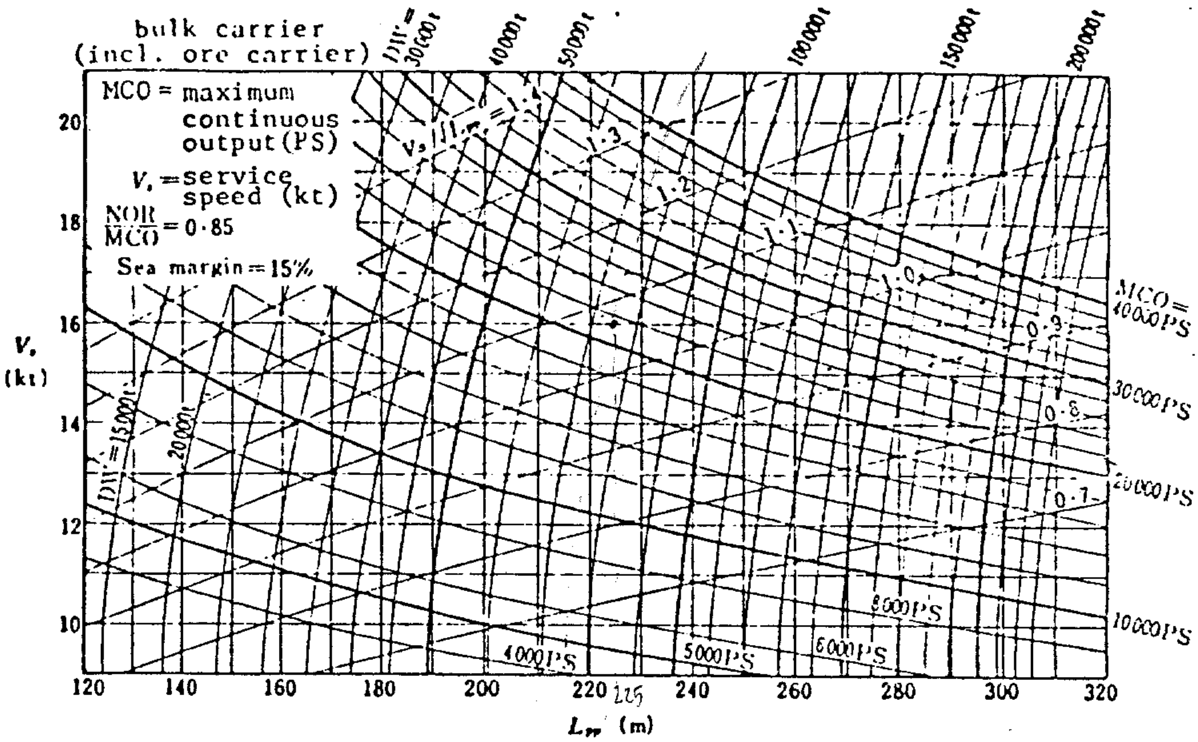


Fig. 164 Approximate Estimation Curve of L_{pp}~V_s~DW~MCO (2)

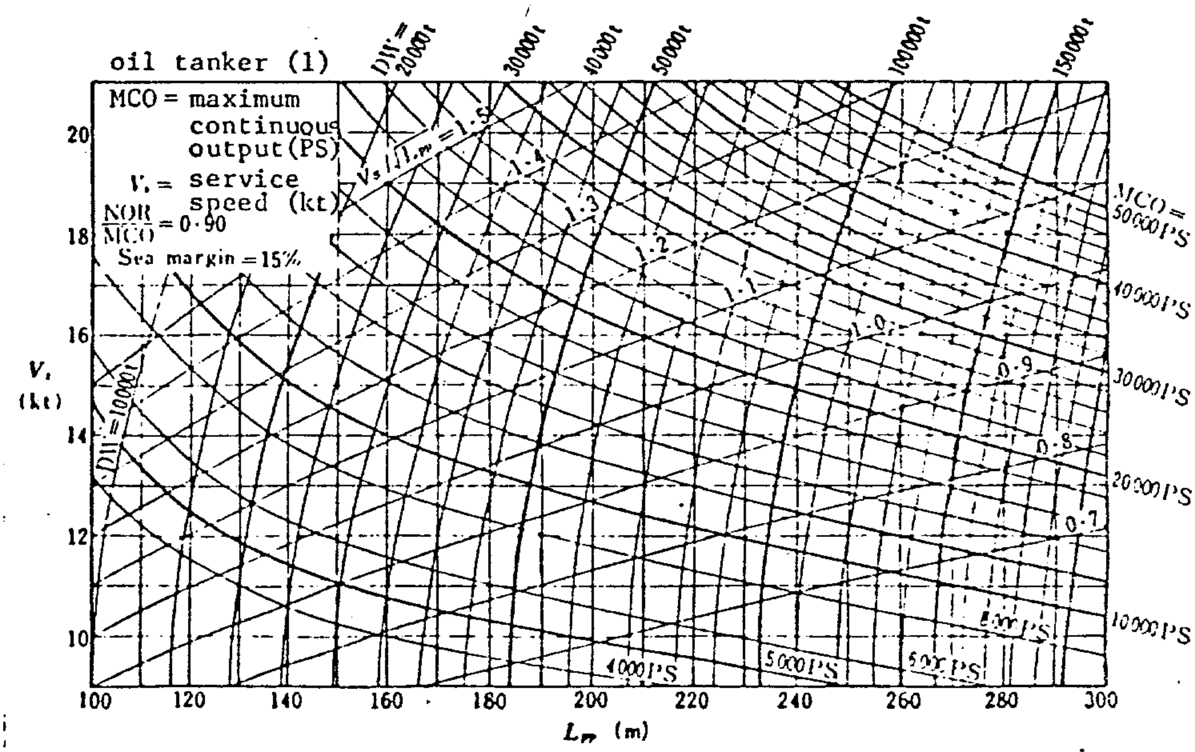


Fig. 165 Approximate Estimation Curve of L_{pp}~V_s~DW~MCO (3)

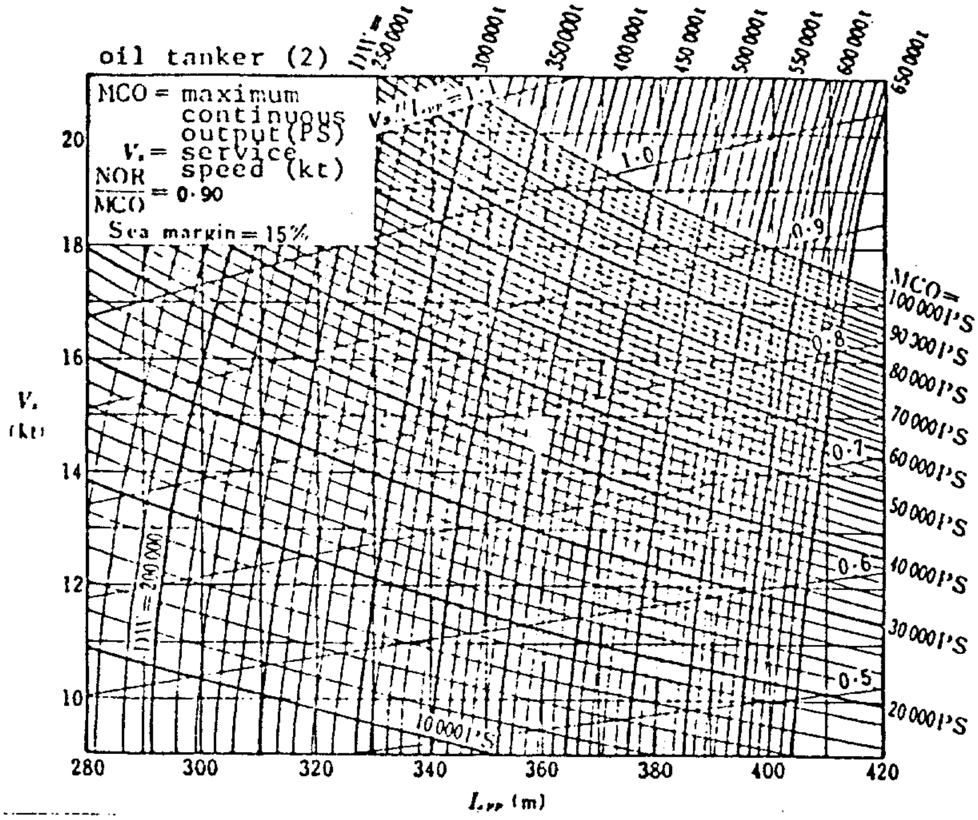


Fig. 166 Approximate Estimation Curve of $L_{pp}\sim V_s\sim$DW$\sim$MCO (4)

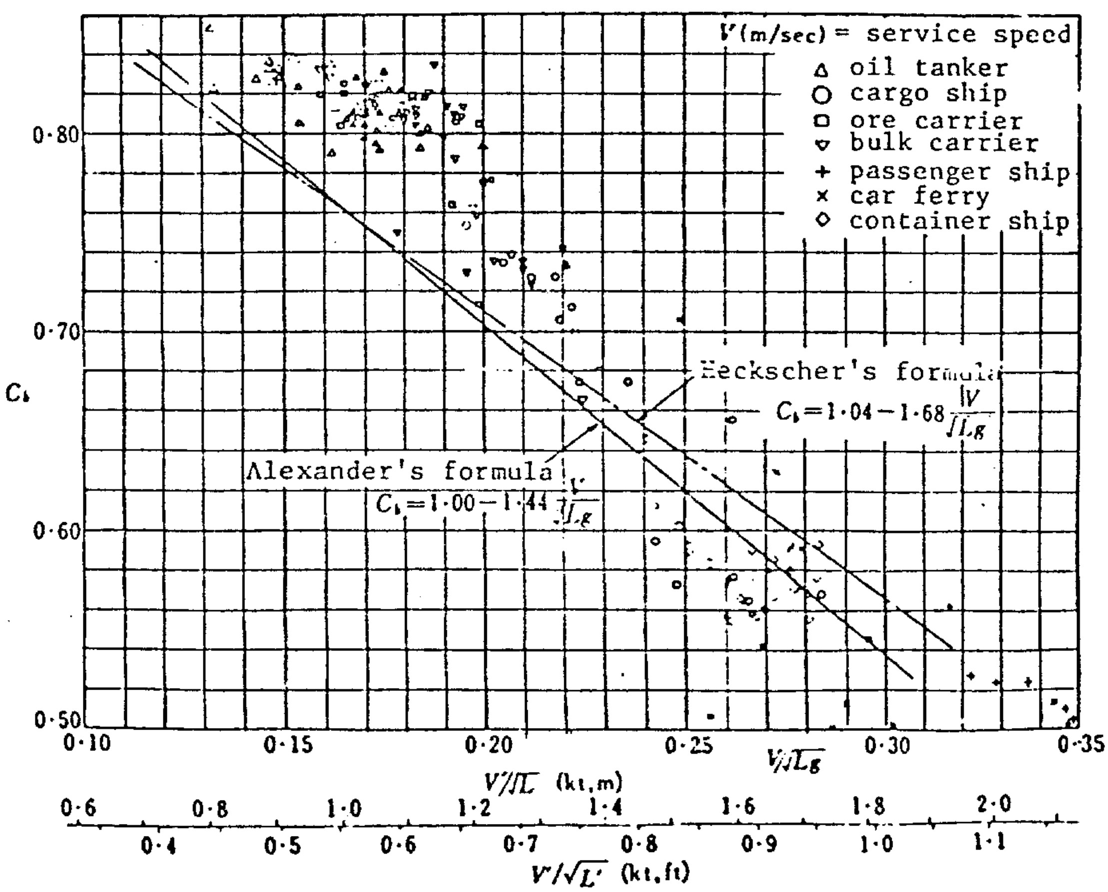


Fig. 167 $V/\sqrt{Lg}\sim C_b$

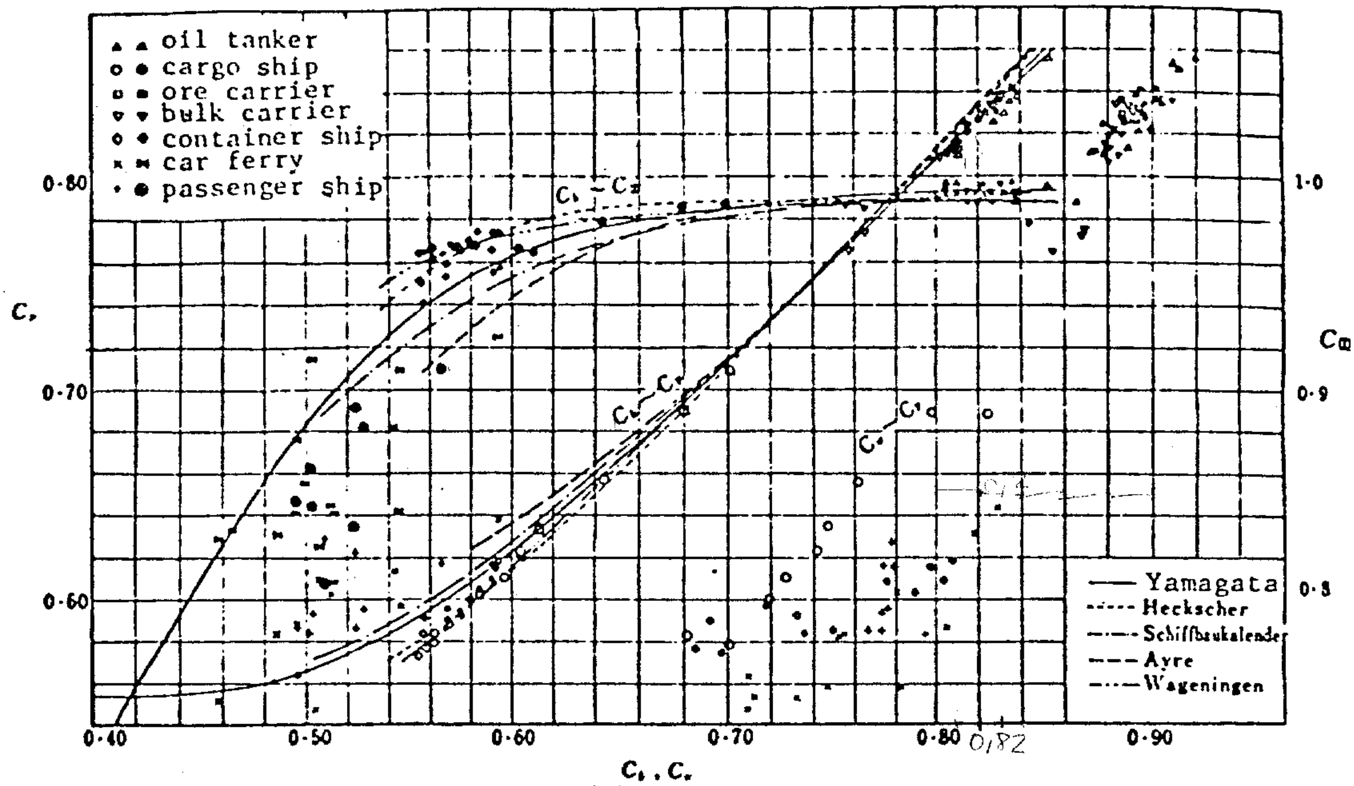


Fig. 168 $C_b \sim C_p$, $C_b \sim C_{\otimes}$, $C_w \sim C_p$

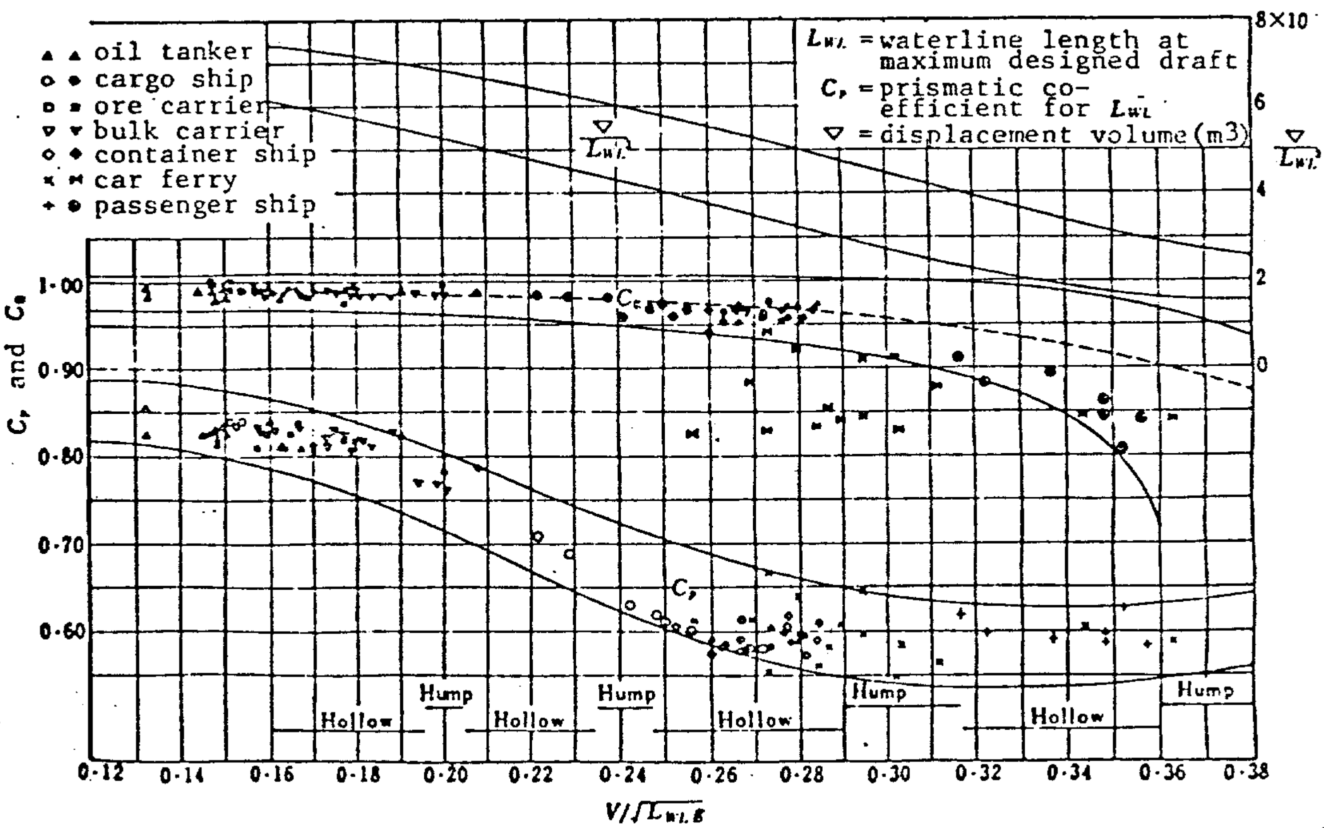


Fig. 169 $V/\sqrt{L_{WL}g} \sim C_p$, $C_{\otimes}$, ∇/L_{WL}^3

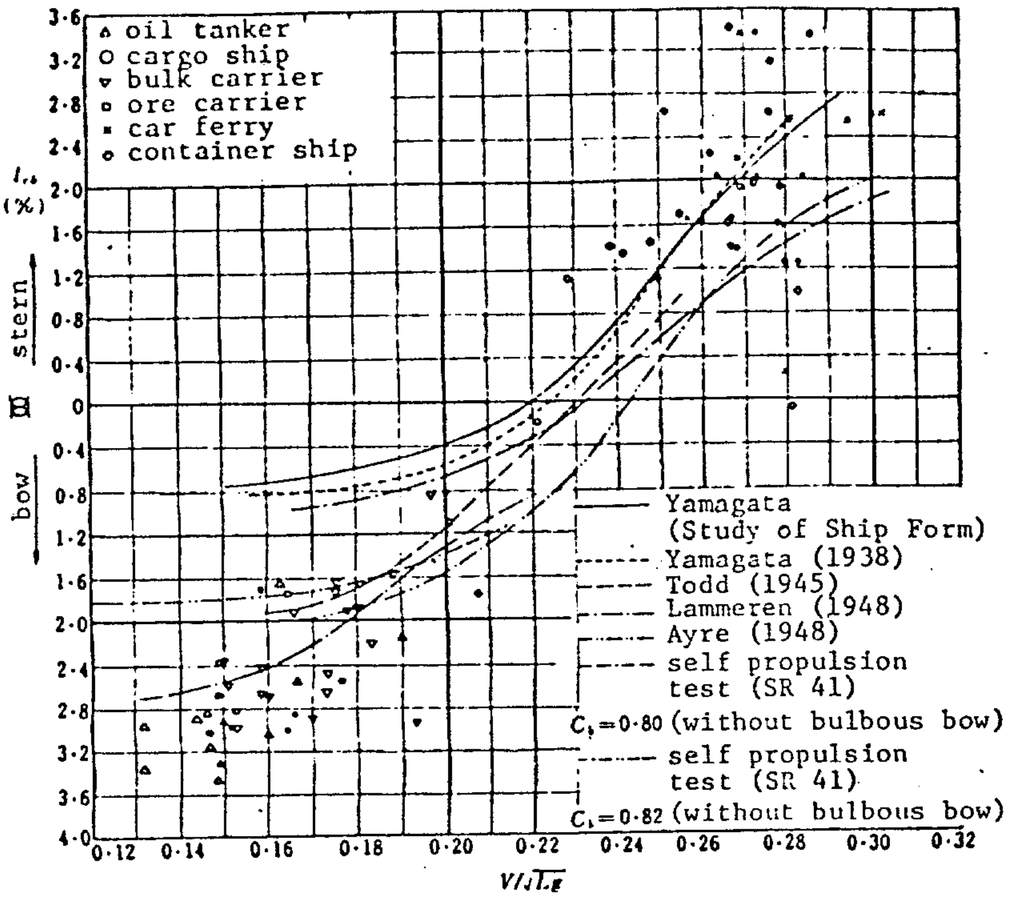


Fig. 170 $V/\sqrt{Lg} \sim l_{cb}$

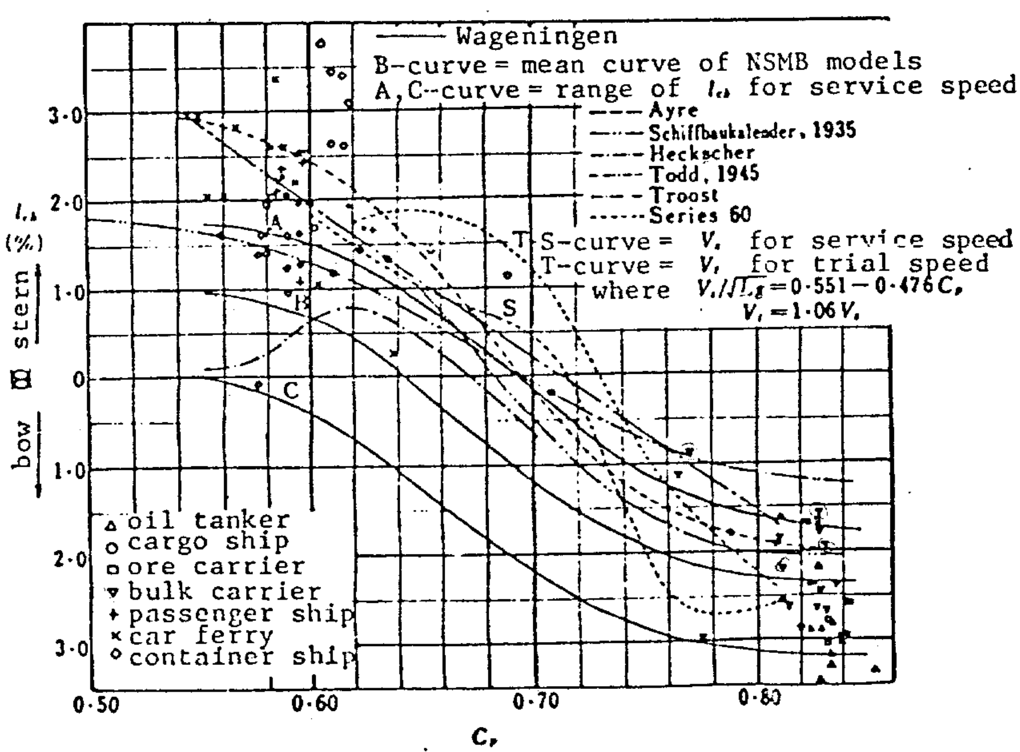


Fig. 171 $C_p \sim l_{cb}$

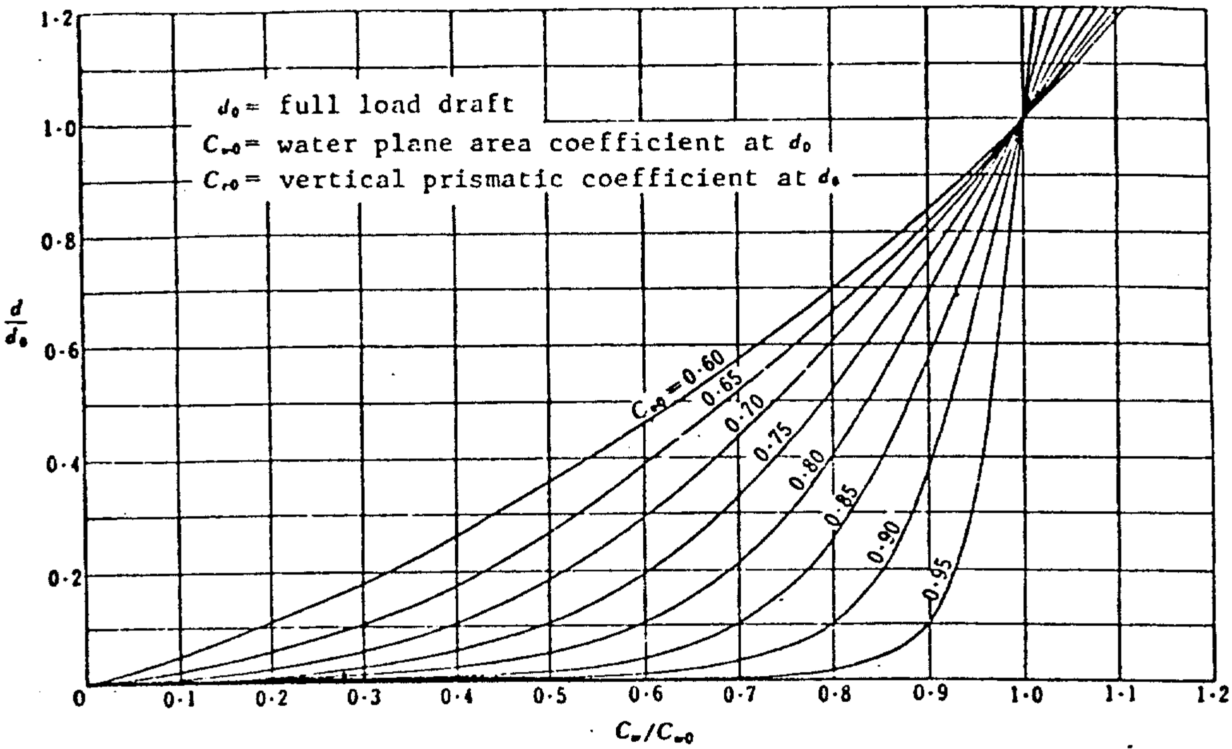


Fig. 172 Change of C_w due to Change of Draft

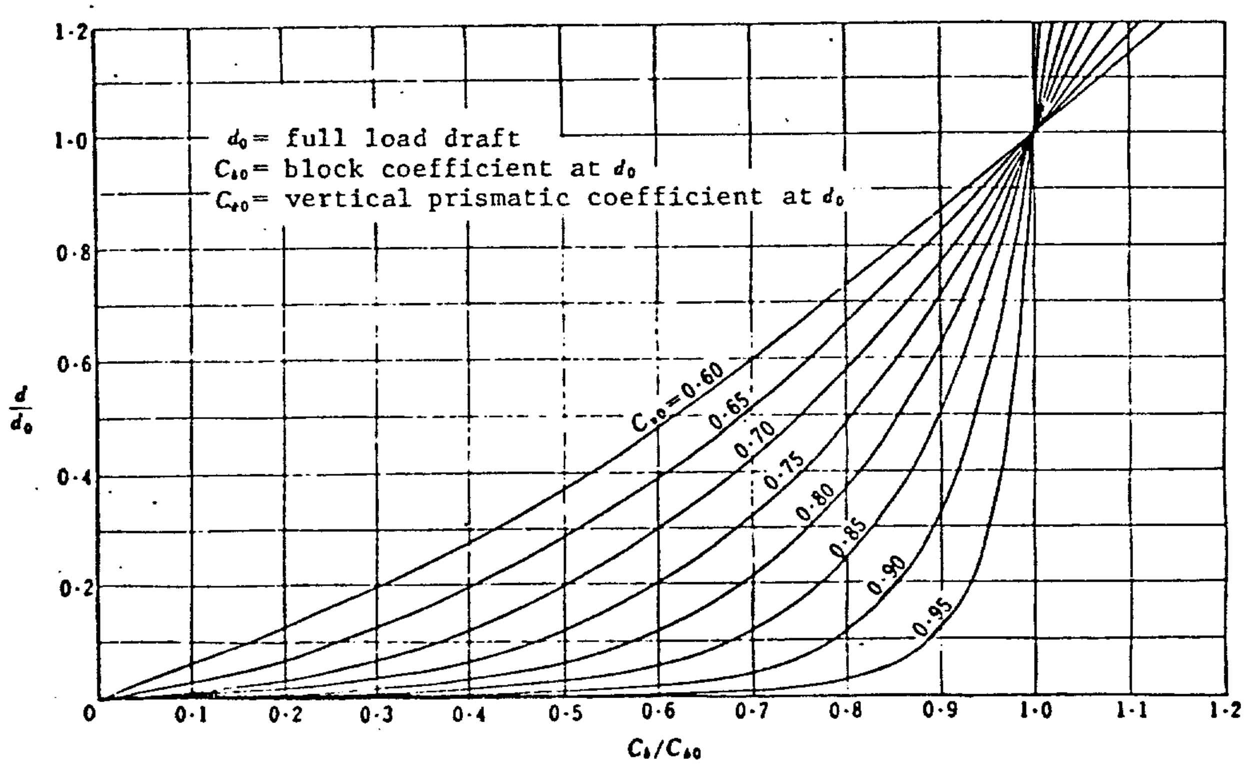


Fig. 173 Change of C_b due to Change of Draft

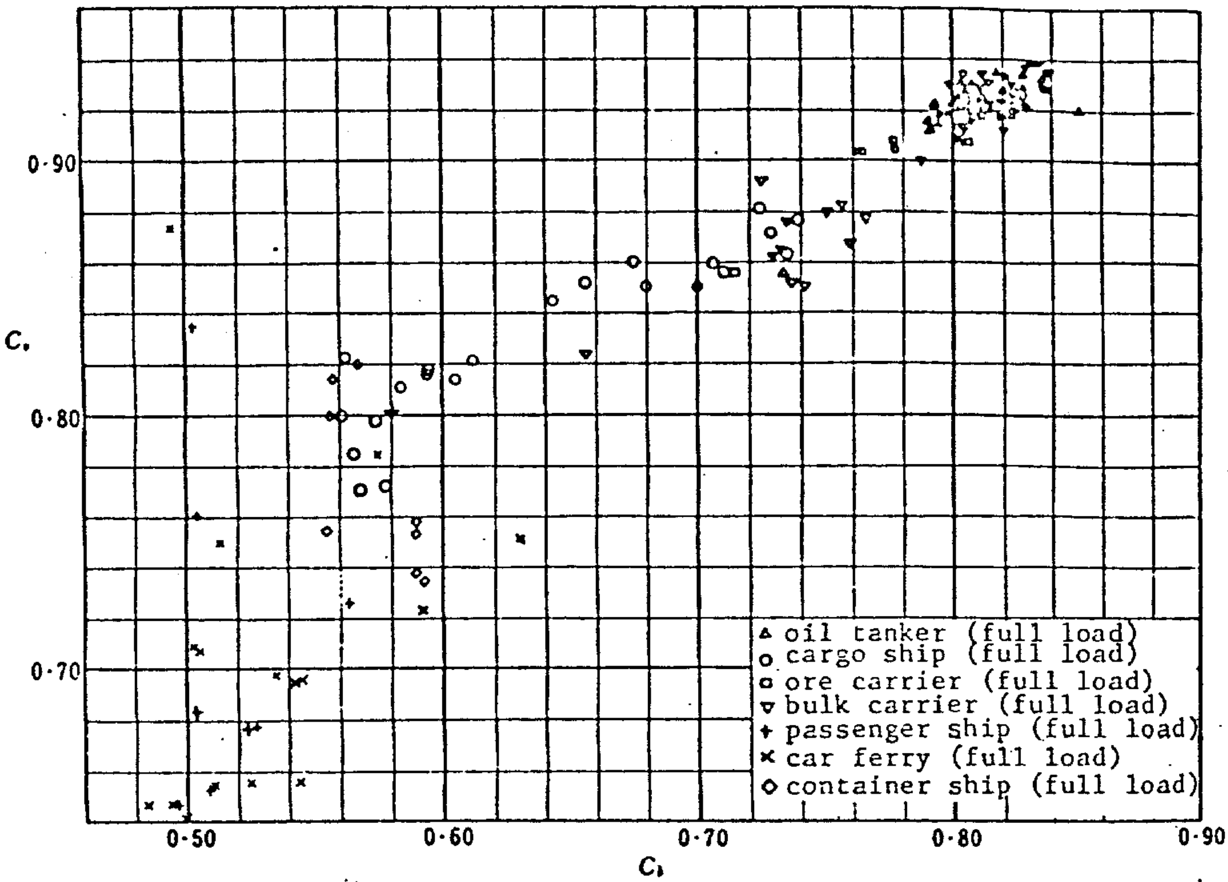


Fig. 174 $C_b \sim C_v$

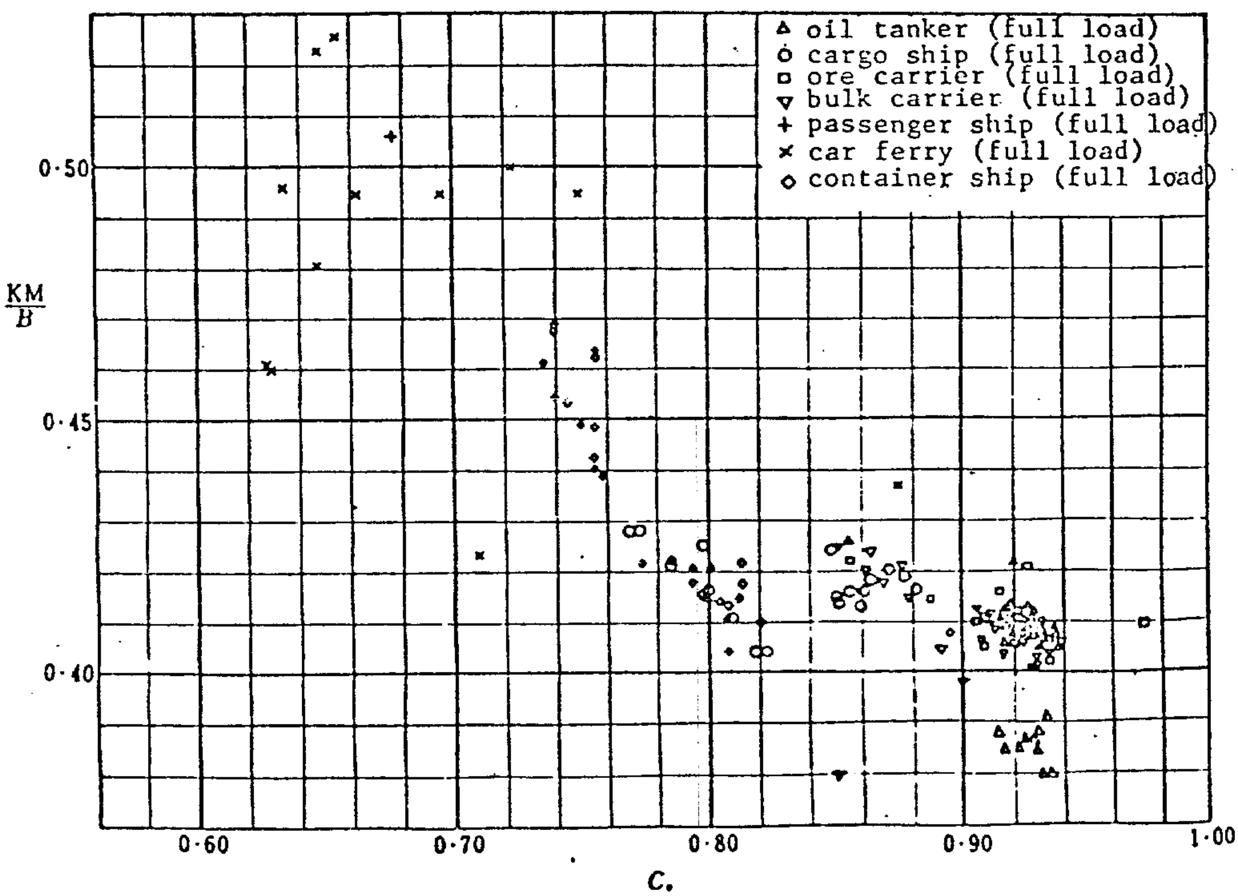


Fig. 175 $C_v \sim KM/B$

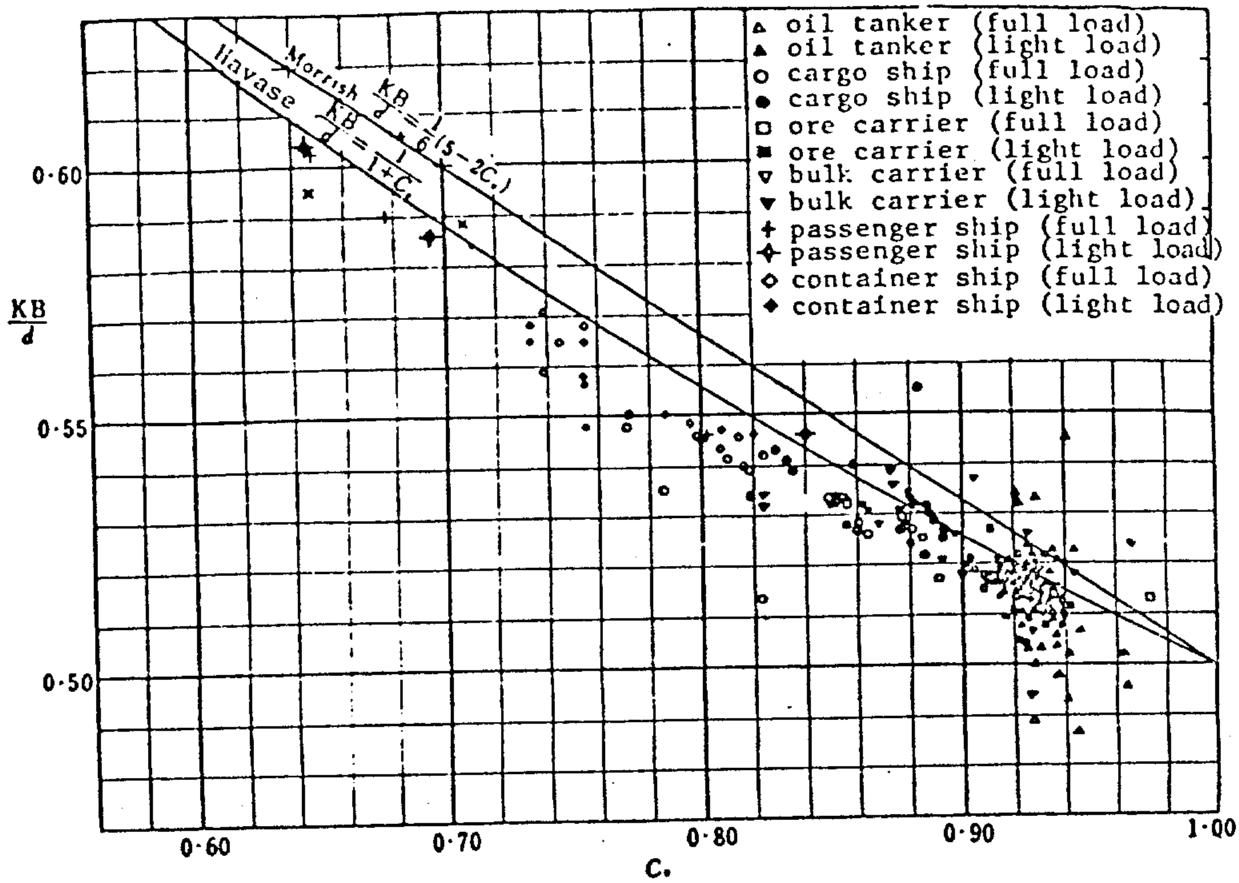


Fig. 176 C_v~KB/d

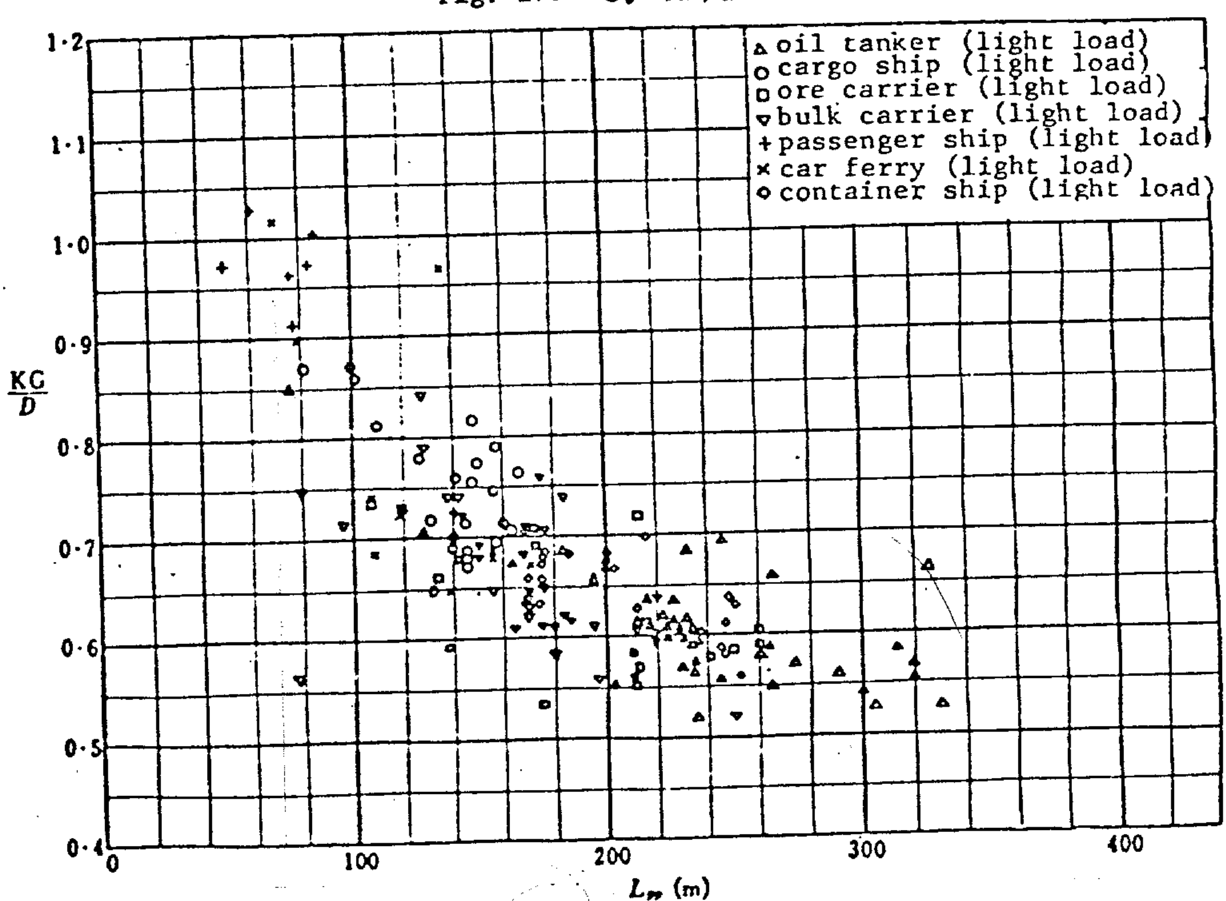


Fig. 177 L_{pp}~KG/D

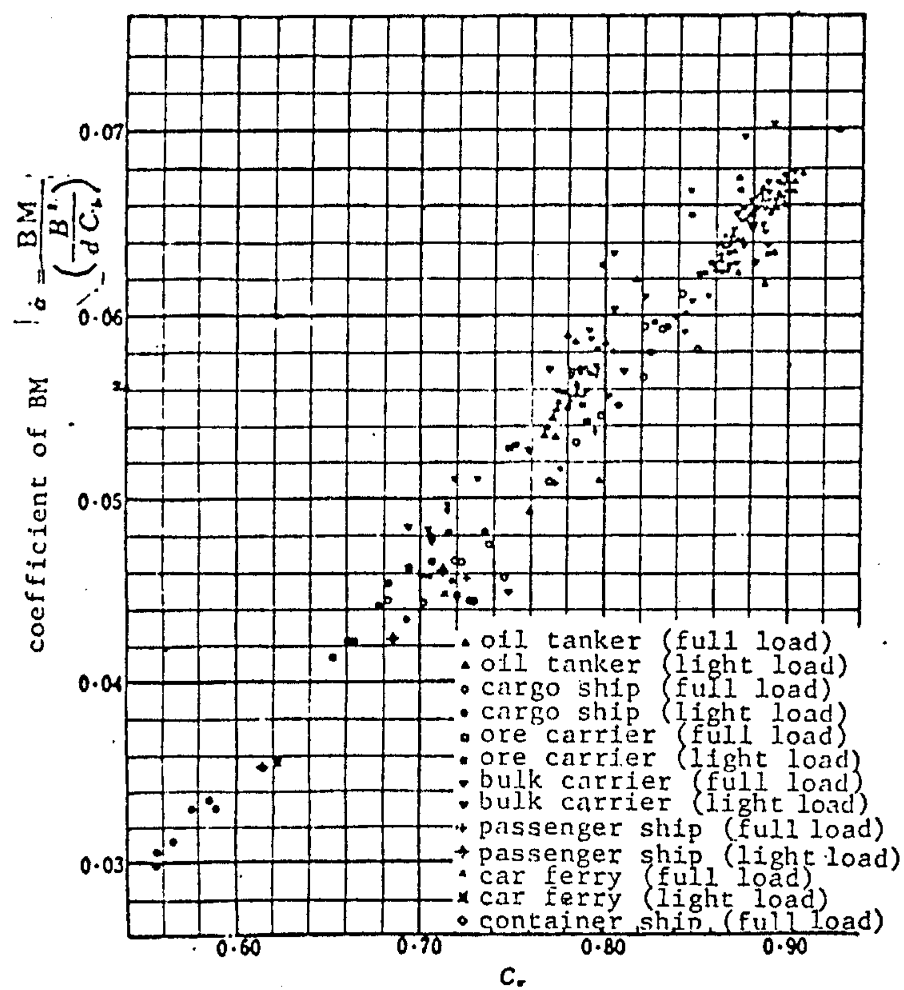


Fig. 178 C_w ~ Coefficient of BM

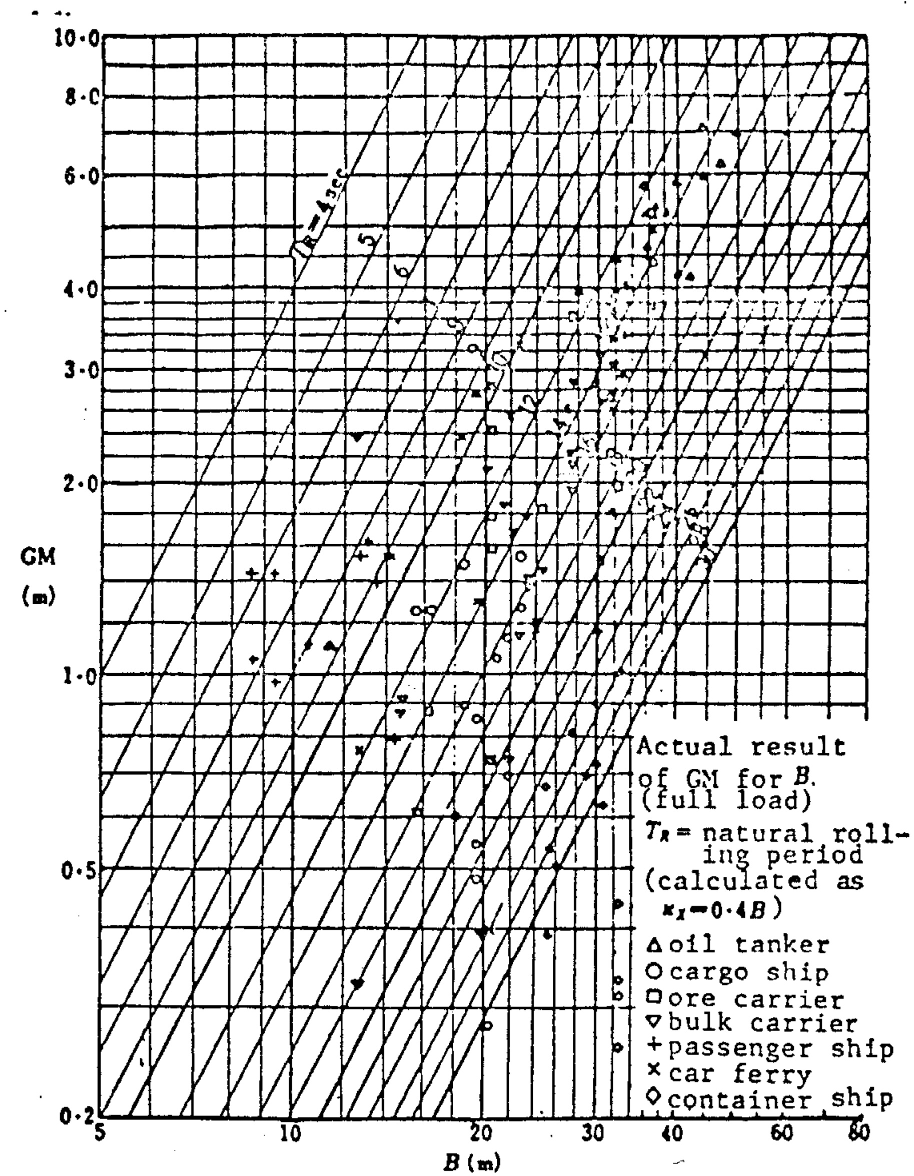


Fig. 179 GM and Rolling Period

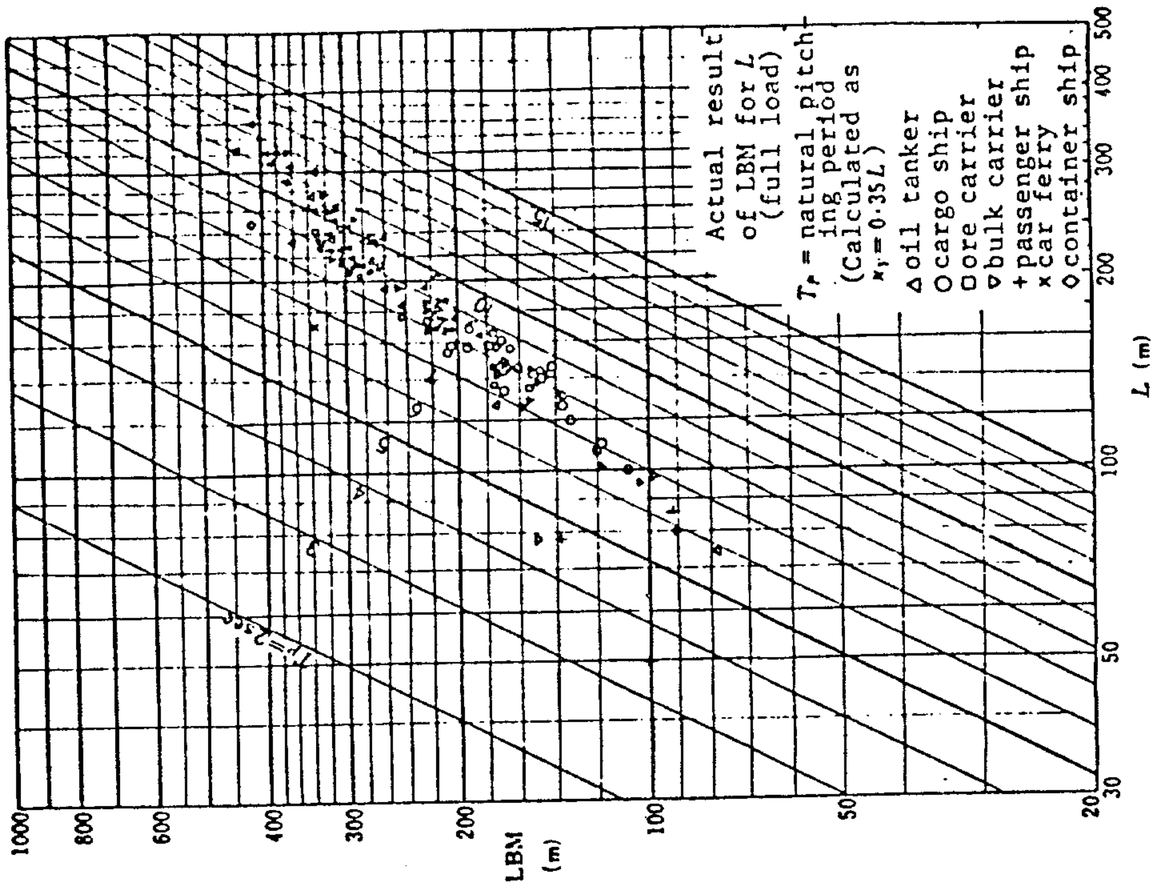


Fig. 180 LBM and Pitching Period

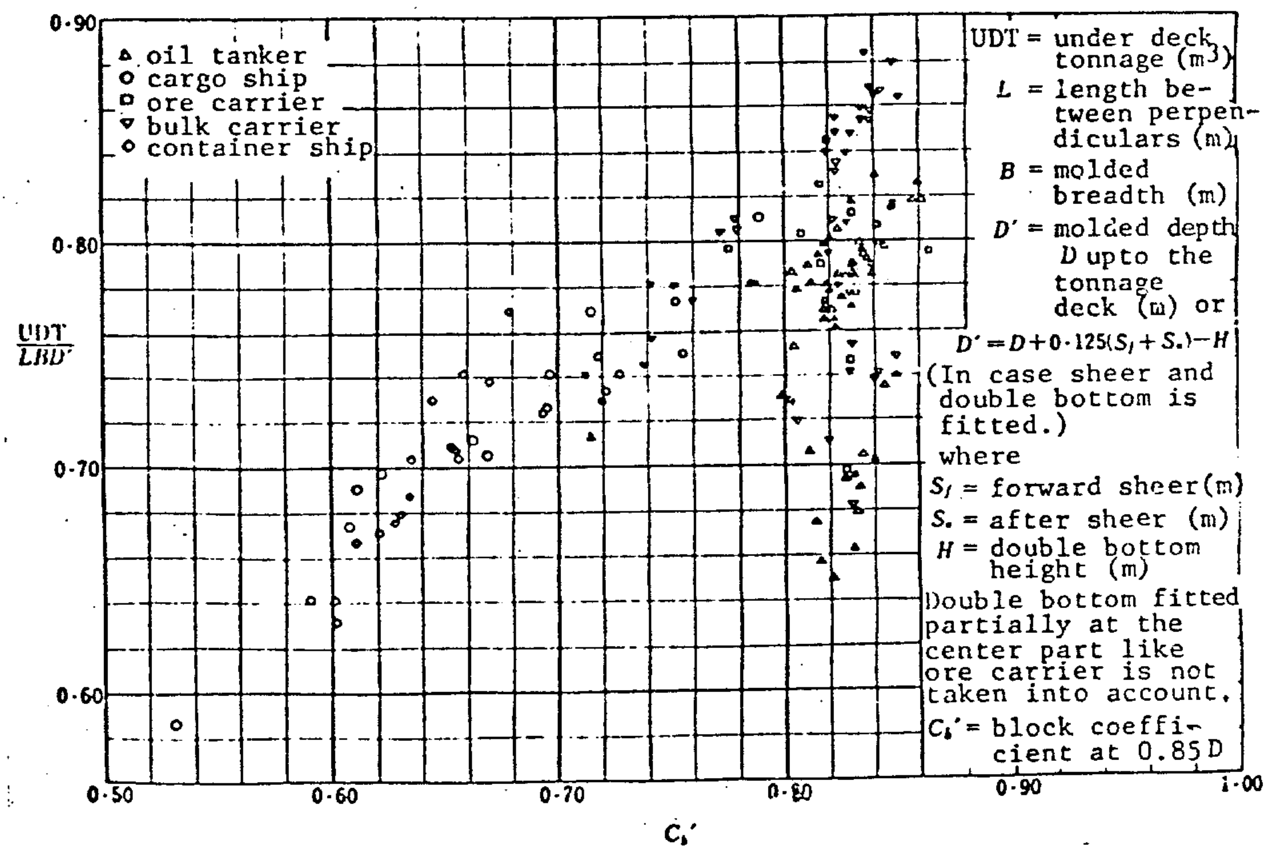


Fig. 181 $C_b' \sim \frac{UDT}{LBD'}$

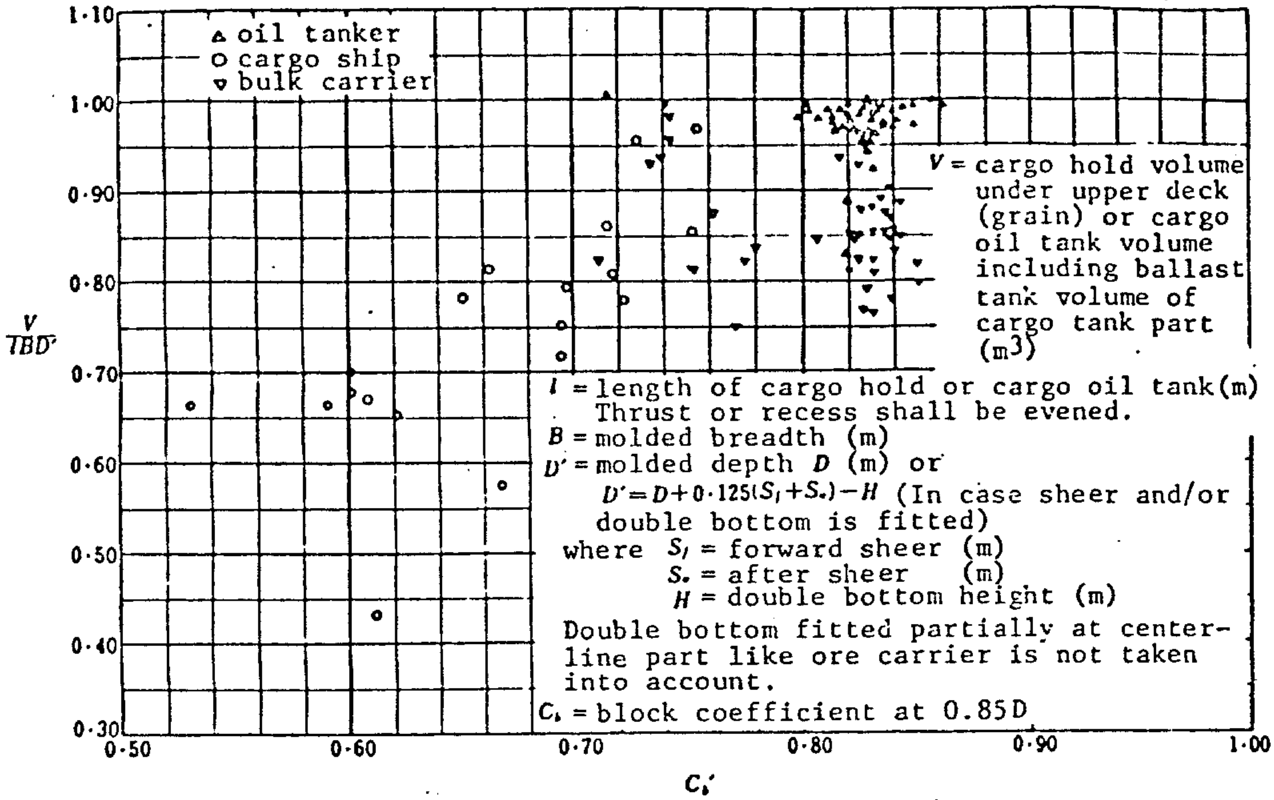


Fig. 182 $C_b' \sim \frac{V}{lBD'}$

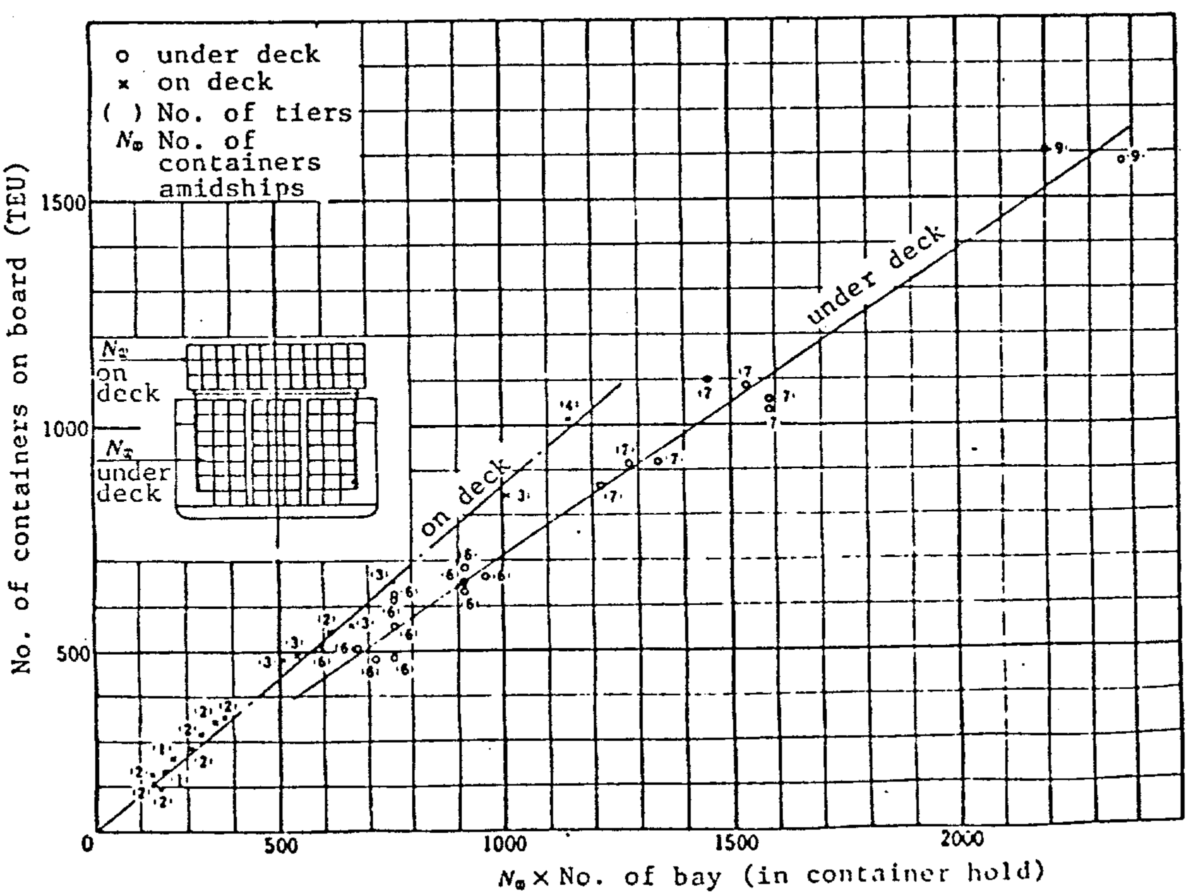


Fig. 183 Estimation Curve of Containers on Board (TEU)

10.4. Data for Making Lines (Fig. 184 - 191, Table 93)

(1) Form of waterplane at fully loaded condition
Entrance angle and location and length of parallel part of the ship are shown on Fig. 184 - 186 for tankers with bulbous bow (hull form SR 98[*1]) and cargo ships (series 57[*2] and series 60[*3]).

(2) Prismatic curve
C_{Pa} and C_{Pf} are shown on Fig. 187 (a) and (b) when C_P and l_{cb} are given. The curves for SR 98 are given for tankers with block coefficient around 0.8 and bulb ratio ($A_{FP}/A_{\otimes}$) of 10%, and those for SR 45[*4] are given for cargo ships with block coefficient around 0.625 and raked stem.

(3) Bulbous bow
Bulbous bows with various features are now put into practice.
Some examples of bulbous bows are shown on Fig. 189 (a), (b) and (c)[*5], where B-1 type of B type series, R-1 type of R type series and C type are depicted.
Original bow form of SR 98 is shown on Fig. 190.

Note) *1 SR 98, Report of studies No. 61 (1967)
*2 F.H. Todd, Trans. SNAME, 59 (1951), 642
*3 F.H. Todd, Trans. SNAME, 61 (1953), 516
*4 SR 45, Report of studies No. 45 (1964)
*5 R.B. Couch, Trans. SNAME, 74 (1966), 392

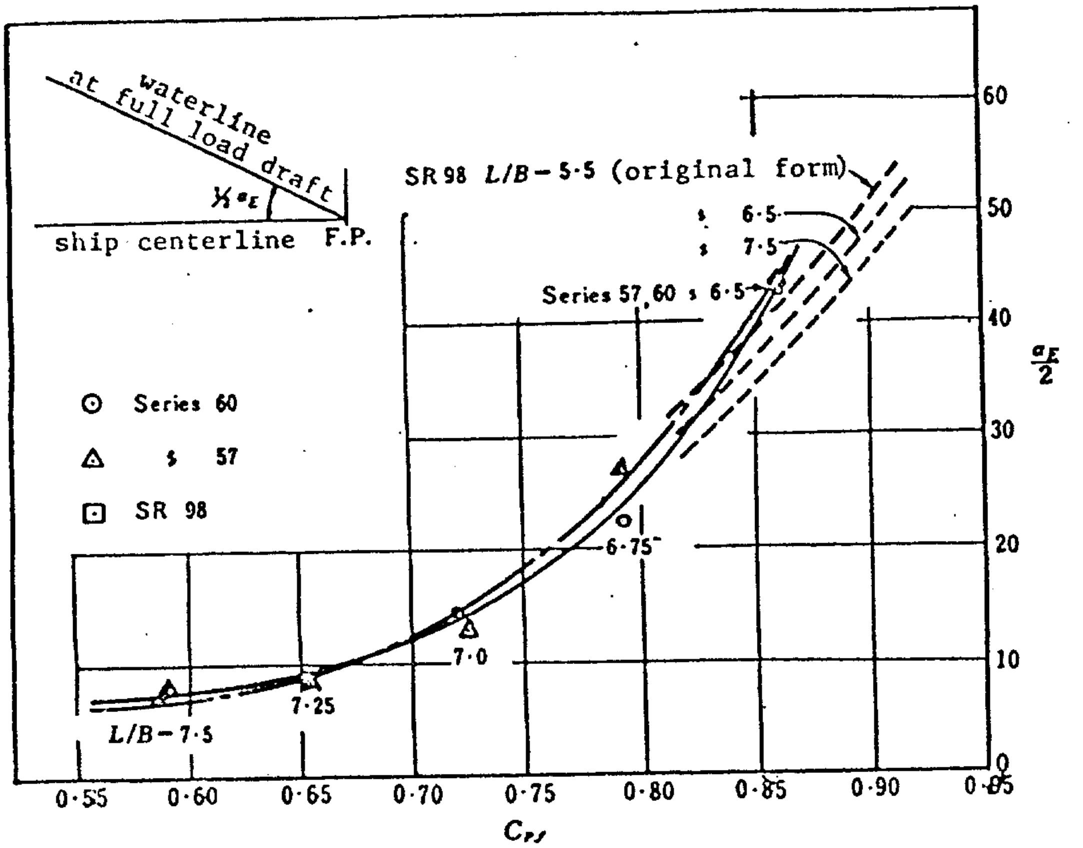
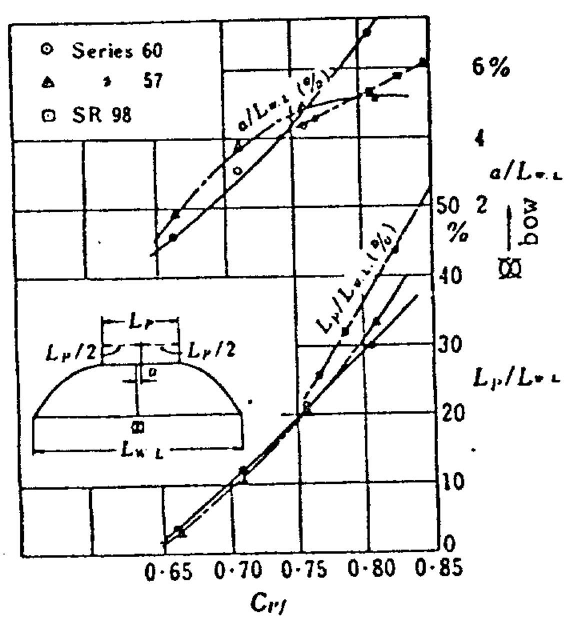


Fig. 184 Entrance Angle at Fully Loaded Condition (α_E)



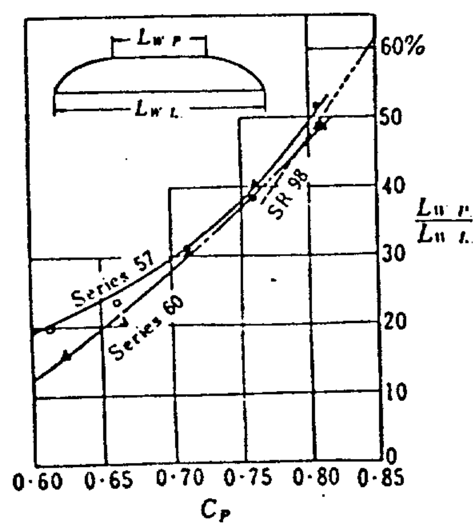


Fig. 185 Length of Parallel Part and Position of Max. Transverse Sectional Area (Center of Parallel Part)

Fig. 186 Length of Parallel Part on Waterplane at Fully Loaded Condition ($L_{W.P.}$)

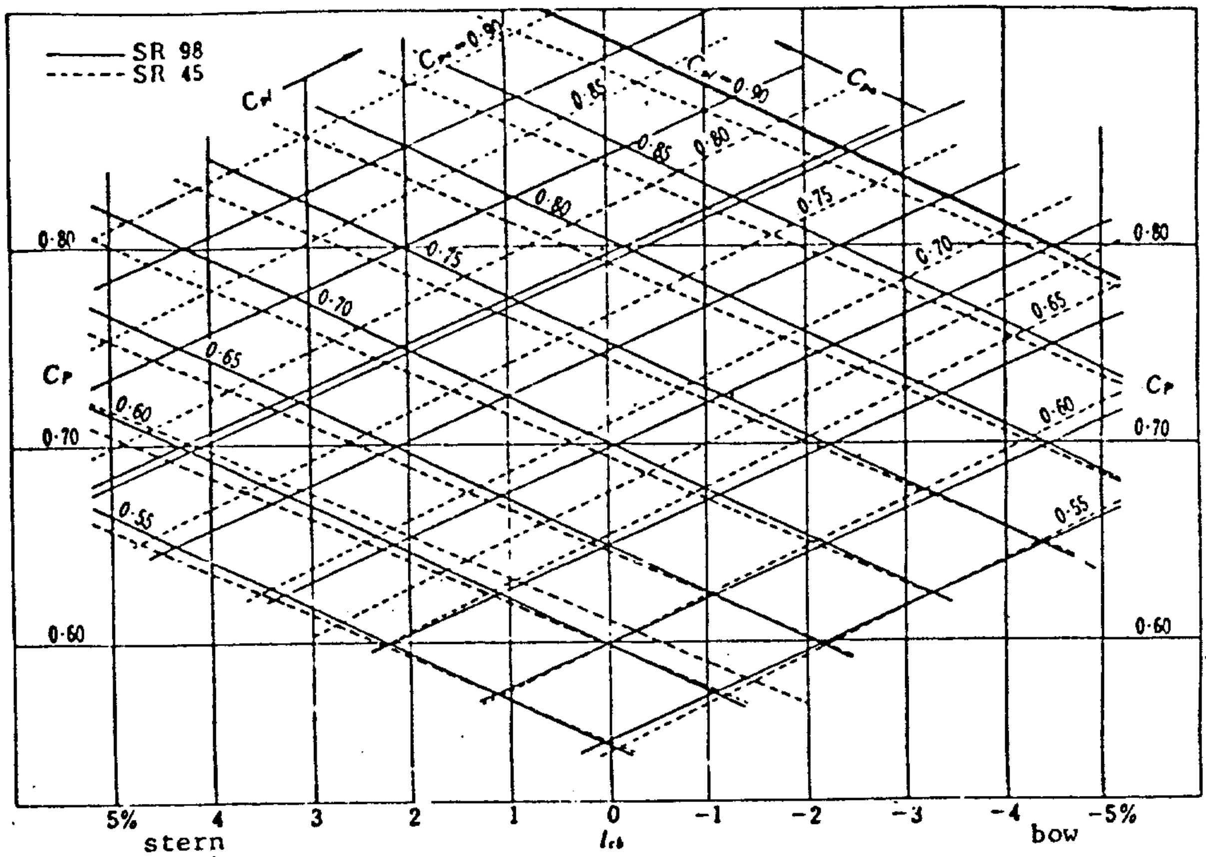


Fig. 187 (a) C_{Pa}, $C_{Pf} \sim l_{cb}$, C_P

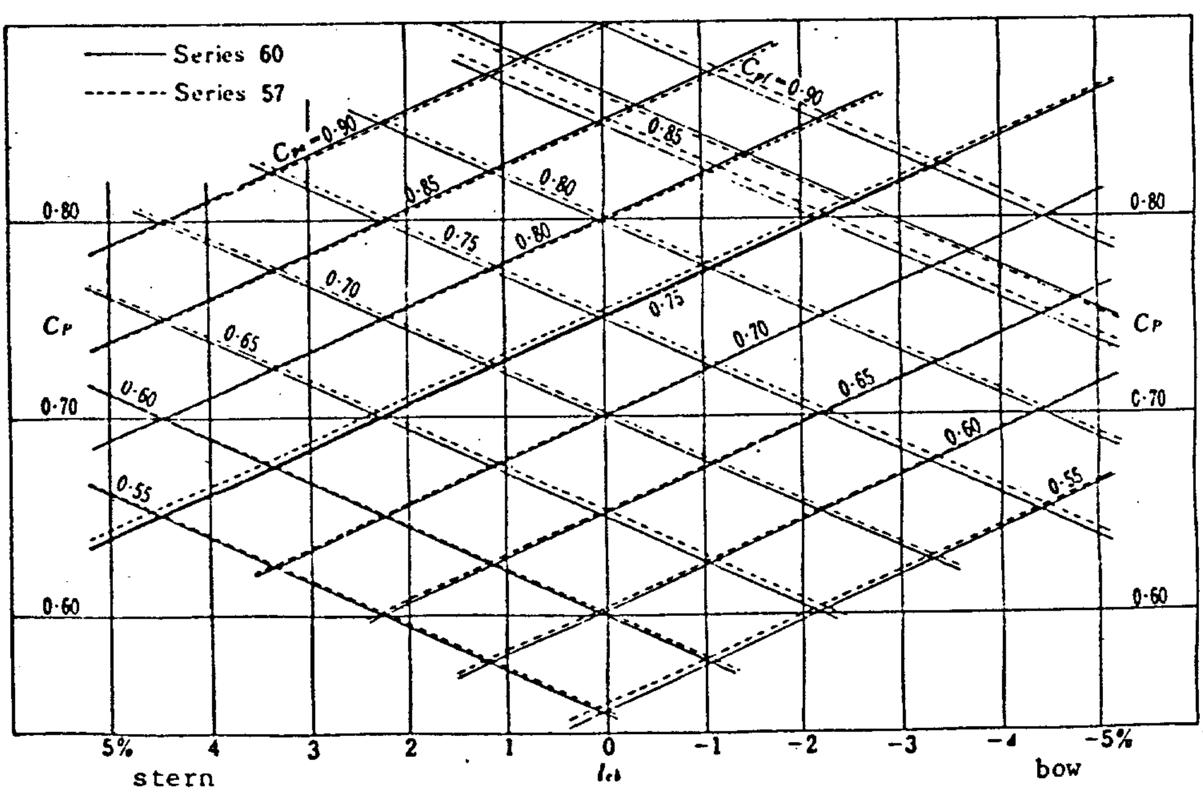


Fig. 187 (b) C_{Pa}, $C_{Pf} \sim l_{cb}$, C_P

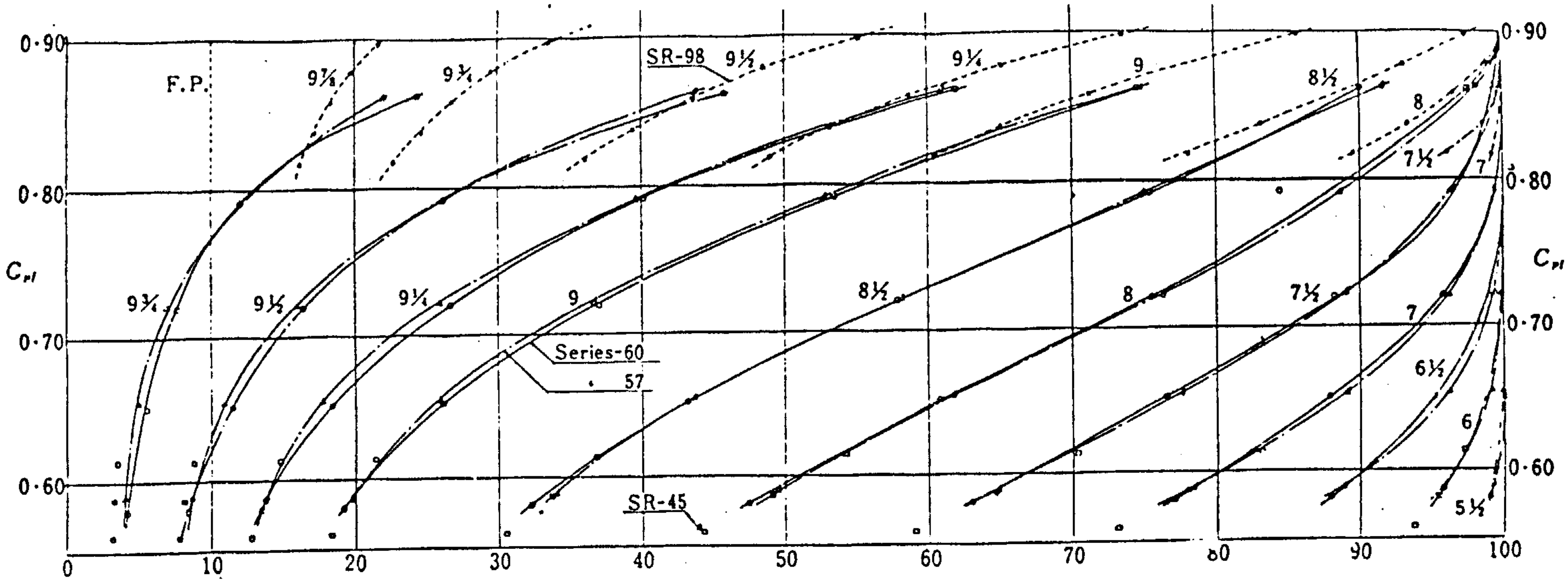


Fig. 188 (a) Ratio (%) of Transverse Sectional Area at Each Station/Midship Sectional Area (Fore Part)

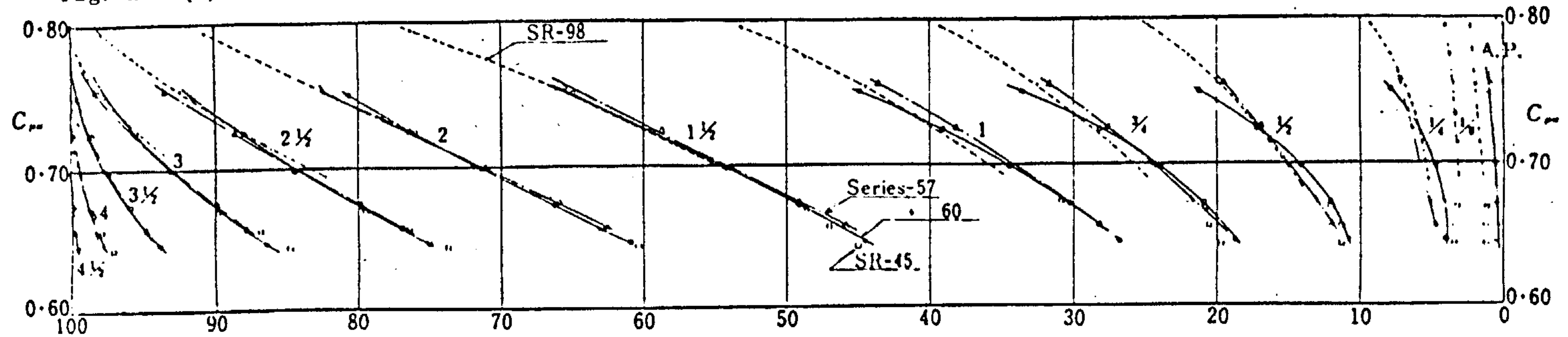


Fig. 188 (b) Ratio (%) of Transverse Sectional Area at Each Station/Midship Sectional Area (Aft Part)

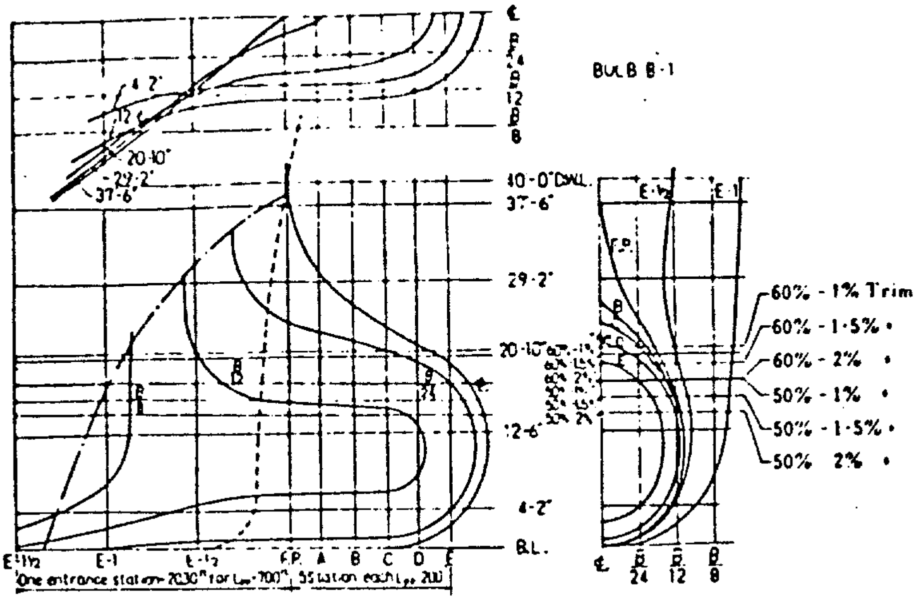


Fig. 189 Bow Form (a)

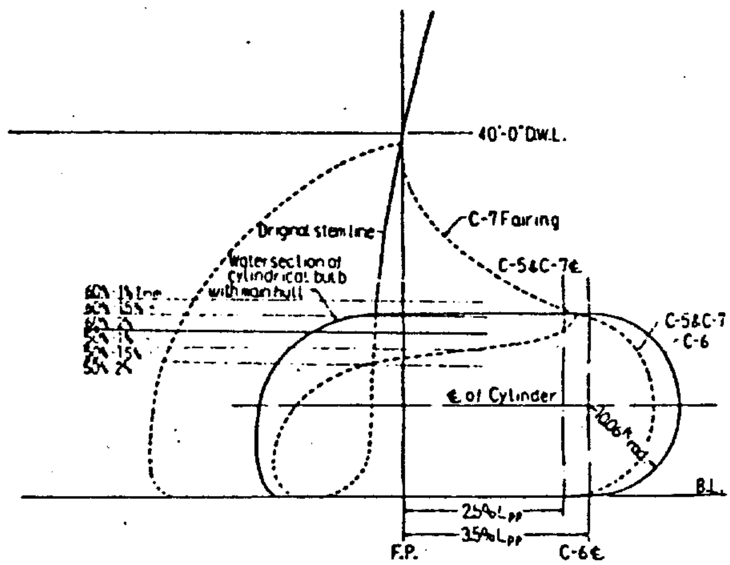


Fig. 189 Bow Form (b)

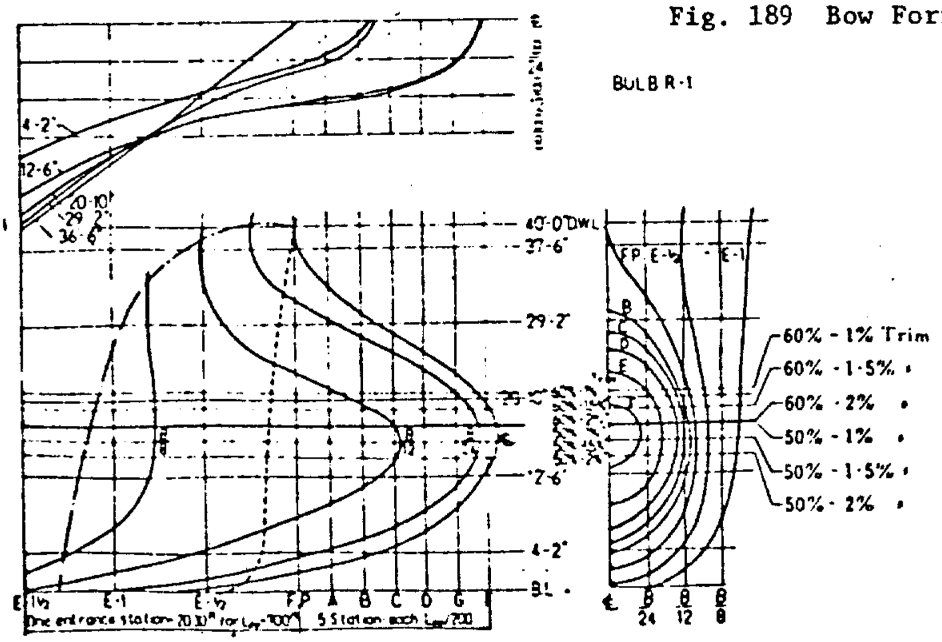


Fig. 189 Bow Form (c)

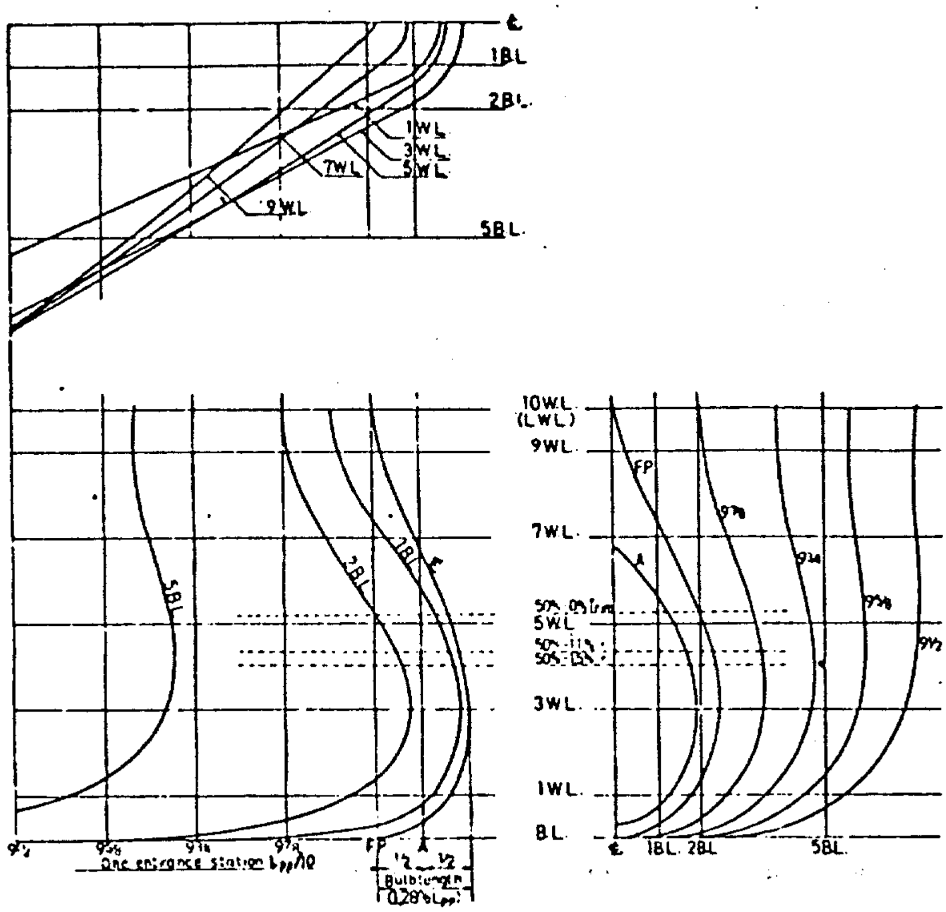


Fig. 190 Prototype of SR 98 Bow Form

(4) Data for making midship section (Fig. 191)

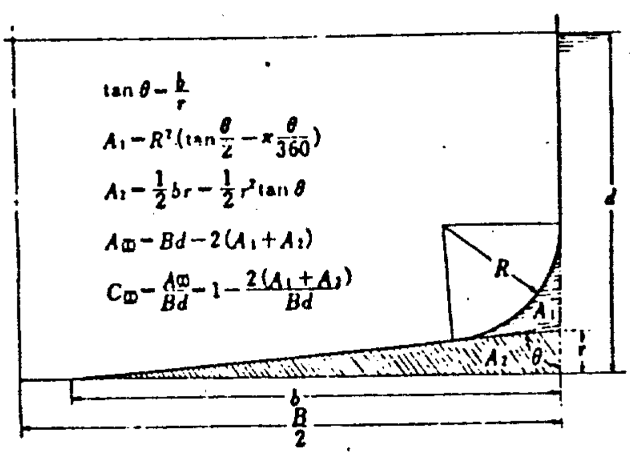


Fig. 191 Data for Making Midship Section

(5) Clearance between hull and propellers (Table 93)

Table 93 Clearance between Hull and Propellers

			α/D	β/D	γ/D	δ/D
Single screw	Target (from experiences)		0.15 - 0.20	0.25 - 0.30	0.20 - 0.30	0.05 - 0.12
	LR	3 bladed	[0·12, t/D]	[1·8 k_1, 0·10]	[1·2 k_1, 0·10]	0.03
		4 bladed	"	[1·5 k_1, 0·10]	[1·0 k_1, 0·10]	"
		5 bladed	"	[1·275 k_1, 0·15]	[0·85 k_1, 0·10]	"
		6 bladed	"	[1·125 k_1, 0·15]	[0·75 k_1, 0·10]	"
	NV		0.1	$0{\cdot}35-0{\cdot}02\,Z$	$0{\cdot}24-0{\cdot}01\,Z$	0.035
	BV	3 bladed	[0·12, t/D]	[1·20 F, 0·15]	[0·80 F, 0·1]	0.03
		4 bladed	"	[0·97 F, 0·15]	[0·65 F, 0·1]	"
		5 bladed	"	[0·825 F, 0·15]	[0·55 F, 0·1]	"
		6 bladed	"	[0·75 F, 0·15]	[0·50 F, 0·1]	"
	Institute de Recherches		0.06 - 0.10	0.15 - 0.17	0.07	0.04
	NPL		0.08 - 0.15	0.20	0.08 - 0.10	0.02 - 0.03
	NSMB		0.08 - 0.12	0.15 - 0.20	0.10 - 0.12	0.03
	Van Lammeren		0.056	0.134	0.082	0.025

			Tip-hull clearance	Clearance between propeller and shaft bracket or bossing
Twin screws	LR	3 bladed	From 0·2 D upto 1·2 $k_1 D$	From 0·15 D upto 1·2 $k_1 D$
		4 bladed	From 0·2 D upto 1·0 $k_1 D$	From 0·15 D upto 1·0 $k_1 D$
		5 bladed	From 0·16 D upto 0·85 $k_1 D$	From 0·15 D upto 0·85 $k_1 D$
		6 bladed	From 0·16 D upto 0·75 $k_1 D$	From 0·15 D upto 0·75 $k_1 D$
	NV		$(0{\cdot}30-0{\cdot}01\,Z)\,D$	—
	BV	3 bladed	[0·80 FD, 0·20 D]	[tip clearance, 0·15 D]
		4 bladed	[0·65 FD, 0·20 D]	"
		5 bladed	[0·55 FD, 0·16 D]	"
		6 bladed	[0·50 FD, 0·16 D]	"

Note) As for the numerals in [ ], the value whichever is the greater shall be adopted.
LR (1974), NV (1974), BV (1973)

LR; $k_1 = (0.1 + L/3050)(2.56 C_b \text{ SHP}/L^2 + 0.3)$
$k_1 = (0.1 + L/3050)(1.28 C_b \text{ SHP}/L^2 + 0.3)$

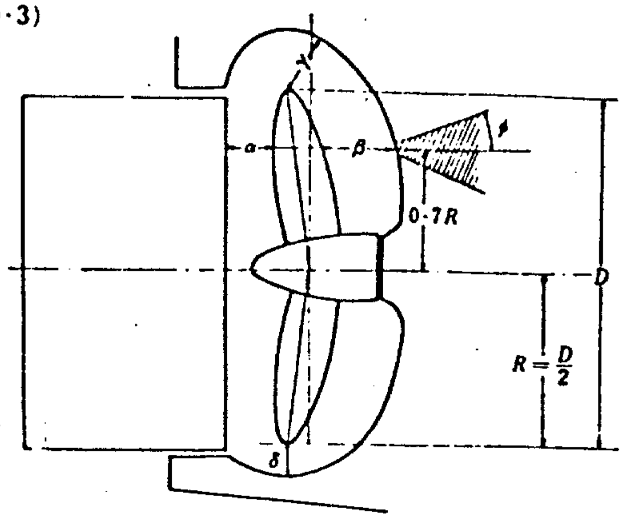


Fig. 192

where SHP = Designed maximum shaft horsepower (total horsepower for twin screws)

t' = Maximum thickness of the rudder at 0.7R of the propeller above shaft center line

NV; Z = Numbers of propeller blades
Radius at after end of the hull water line and angle ϕ forward of the propeller shall be as small as possible.

BV; $F = (C_b \text{ SHP})^{2/3}/(10L)$

where, SHP = Designed maximum horsepower on each shaft.
t = Maximum thickness of the rudder
L = Length of the ship (m)
C_b = Block coefficient at full load draft.

10.5. Data for Determination of Arrangement

(1) Volume of chain locker (Cylindrical type) (refer to Fig. 193)

$n \fallingdotseq 8d$
$s \fallingdotseq 25d \sim 30d$
$D \fallingdotseq 26d \sim 32d$
$h \fallingdotseq 1.1(0.92 \times 10^{-5}\, ld^2)/(\pi D^2/4)$

where, d = Diameter of anchor chain (mm)
l = Length of chain stowed (m)
D = Diameter of chain locker (m)
h = Height of chain in the chain locker at stowed condition (m)

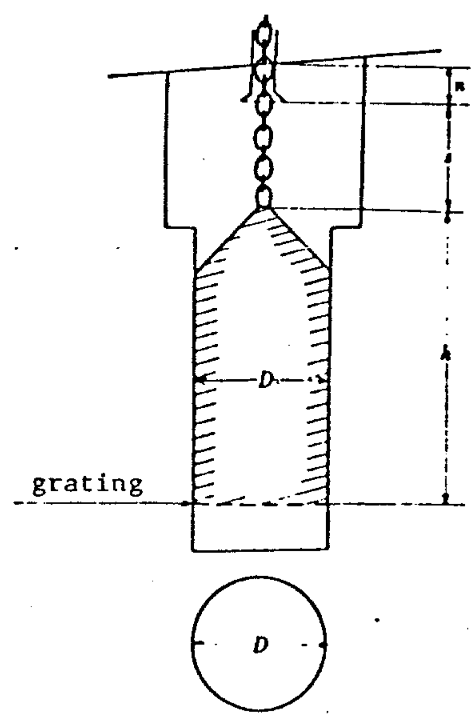


Fig. 193 Chain Locker

(2) Volume of refrigerated provision chamber
Approximate standard of virtual volume (m^3/person/day) is shown in the following table. (Refer to Chapter V, 18.1)

Unit: m^3/person/day

	Large tankers		Other ships	
	Japanese	European	Japanese	European
Meat room	0.010	0.020	0.003	0.006
Fish room	0.010	0.003	0.003	0.001
Vegetable room	0.023	0.023	0.010	0.010

(3) Volume of CO_2 bottle room
The required floor area for one CO_2 bottle (cylindrical type) containing 45 kg (100 lbs.) is 0.28 - 0.36 sq.m although it varies according to the shape of the room. In case three units of bottles mentioned above, each of which is composed of ten bottles in one longitudinal row arranged transversely, the required floor area becomes 4 m in length by 1.2 m in width, and a passage over 60 cm in width is additionally required around the bottles for their maintenance.

(4) Stowage space of cars
Stowage space, location and arrangement of cars are decided taking the following constraints and/or conditions into consideration.

i) Constraints on arrangement such as
- Space for lashing work of cars
- Fastening device of cars (chains and other special equipment)
- Ventilation trunks
- Access and traffic system in hold (stairways, ladders, hatches and passages for inspection of cars)
- Pipings and accessories in hold
- Hanging device of liftable car deck (linkage and wire)
- Hull structural members (deck beams, side frames, pillars, etc.)
- Rampways in hold
- Entrance and exit of elevator
- Opening and closing direction of bulkhead doors

ii) Procedure of loading/unloading cars

iii) Orbit of cars driven

iv) Strength of deck against bounding of the car caused by ship's motion and weight of cars

v) Deflection of car deck.

(a) Stowage space
Following clearances are usually taken.

Top clearance	about 100 mm
Clearance between side to side of cars or clearance between side of cars and side frame of the ship	about 100 mm
Fore-and-aft clearance of cars or clearance between fore or aft of cars and transverse bulkhead or obstacles	about 300 mm

(b) Passages in hold
At least one passage over 300 mm in width is arranged in longitudinal direction of the ship for inspection in hold during navigation. The floor area per medium-sized Japanese make car is increased by 20 - 30% of calculated floor area based on the above clearances because of the various constraints as mentioned before. Apart from the above, following passages shall be arranged in vehicle area of car ferries (structural standard of car ferries)

In longitudinal direction of ship	Passages over 60 cm in width on both sides of rows of cars
In transverse direction of ship	One passage over 1,000 mm in width according to the length of the vehicle area, except bow and stern part.

The arrangement of cars are usually studied taking into account the fore-and-aft clearance between cars to be about 60 cm.

10.6. Weight

10.6.1. Category of Weight

Lightweight is usually divided into three categories for convenience standpoint, that is, hull steel weight W_h , fitting weight W_f and weight of machinery part W_m . Therefore, LW becomes

$$LW = W_h + W_f + W_m$$

(1) Hull steel weight

Hull steel weight is the total weight of steel material for bottom structure, side structure, decks, superstructure, machinery casing, bulkheads shaft tunnel, deep tanks, pillars, foundations, bow and stern structure, rudder, etc., rivets, welding deposits and forgings and castings.

(2) Fitting weight

Fitting weight is the total weight of steering system, anchoring and mooring system, mast and cargo handling system, access and traffic system, doors, scuttles and skylights, awnings, rails, covers, life-saving appliances, navigational equipment, riggings, tackles, inventories, accessories, pumping system, fire extinguishing apparatus, natural ventilation, mechanical ventilation and air conditioning system, refrigerating system, insulation system, noise protection and anti-vibration system, accommodation, deck covering, inert gas system, cell guide for containers, fire-proof system, deratting equipment, painting, ceiling and sparring in hold, deck machinery, etc.

(3) Weight of machinery part

Weight of machinery part is the total weight of main engine, boilers, condensers, shaftings, propellers, stacks and funnels, auxiliary machinery, electrical equipment, tanks in engine room, inventories of machinery part, air reservoirs, silencers, pipings in engine room, access and traffic system, insulations, control room equipment, air ducts, spares required by the rules, oil and water of machinery part, etc.

10.6.2. Hull Steel Weight $W_h = W_{h0} + W_s$

(1) Estimation by principal dimensions

(a) Main hull steel weight (excluding superstructures and deck houses) W_{h0}

i) $W_{h0} = C_h L (B+D)$ where, C_h = A factor shown on Fig. 194

ii) $W_{h0} = C_h' LBD/100$ where, C_h' = A factor shown on Fig. 195 (for tankers only)

iii) Hull steel weight of cargo oil tank and/or cargo hold part

$$W_t = C_h'' l_t BD/100$$

Hull steel weight of fore and aft part

$$W_e = W_t \left(\frac{a}{l_t/L} - 1 \right)$$

where, l_1 = Length of cargo oil tank and/or cargo hold part, (m)
C_h^* = A factor shown on Fig. 196
α = A factor shown on Fig. 197

accordingly, main hull steel weight becomes

$$W_{h\bullet} = W_1 + W_e$$

(b) Steel weight of superstructures and deck houses

i) Steel weight of forecastle deck (Fig. 198)
ii) Steel weight of poop deck, deck houses etc. (Fig. 199)

(2) Hull steel weight calculated from midship section plan

$$W_{h\bullet} = CW_{\text{D}}\,L$$

where, W_D = Weight per unit length amidships calculated from midship section plan
C = A factor obtained from a similar ship

The hull steel weight is estimated from the calculated hull steel weight mentioned above, by adding some corrections due to arrangement (numbers of decks, etc.), kind of machinery, classification societies, owner's requirements, etc., where necessary. And also the hull steel weight is increased by 1 - 3% of the calculated weight, considering the mill tolerance of the steel plates, when the calculation is done by summing up the weight of all the plates and members of the steel structure based on the working plan.

10.6.3. Fitting Weight

$$W_f = C_f L(B+D)$$

where, C_f = A factor shown on Fig. 200

As the fitting weight varies greatly according to the differences of the specifications, it is necessary that the weight is estimated from a similar ship or by detailed calculation of all the systems.

10.6.4. Weight of Machinery Part

$$W_m = C_m \text{SHP} \quad \text{(or BHP)}$$

where, C_m = A factor shown on Fig. 201

10.6.5. Weight of Each Item (Fittings and Deck Machinery)

(1) Deck machinery

(a) Windlass (Fig. 202)
(b) Mooring winch (Fig. 203)
(c) Cargo winch (Fig. 204)
(d) Steering gear (Fig. 205)
(e) Refrigerator (Fig. 206)
(f) Others

i) Boat winch, electric motor driven (5 - 7 PS) approx. 700 kg
ii) Accommodation ladder winch, electric motor driven (5 PS) approx. 500 kg

(2) Cargo gear

(a) Mast and derrick post (Fig. 207)
(b) Derrick boom (Fig. 208)
(c) Cargo oil piping system (Fig. 209)

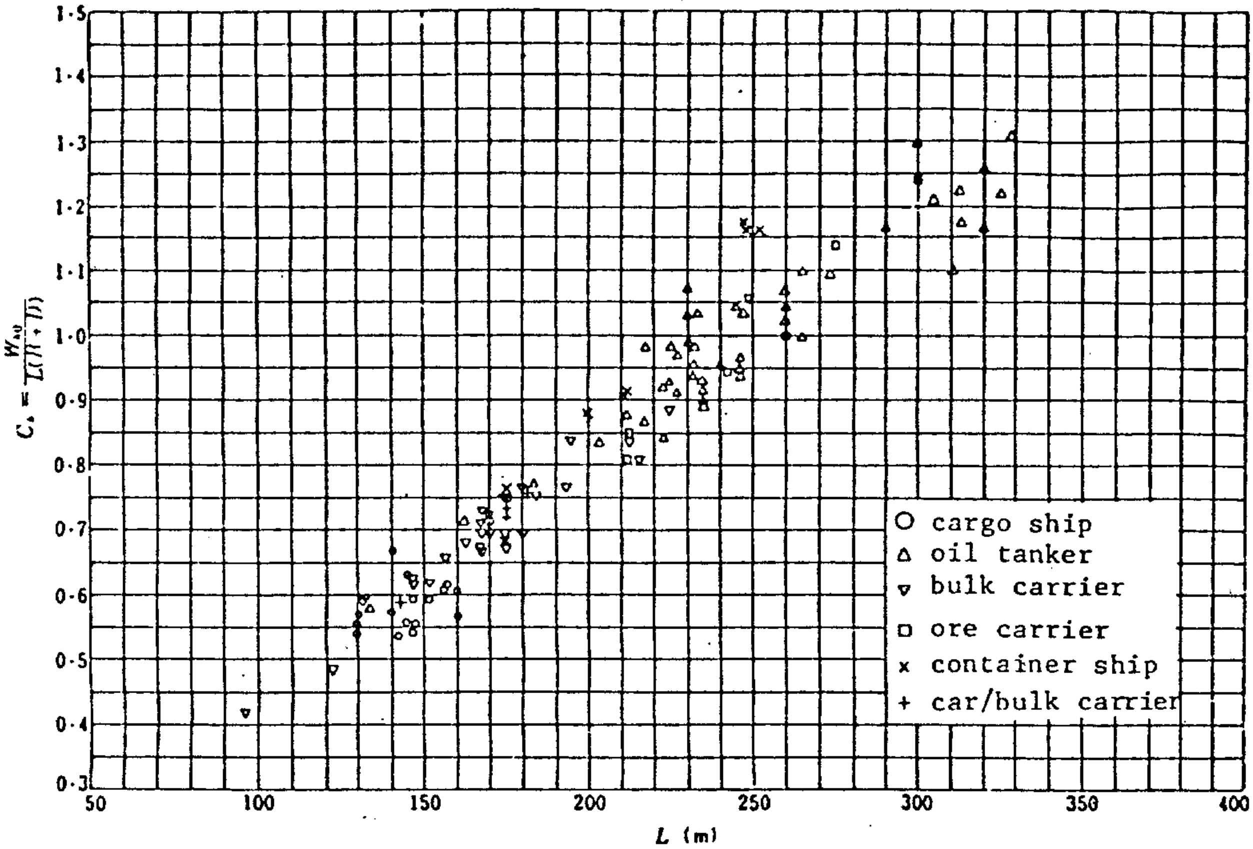


Fig. 194 Hull Steel Weight (excluding superstructures & deck houses) W_{h0}

Correction for C_b

correction amount of W_{h0} for difference of $C_b = 0.01$

$$= \frac{5 \cdot 11 L^{3 \cdot 3} B/D + 2 \cdot 56 L^2 (B+D)^2}{3(0 \cdot 80 C_b^2)^{1/2}} \times 10^{7}$$

Correction for B/D

correction amount of W_{h0} for difference of $B/D = 0.1$

$$= \left(\frac{C_b}{0 \cdot 80}\right)^{1/2} (5 \cdot 11 L^{3 \cdot 3} + 0 \cdot 01 k L^4) \times 10^{6}$$

k is shown below.

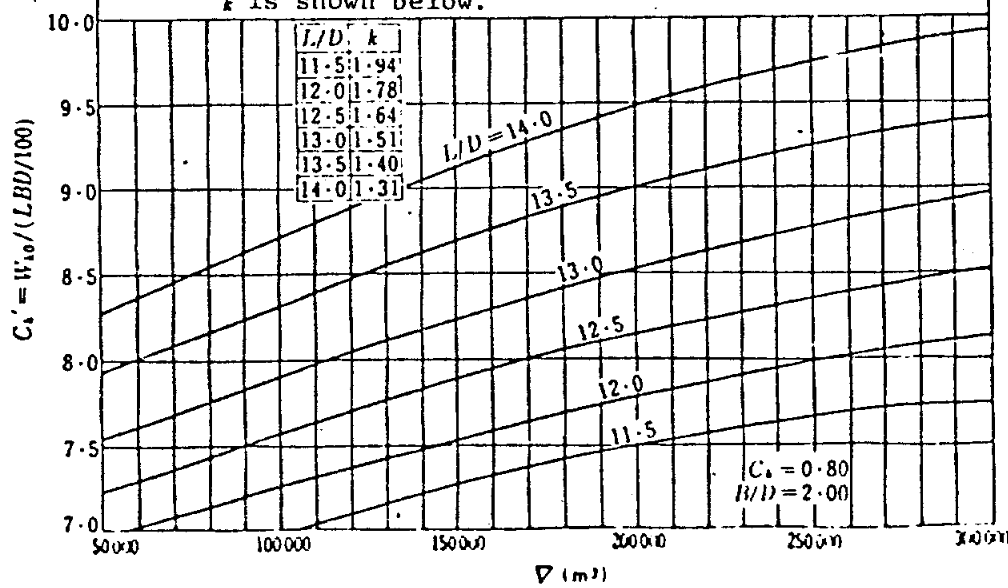
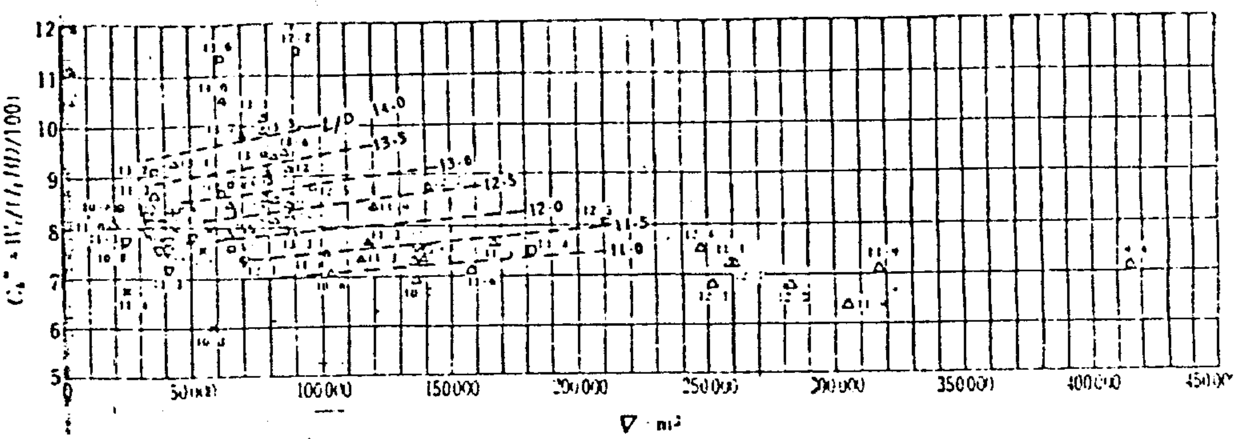


Fig. 195 Hull Steel Weight of Tankers (excluding superstructures and deck houses) W_{h0}



○ cargo ship △ oil tanker ▽ bulk carrier □ ore carrier
⊞ ore/oil carrier ✕ container ship + car/bulk carrier
l_t length of cargo oil tank/cargo hold part (m)

Numerals denote L/D .
------ shows the approximate mean line of oil tankers with $B/D = 2{\cdot}0$, $C_b = 0{\cdot}8$, and five cargo tanks, which is corrected from actual results.

Fig. 196 Hull Steel Weight of Cargo Oil/ Cargo Hold Part, W_t

$$\alpha = \frac{W_{h0}}{W_t/(l_t/L)}, \qquad W_e = W_t\left(\frac{\alpha}{l_t/L} - 1\right)$$

W_{h0} = hull steel weight (t) (excl. superstructures and deckhouses)
W_e = hull steel weight of bow and stern part (t)
W_t = weight of cargo oil tank/cargo hold part (t)
l_t = length of cargo oil tank/cargo hold part (m)
Pump room and cofferdams are not included in W_t and l_t .

△ oil tanker
▽ bulk carrier
□ ore carrier
⊞ ore/oil carrier
+ car/bulk carrier

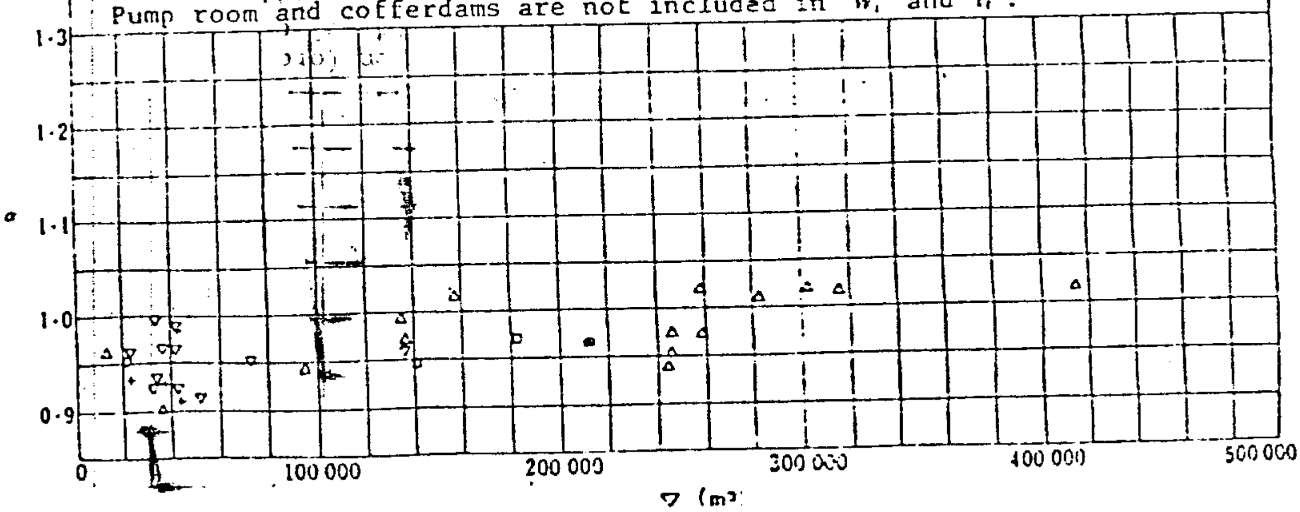


Fig. 197 Weight Estimation Factor α of Bow and Stern Part W_e

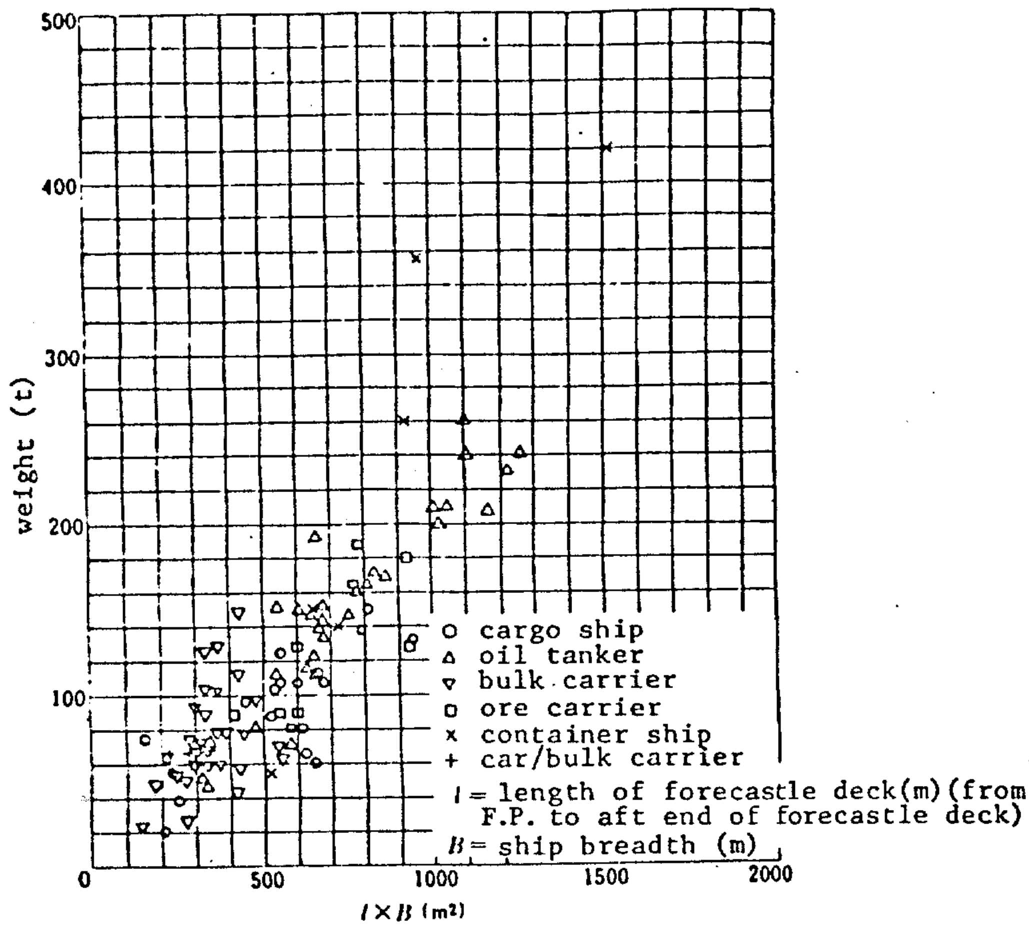


Fig. 198 Hull Steel Weight of Forecastle Deck

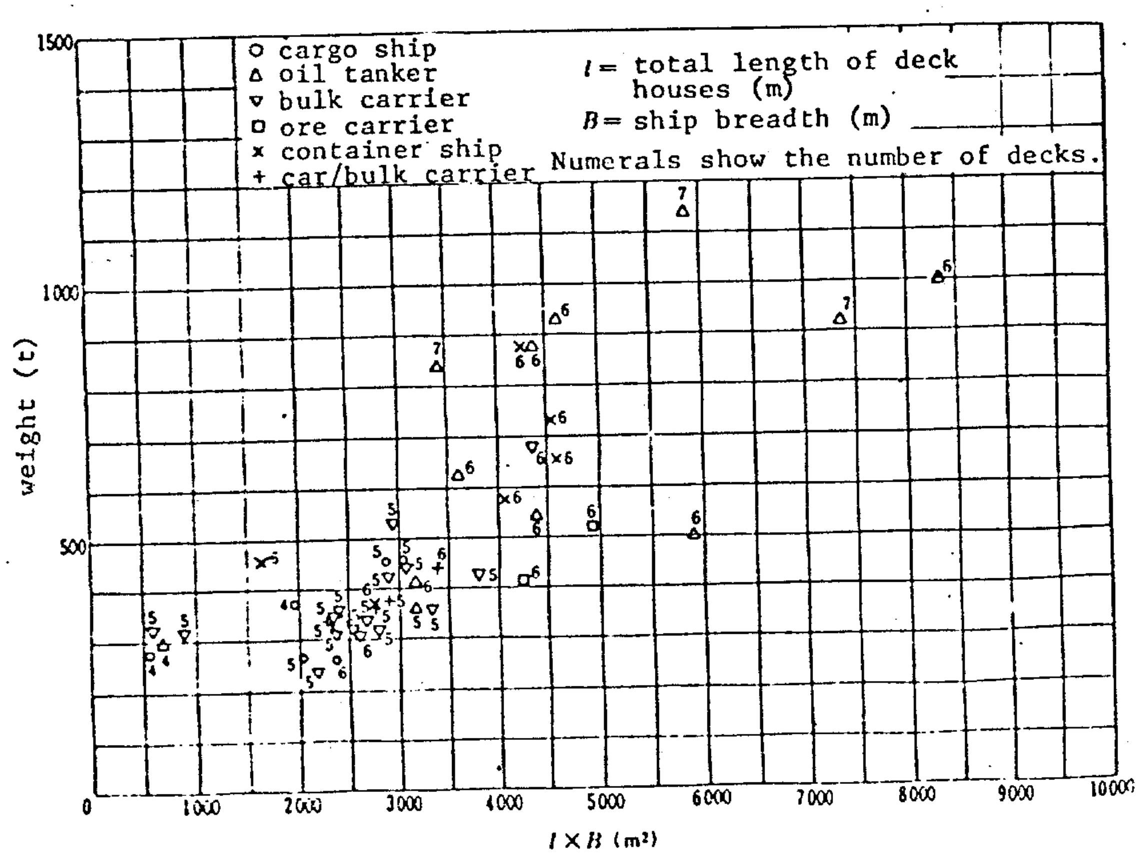


Fig. 199 Hull Steel Weight of Poop Deck and Deck House

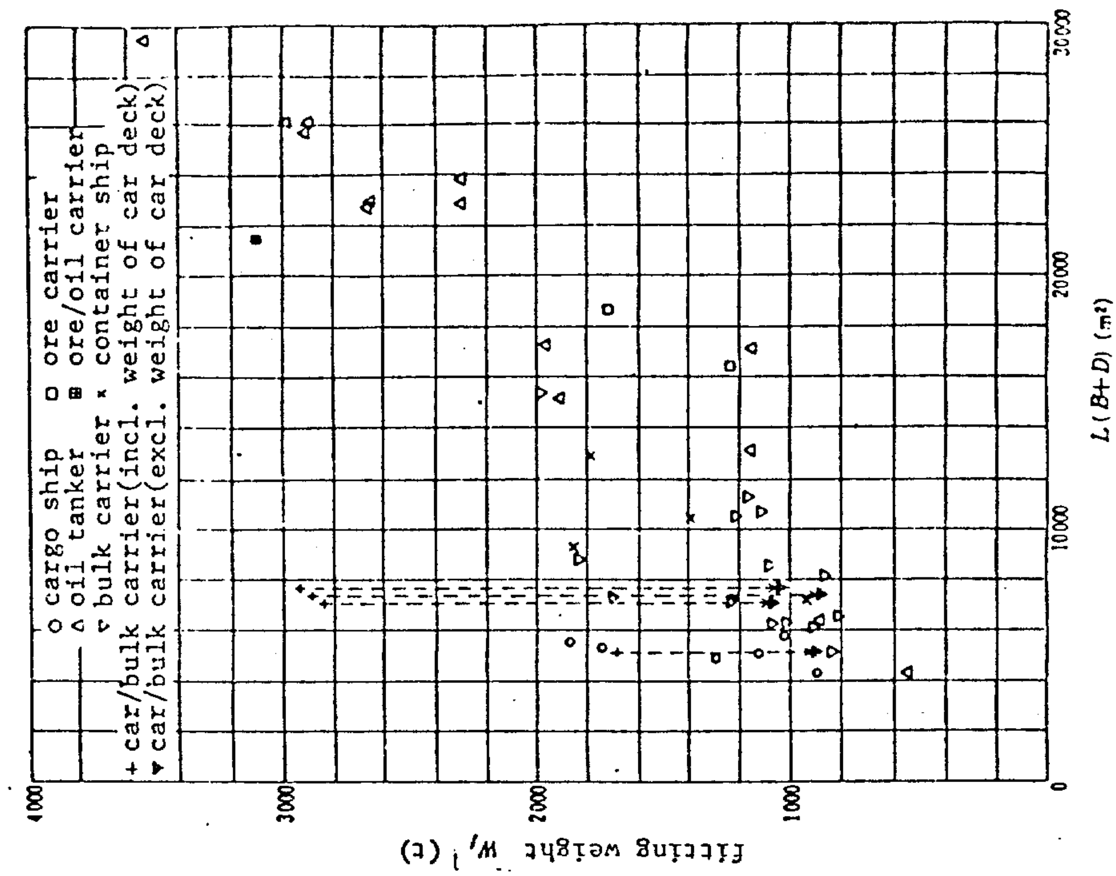
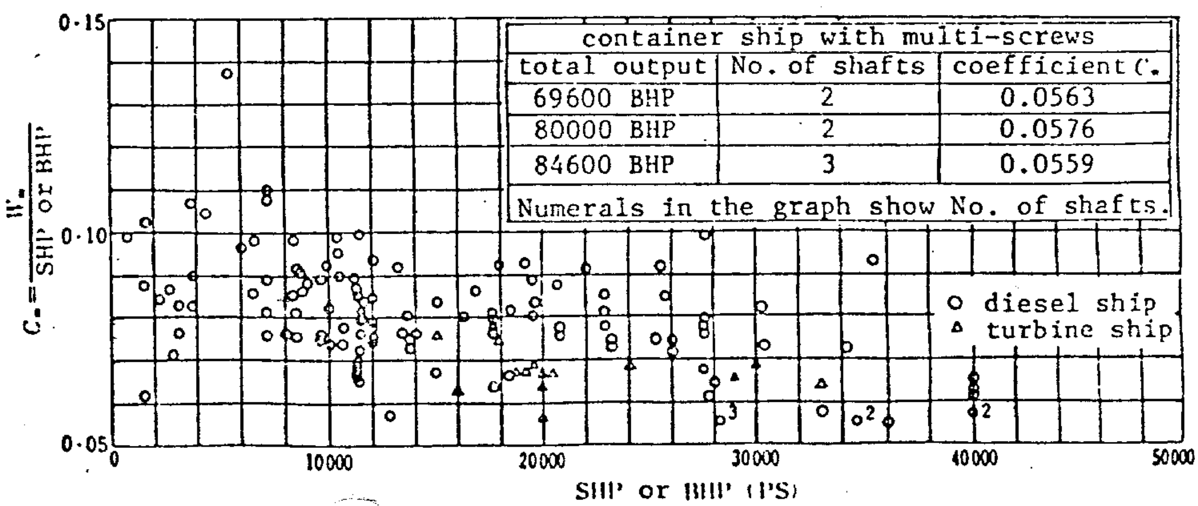
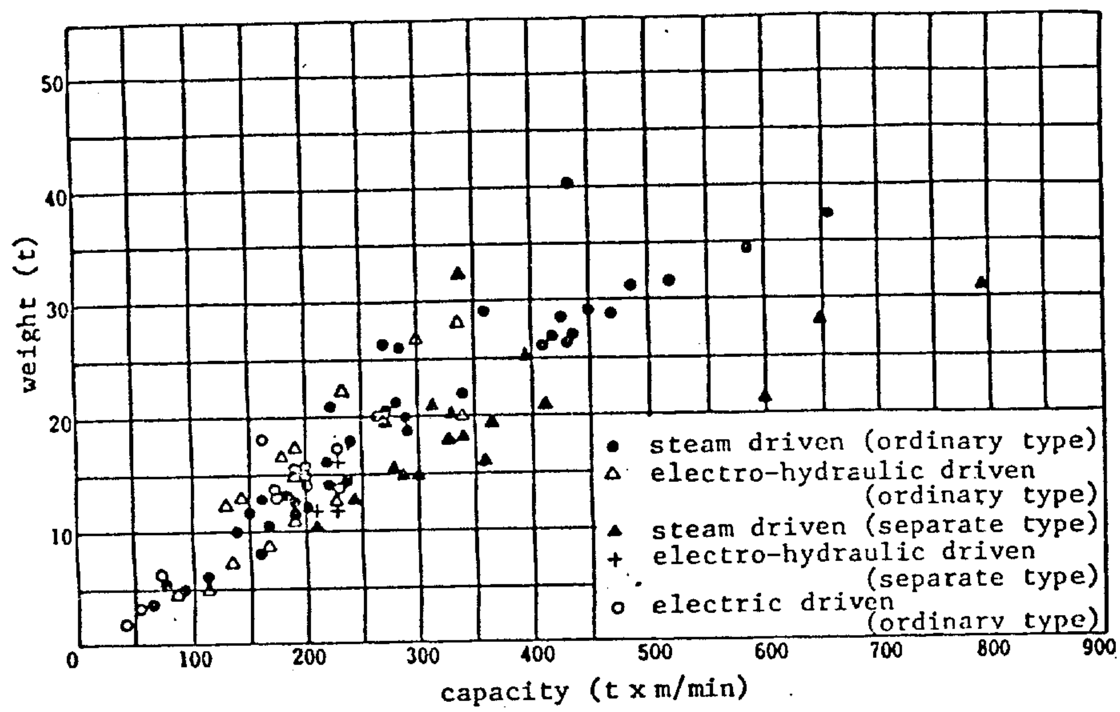


Fig. 200 Fitting Weight W_f



container ship with multi-screws		
total output	No. of shafts	coefficient C_m
69600 BHP	2	0.0563
80000 BHP	2	0.0576
84600 BHP	3	0.0559
Numerals in the graph show No. of shafts.		

Fig. 201 Weight of Machinery Part W_m



Ordinary type windlass is the one of which gypsy wheels at both sides are incorporated in one common foundation.
Separate type windlass is the one which is separated completely.
Windlass in common use with mooring winch is not included.

Fig. 202 Weight of Windlass

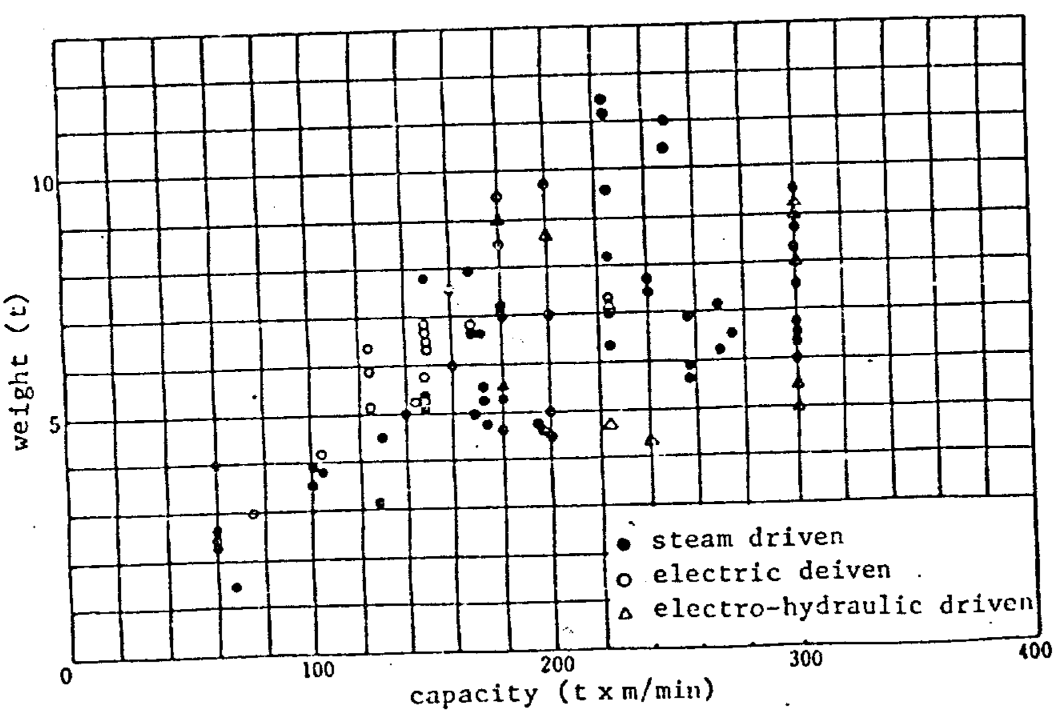


Fig. 203 Weight of Mooring Winch

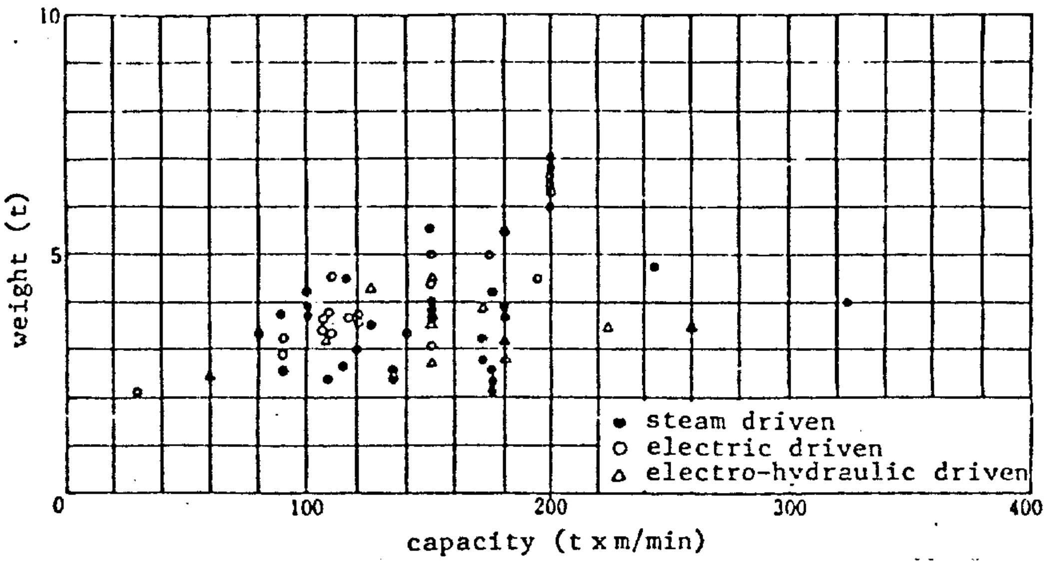
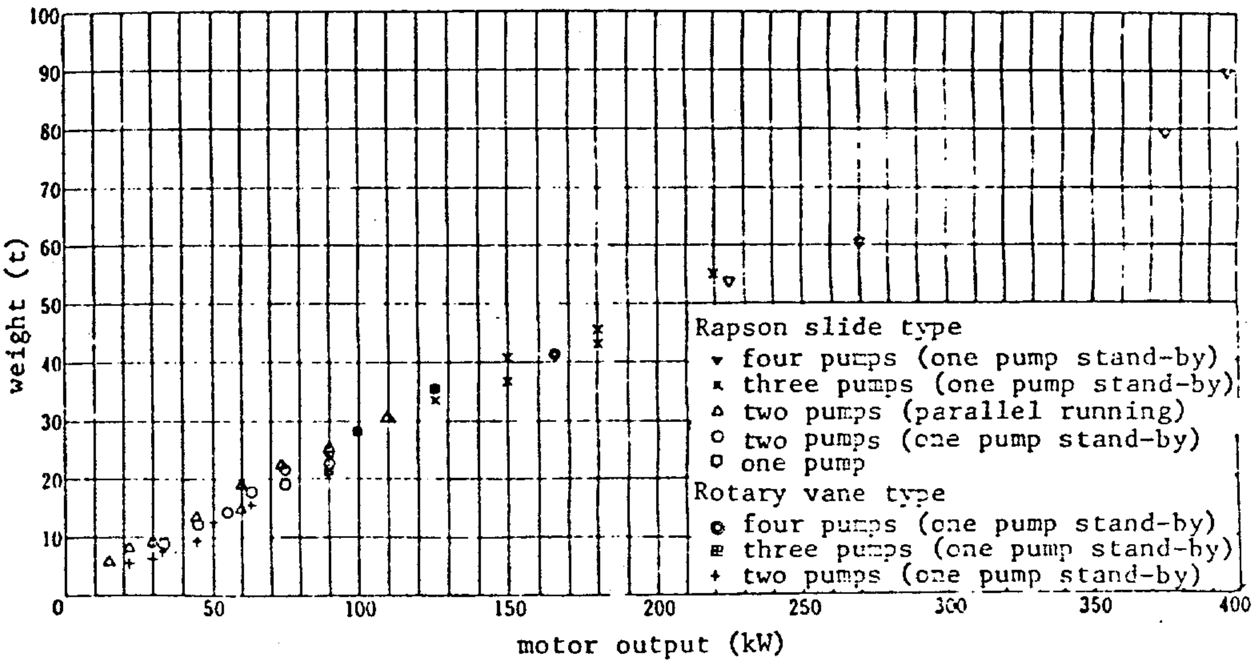


Fig. 204 Weight of Cargo Winch



Stand-by pump motor is not included in the motor output.

Fig. 205 Weight of Steering Gear (incl. electric motor)

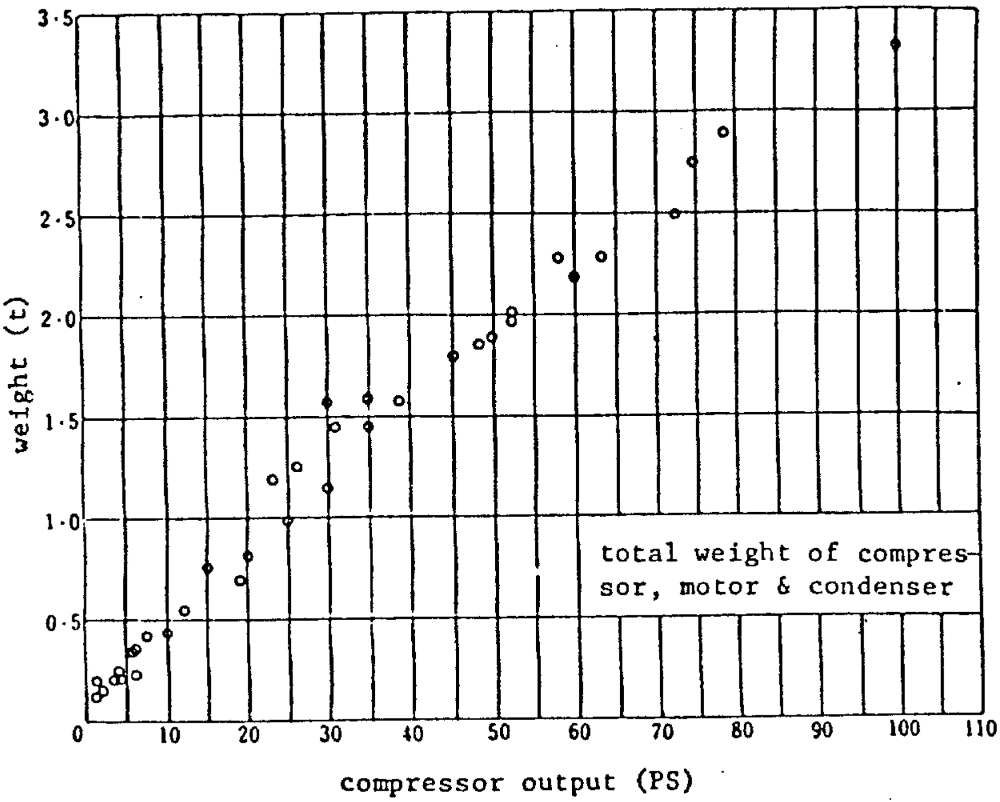


Fig. 206 Weight of Refrigerator

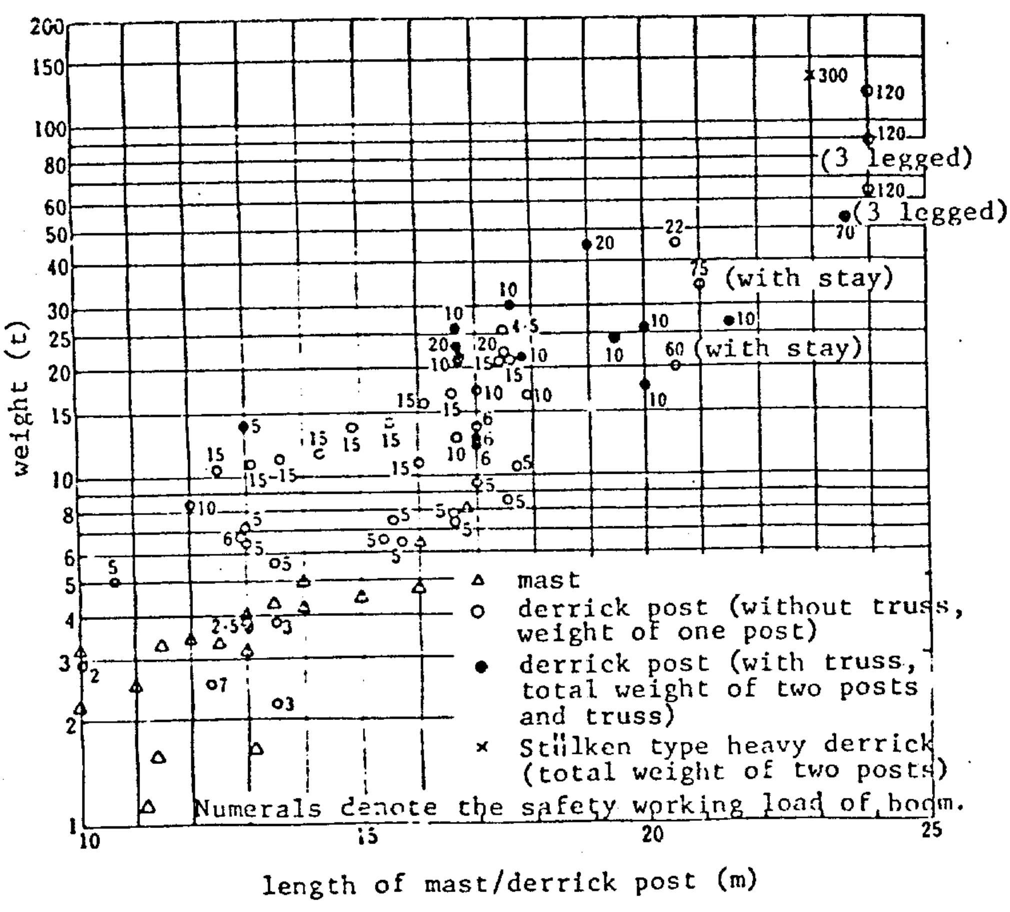


Fig. 207 Weight of Mast and Derrick Post

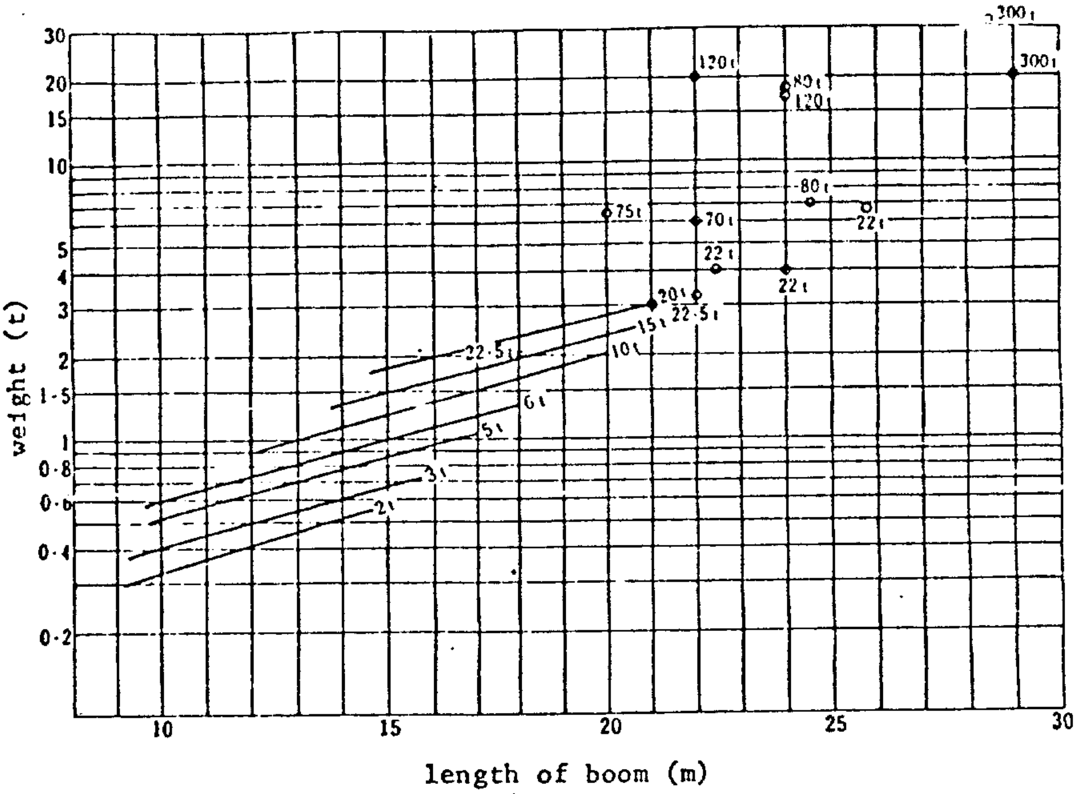
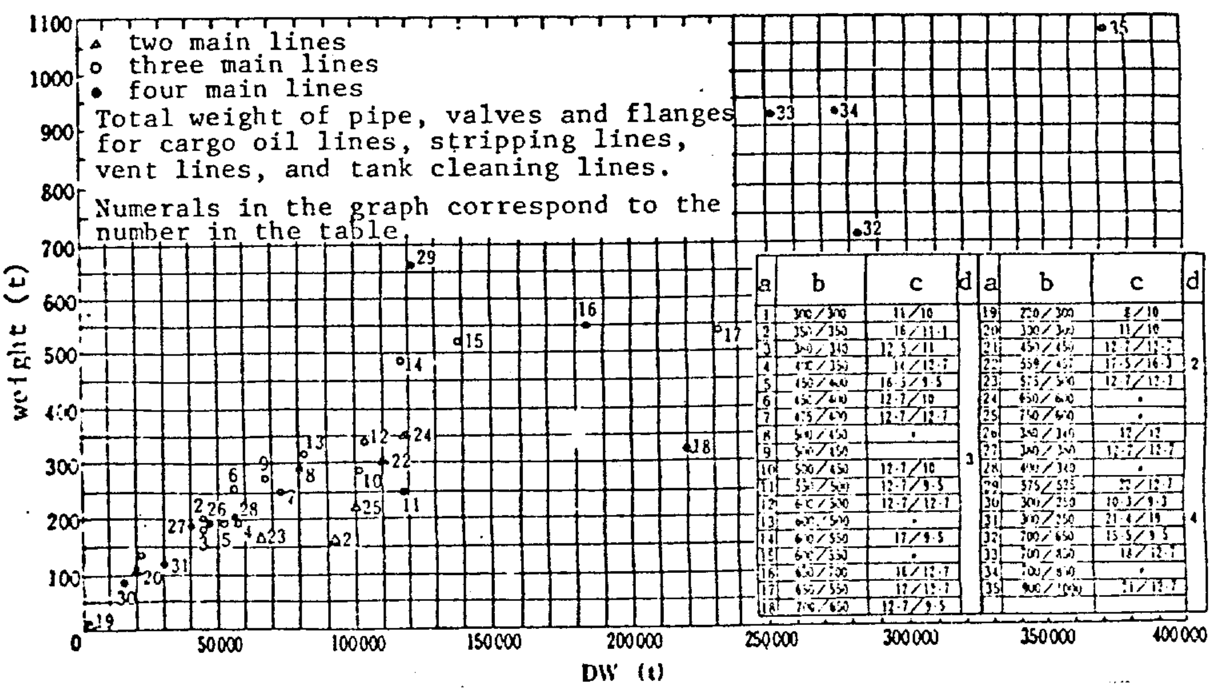


Fig. 208 Weight of Derrick Boom



a	b	c	d	a	b	c	d
1	300/300	11/10	3	19	250/300	8/10	2
2	350/350	16/11.1		20	300/300	11/10	
3	340/340	12.5/11		21	450/450	12.7/12.7	
4	400/350	14/12.7		22	550/450	17.5/16.3	
5	450/400	16.5/9.5		23	575/500	12.7/12.7	
6	450/400	12.7/10		24	650/600	•	
7	475/400	12.7/12.7		25	750/600	•	
8	500/450	•		26	340/340	12/12	4
9	500/450			27	340/340	12.7/12.7	
10	500/450	12.7/10		28	400/340	•	
11	550/500	12.7/9.5		29	575/525	22/12.7	
12	600/500	12.7/12.7		30	300/250	10.3/9.3	
13	600/500	•		31	300/250	21.4/19	
14	600/550	17/9.5		32	700/650	15.5/9.5	
15	600/550	•		33	700/850	18/12.7	
16	650/700	16/12.7		34	700/850	•	
17	650/550	17/12.7		35	900/1000	21/12.7	
18	700/650	12.7/9.5					

a: No.
b: pipe dia. of tank/deck
c: thickness of tank/deck
d: No. of main lines

Fig. 209 Weight of Cargo Oil Piping System

(3) Pumping system (Fig. 210)

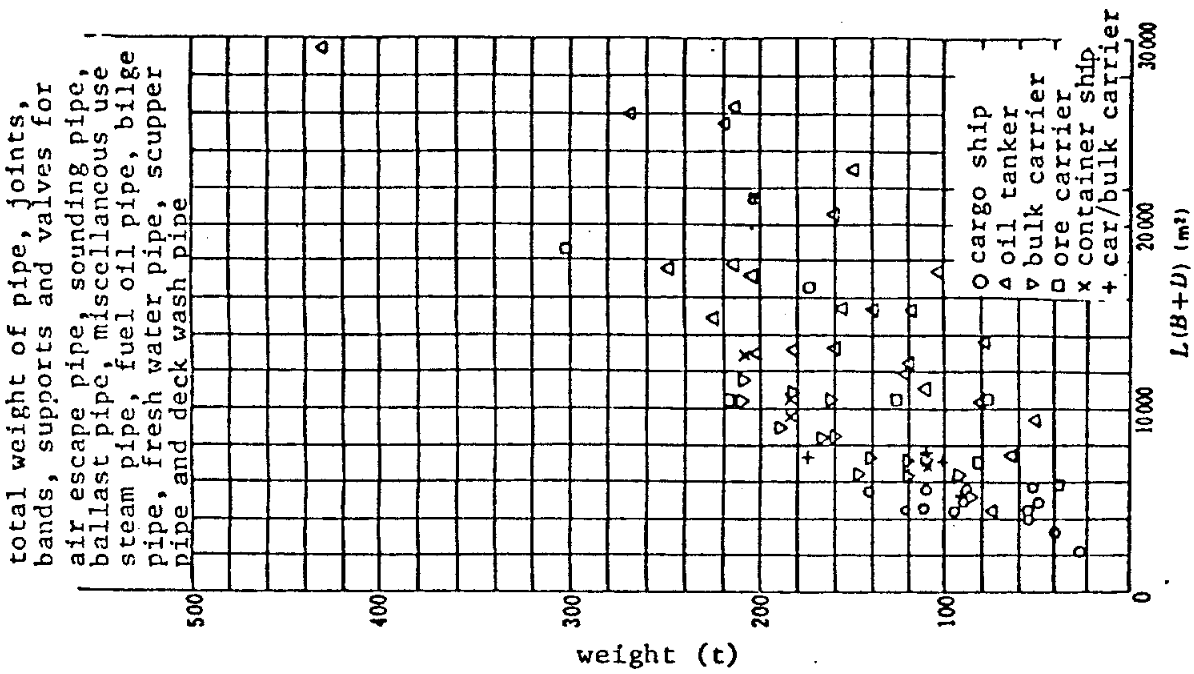


Fig. 210 Weight of Pumping System

(4) Refrigerated provision chamber (Fig. 211)

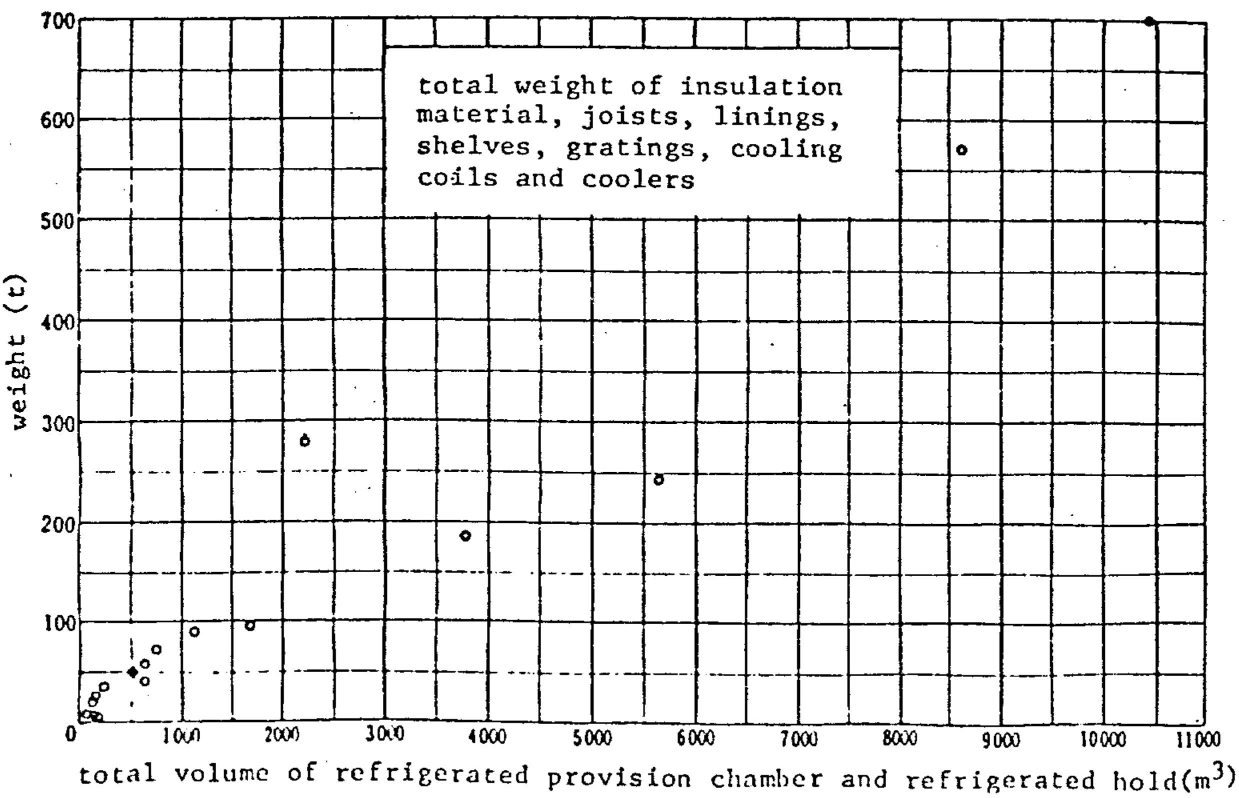


Fig. 211 Weight of Refrigerated Provision Chamber and Refrigerated Hold

(5) Accommodation (Fig. 212)

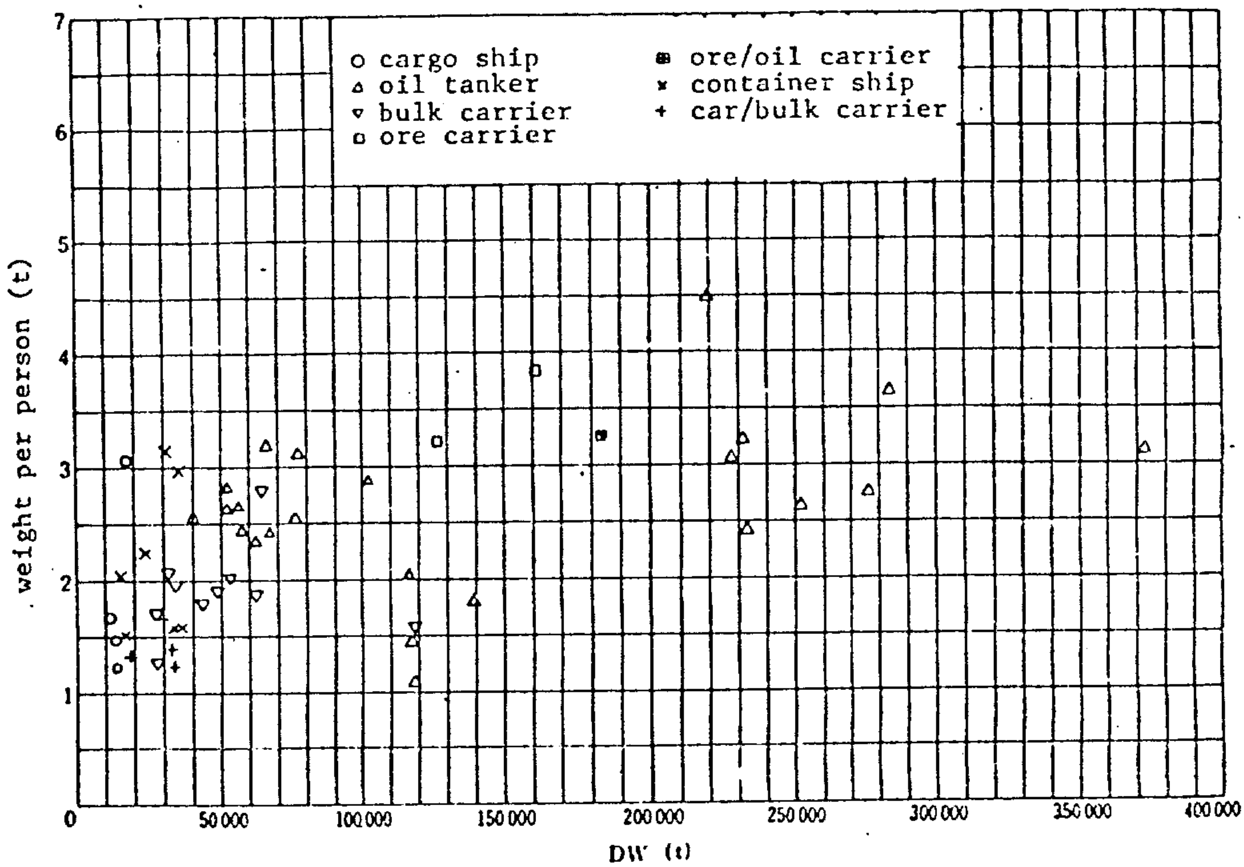


Fig. 212 Weight Concerning Accommodation (Wooden Divisional Walls, Lining, furnitures, inventories, etc. in the cabins, public rooms and offices)

(6) Hatch covers

(a) Hatch board
About 48.3 kg/m^2 for Japanese cypress with 75 mm in thickness.

(b) Hatch beam
About 72 kg/m^2 for hatch area
About 112 kg/m for total length of beams.

(c) Steel hatch cover (Refer to CHAPTER V, 5.2.4)

(7) Linings in hold

(a) Weight of ceiling (t) $\fallingdotseq$ 0·037 x length of hold (m) x B (m)

(b) Weight of sparring (t) $\fallingdotseq$ 0·023 x length of hold (m) x D (m)
(In case of sparring being horizontally lined)

(8) Deck covering (Table 94)

Table 94 Weight of Deck Covering

Items	Location	Type		Weight/mm t. kg/m^2	Thickness mm	Note
Wooden deck				0.5	50 - 65	Oregon pine
Latex type deck composition	Exposed part	Ordinary type		1.8 - 2.1	6 - 10	At the finished condition
		Heat-proof type	Sandwich type	0.8	30 - 38	
			Mixed type	1.10 - 1.52		
	Enclosed part	Ordinary type		1.4 - 2.35	7 - 9	
		Heat-proof type	Sandwich type	0.46 - 0.86	30 - 40	
			Mixed type	1.10 - 1.49		
Magnesia type deck composition	Enclosed part			0.96	12 - 22	
Cement				1.8 - 2.4	25 - 50	
Tile				1.8 - 2.3*	5	* mean weight of tile on cement with 50 mm in thickness

(9) Paint

(a) Weight of paint adhered to the hull

For the first under coat 0.305 - 0.205 kg/m^2, mean 0.25 kg/m^2 .
For the second coat and later, the weight for one coat becomes to about 2/3 of that of the first coat.

(b) Weight of paint for one ship

Required quantity (Invoice weight) for one ship is shown on Fig. 213.
The weight which is included in LW becomes 40% of required quantity taking following conditions into account.

i) Quantity spilled or attached to the cans 10%
ii) Touch-up 10%
iii) Decrease of weight by drying 50%

(10) Cement and tile (Fig. 214)

(11) Solid ballast (Table 95)

Table 95 Solid Ballast

Kind of ballast	Virtual specific gravity	Note
Concrete	2.2 - 2.4	When laid entirely in the space
Copper sediments	2.0 - 2.7	Brick size, specific gravity of 3.45
Cutting scraps of steel plate	2.5 - 5.8	
Liquid ballast	2.0	

Note) Above ballast are supposed to be loaded in the narrow space such as double bottom.

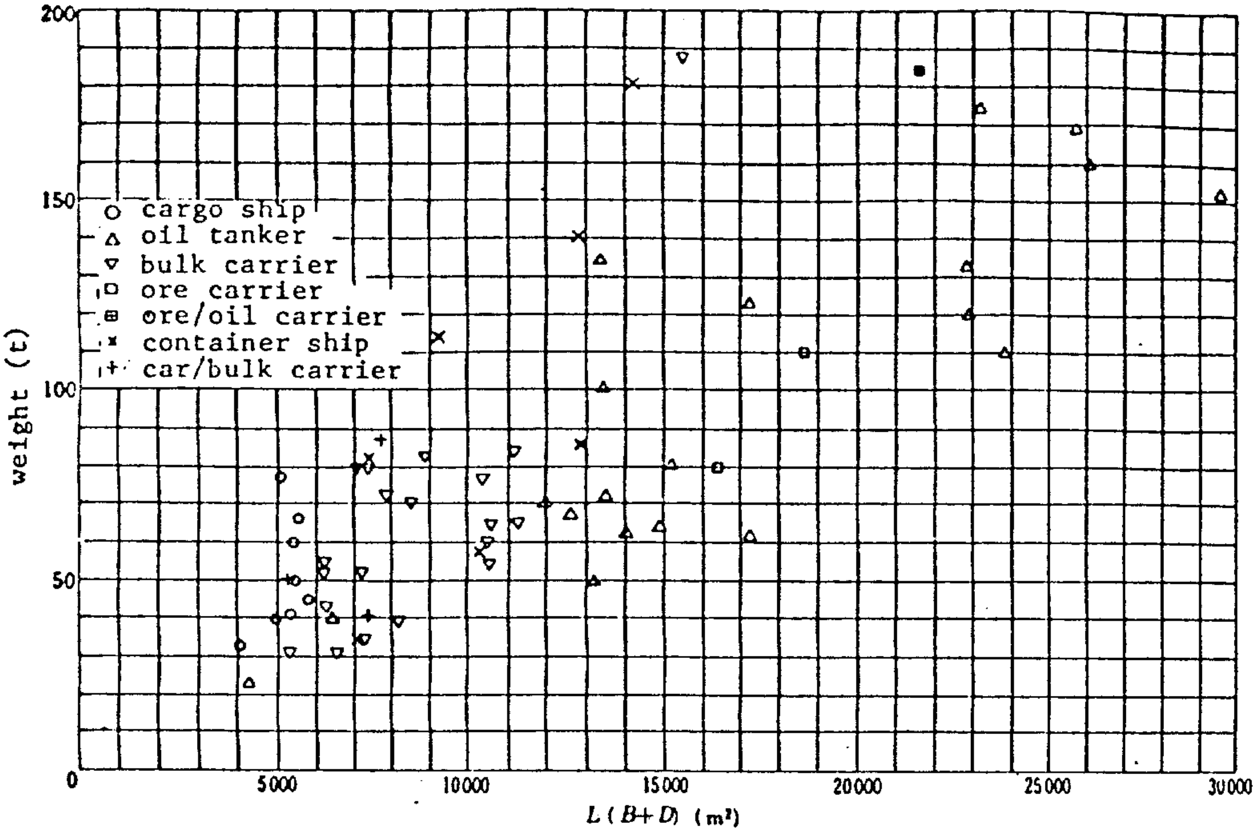


Fig. 213 Required Weight of Paint

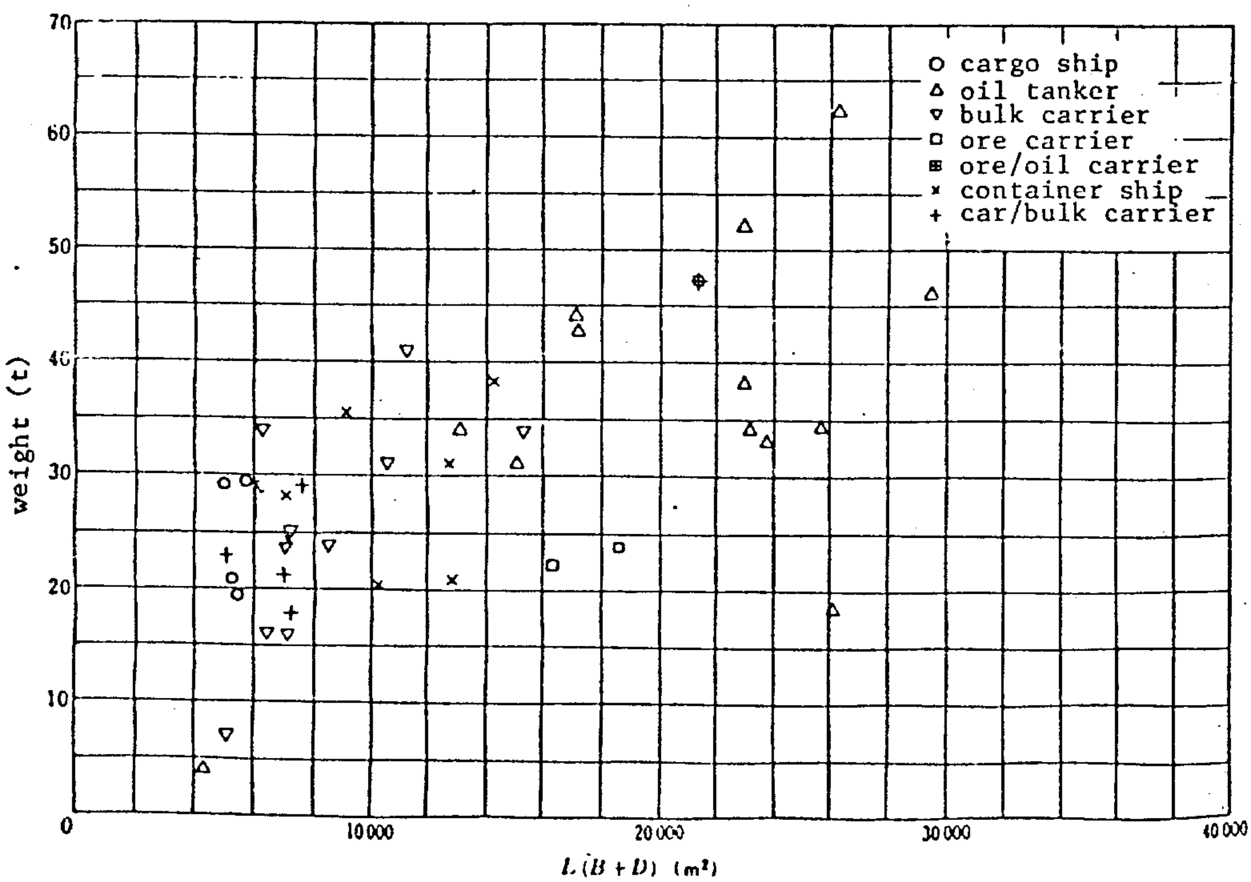


Fig. 214 Total Weight of Cement and Tile

10.7. Class of Ships, Navigation Areas, etc. according to Japanese Government Rules

(1) Class of Ship (Table 96)
(Article 1 of the Rules for Life Saving Appliances of Ships, Article 1, Clause 2 of the Enforcement Regulation of the Ship Safety Law, Article 47 of the Special Rules for Fishing Vessels)

Definition of passenger ship	Article 4, clause 1, paragraph 1 of the Ship Safety Law
Definition of fishing boat	Article 1, clause 2 of the Enforcement Regulation of the Ship Safety Law
Definition of small ships	Article 304, clause 1 of the Ship Provision Rules
Definition of tanker	Article 1, clause 7 of the Rules for Life Saving Appliances of Ships
Definition of car ferry	Annex 3, 1-1 of volume 1 of the Guideline for Ship Inspection

Table 96 Class of Ships

Vessel	Voyage, etc.			Class 1 Ship	Class 2 Ship	Class 3 Ship	Class 4 Ship	Class 5 Ship	Factory Ship	General Fishing Boat
Passenger Ship	International voyage			○						
	Non-international voyage				○					
Non-passenger Ship (excl. Fishing Boat)	International voyage	500GT and above				○				
		Less than 500GT					○			
	Non-international voyage						○			
Fishing Boat	Fishery boat	International voyage								○
		Non-international voyage								○
	Factory ship (Whale mother ship, etc)	International voyage	500GT and above						○	
			Less than 500GT							○
		Non-international voyage								○
	Fishery transport ship	International voyage	500GT and above			○				
			Less than 500GT							○
		Non-international voyage								○
	Fishery research patrol boat, etc.	International voyage	500GT and above			○				
			Less than 500GT							○
		Non-international voyage								○
	Small Boat							○		

(2) Navigation area
(Article 1, Clause 5-8 of the Enforcement Regulation of the Ship Safety Law)

Smooth water area	Lakes, rivers, ports and special area regulated by the rule
Limited coasting area	Limited area where the ship can make a round trip in two hours at her max. speed from the Inland Sea of Seto or smooth water area
Coasting area	Special area regulated by the rule (in principle, the area within 20 sea miles from the shore line)
Major coasting area	Area surrounded by 175° E. Long., 11° S. Lat., 94° E. Long. and 63° N. Lat.
Ocean going area	All water area

(3) Kind of navigation
(Article 1, Clause 1 of the Enforcement Regulation of the Ship Safety Law) (Article 1, Clause 6 of the Rules for Life Saving Appliances of Ships)

International voyage	Voyage between one country and other countries
Short international voyage	International voyage in the course of which a ship is not more than 200 miles from a port or place in which passengers and crew could be placed in safety, and which does not exceed 600 miles in length between the last port of call in the country in which the voyage begins and the final port of destination.
Long international voyage	International voyage other than short international voyage.
Non-international voyage	Voyage other than international voyage.

10.8. Definition of Ship's Length, Breadth and Depth

(1) Identification/registered length, breadth and depth

(a) Length
Length is the horizontal distance between fore end and aft end shown in Table 97. (Fig. 215)

(b) Breadth
(Table 98, Fig. 216)

(c) Depth
(Table 99, Fig. 216)

(2) Abstract of regulations of classification societeis (1974) (Table 100)

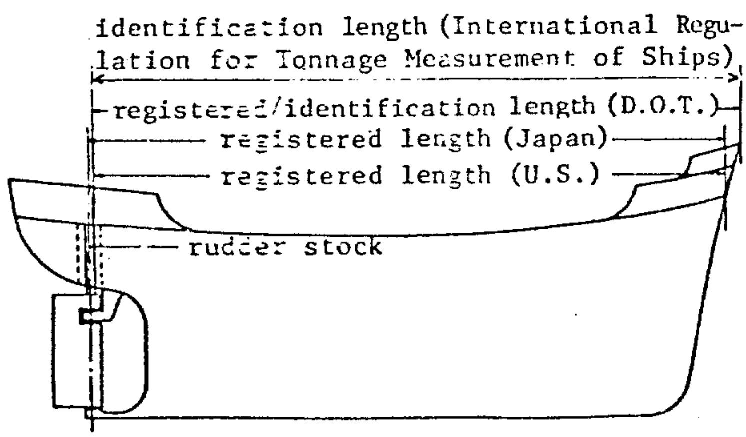


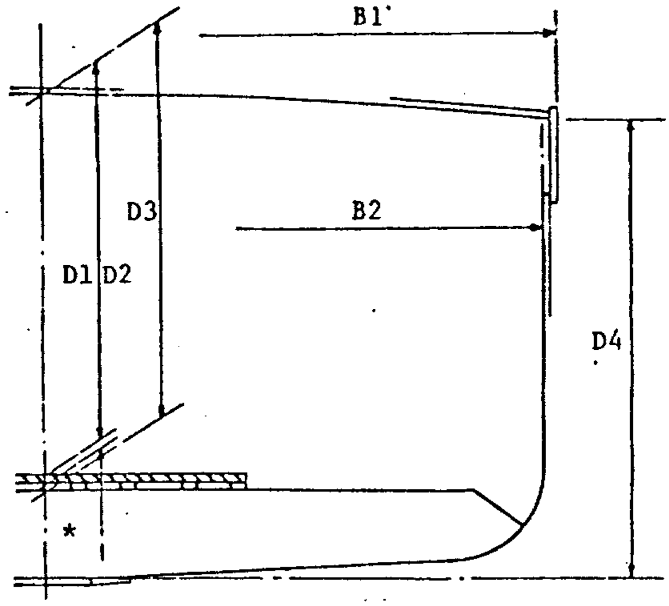
Fig. 215

Table 97 Length

Length	Fore End	After End: With Rudder Post	After End: Without Rudder Post	Application
Freeboard length (L_f)	The fore side of the stem on the waterline at 85% of the least molded depth	The axis of the rudder stock on the waterline at 85% of the least molded depth, or the after end of 96% of total length on that waterline, whichever the greater is taken		LLC 1966 Japanese Load Line Rules
Length by subdivision loadline	The fore side of stem at the deepest subdivision loadline	After end of the length at the deepest subdivision loadline		SOLAS 1960 (Chapter II, Construction) Japanese Ship Subdivision Rules
Registered length (Japan)	The fore side of the stem at the top of the upper deck beam	The after end of the rudder post or its extension through the top of upper deck beam	The center of the rudder stock or its extension through the top of upper deck beam	Ship Law Detailed Enforcement Regulation of the Ship Law Laws of Tonnage Measurement of Ships Regulations of Tonnage Measurement of Ships Ship Safety Law Enforcement Regulation of the Ship Safety Law Ship Provision Rules Rules for Life Saving Appliance of Ships
Identification/registered length (D.O.T.)	The upper most fore end of the stem	The after side of the top of the rudder post	The fore side of the rudder stock	SOLAS 1960 (Excluding Chapter II, Construction)
Registered length (U.S.)	The fore end of lap of outer plating on tonnage deck	The after side of the rudder post or its extension through tonnage deck	The fore side of the rudder stock or its extension through tonnage deck	
Identification length (International Regulation for Tonnage Measurement of Ships)	The upper most fore end of the stem	The after side of the top of the rudder post	The fore side of the rudder stock or its extension through the upper most deck	
Length by International Convention on Tonnage Measurement of Ships, 1969	The fore side of the stem on the waterline at 85% of the least molded depth	The axis of the rudder stock on the waterline at 85% of the least molded depth or the after end of 96% of total length on that waterline, whichever the greater is taken.		

Table 98 Breadth

Breadth	Definition	Application
Freeboard breadth	Maximum horizontal distance measured from outside of frame to outside of frame at the midst of *L*,	LLC 1966 Japanese Load Line Rules
Breadth by subdivision loadline	The extreme width from outside of frame to outside of frame at or below the deepest subdivision loadline	SOLAS 1960 (Chapter II, Construction) Japanese Ship Subdivision Rules
Registered breadth (Japan)	The horizontal distance from outside of frame to outside of frame at the widest part of the hull	Ship Law Detailed Enforcement Regulation of the Ship Law Law of Tonnage Measurement of Ships Regulation of Tonnage Measurement of Ships Ship Safety Law Enforcement Regulation of the Ship Safety Law Ship Provision Rules Rules for Life Saving Appliance of Ships
Registered or identification breadth (D.O.T., U.S., International Regulation for Tonnage Measurement of Ships)	The extreme horizontal distance from the outboard face of the outer skin on one side to the same point opposite, taken at or below the upper deck. (Lap of outer plating is included, but the thickness of the fender is not included.)	
Breadth by International Convention on Tonnage Measurement of Ships, 1969	Maximum molded breadth at the midst of the length	



B1: Registered/identification breadth (U.S., D.O.T., International Regulation for Tonnage Measurement of Ships)

B2: Registered breadth (Japan)

D1: Registered depth (U.S.) (at the midst of tonnage deck)

D2: Registered depth (D.O.T.) (at the midst of registered length)

D3: Identification depth (International Regulation for Tonnage Measurement of Ships) (at the midst of identification length)

D4: Registered depth (Japan) (at the midst of registered length)

* As for the registered depth (U.S., D.O.T.), thickness of bottom ceiling shall be disregarded. (Joists of bottom ceiling is included in the depth.)

Fig. 216

Table 99 Depth

Kind of Depth	Measurement Point along the Ship Length	Lowest Point	Uppermost Point	Note
Freeboard depth	Middle of the freeboard length	Top of keel	Top of freeboard deck beam plus the thickness of the stringer plate at ship side	
Registered depth (Japan)	Middle of the registered length	Top of keel	Top of upper deck beam at ship side	
Registered Identification depth (D.O.T.)	Middle of the registered length	Top of inner bottom plate or the floor at the centerline of the ship	Under side of the tonnage deck or the line of its extension at the centerline of the ship	In case the bottom ceiling is fitted, the depth becomes as shown on Fig. 216
Registered depth (U.S.)	Middle of the length of the tonnage deck	Top of inner bottom plate or the floor at the centerline of the ship	Under side of the tonnage deck or the line of its extension at the outer line of the ship	In case the bottom ceiling is fitted the depth becomes as shown on Fig. 216
Registered height (U.S.)	Middle of the length of the tonnage deck	Top of tonnage deck at the center-line of the ship (Top of wooden plank for the wooden deck)	Under side of the uppermost complete deck at the centerline of the ship	Registered height as well as registered depth shall be described for the ship with 3 decks and more.
Identification depth (International Regulation for Tonnage Measurement of Ships)	Middle of the identification length	Top of the inner bottom plate or the floor at the centerline of the ship	Under side of the upper deck at the center-line of the ship	
Depth by the International Convention on Tonnage Measurement of Ships, 1969	Middle of the length	Top of keel	Under side of the upper deck at ship side	

Table 100 Definition of L, B, D and C_b

Classification Society	LR	AB	NV
L	L_{pp}. For the ship with cruiser stern, L should be L_{pp} or 96% of L_{wl}, whichever is the greater. Length used for longitudinal strength (L_1) should be L mentioned above or 97% of L_{wl}, whichever is the less.	L should not be less than 96% of L_{wl} but need not be greater than 97% of L_{wl}	L_{pp} or 96% of L_{wl}, whichever is the greater. Length used for longitudinal strength (L_1) should be L above-mentioned, but need not be over 97% of L_{wl}
B	Horizontal distance from the outside of the frame to the outside of the frame at the widest part of the hull.	Maximum molded breadth	
D	Vertical distance at ship side from the top of keel to the top of freeboard deck beam. In cases where watertight bulkheads extend to a deck above the freeboard deck and are registered as effective ones, D should be measured to that bulkhead deck. The depth for strength of the ship should be the vertical distance up to the superstructure deck when it is regarded as strength deck, otherwise up to the freeboard deck.	Vertical distance at ship side from the molded base line to the top of the freeboard deck beam. In cases where water-tight bulkheads extend to a deck above the freeboard deck and are registered as effective ones D should be measured to that bulkhead deck. The depth (D_1) used for the strength of the ship should be the vertical distance from the top of the keel to the strength deck.	Vertical distance at ship side from the top of the keel to the under edge of the stringer plate of the uppermost continuous deck at the middle of L
C_b	$\frac{\nabla}{LBd}$ For cargo ship; d should be fully loaded draft or 0.045 L whichever is the greater. C_b should not be taken less than 0.60. For tanker; d should be fully loaded draught. C_b should be $(C_b+0.75)/2$ when actual C_b is less than 0.75.	$\frac{\nabla}{L_{wl}Bd}$ C_b should not be taken less than 0.62	$\frac{\Delta_1}{1.025\,LBd}$ C_b should not be taken less than 0.50.

Note) 1. L_{pp} = Distance from the fore side of the stem to the after side of the rudder post or the center of the rudder stock at the summer load waterline. LR regards the rudder horn of the open type ship like mariner type stern as rudder post.
L_{wl} = Waterline length of the ship at the summer load waterline.
∇ = Molded displacement volume at the summer load waterline.
Δ_1 = Molded displacement in sea water (specific gravity = 1.025) at the summer load waterline (t).

2. Definitions of length, breadth and depth by the Japanese Regulation of Hull Structure of Steel Ships follow those of NK, except the length for longitudinal strength and the depth for strength, and also freeboard deck beam in "D" (Depth) should read upper deck beam.

Table 100 Definition of L, B, D and C_b

Classification Society	NK	LR	AB	NV
L	L_{pp} For the ship with cruiser stern, L should be L_{pp} or 96% of L_{wl} whichever is the greater. Length used for longitudinal strength (L_1) should be L mentioned above or 97% of L_{wl}, whichever is the less.	L_{pp} L should not be less than 96% of L_{wl} but need not be greater than 97% of L_{wl}		L_{pp} or 96% of L_{wl}, whichever is the greater. Length used for longitudinal strength (L_1) should be L above-mentioned, but need not be over 97% of L_{wl}
B	Horizontal distance from the outside of the frame to the outside of the frame at the widest part of the hull.	Maximum molded breadth		
D	Vertical distance at ship side from the top of keel to the top of freeboard deck beam. In cases where watertight bulkheads extend to a deck above the freeboard deck and are registered as effective ones, D should be measured to that bulkhead deck. The depth (D_s) used for strength of the ship should be the vertical distance up to the superstructure deck when it is regarded as strength deck, otherwise up to the freeboard deck.	Vertical distance at ship side from the top of the keel to the top of the uppermost complete deck.	Vertical distance at ship side from the molded base line to the top of the freeboard deck beam. In cases where watertight bulkheads extend to a deck above the freeboard deck and are registered as effective ones, D should be measured to that bulkhead deck. The depth (D_s) used for the strength of the ship should be the vertical distance from the top of the keel to the strength deck.	Vertical distance at ship side from the top of the keel to the under side of stringer place of the uppermost continuous deck at the middle of L
C_b	$\frac{\nabla}{LBd}$	$\frac{\nabla}{LBd}$ For cargo ship; d should be fully loaded draft or $0{\cdot}045\,L$ whichever is the greater. C_b should not be taken less than 0.60. For tanker; d should be fully loaded draught. C_b should be $(C_b+0{\cdot}75)/2$ when actual C_b is less than 0.75.	$\frac{\nabla}{L_{wl}Bd}$ C_b Should not be taken less than 0.62.	$\frac{\Delta_1}{1{\cdot}025\,LBd}$ C_b should not be taken less than 0.50.

Note) 1. L_{pp} = Distance from the fore side of the stem to the after side of the rudder post or the center of the rudder stock at the summer load waterline. LR regards the rudder horn of the open type ship like mariner type stern as rudder post.

L_{wl} = Waterline length of the ship at the summer load waterline.

∇ = Molded displacement volume at the summer load waterline.

Δ_1 = Molded displacement in sea water (specific gravity = 1.025) at the summer load waterline (t).

2. Definitions of length, breadth and depth by the Japanese Regulation of Hull Structure of Steel Ships follow those of NK, except the length for longitudinal strength and the depth for strength, and also freeboard deck beam in "D" (Depth) should read upper deck beam.

10.9. Restrictions by Length and Gross Tonnage

(1) Restrictions by length (Japanese ships) (Table 101)

Table 101 Restrictions by Length (Japanese Ships)

Rule (Article)	Item	L	Length range (50 / 100 / 150)	Note
Detailed Enforcement Regulation of the Ship Law (44)	Items to be denoted on ship	L_s	20 (Name or usage of rooms which are deducted from gross tonnage to be denoted where they can be seen easily.)	
Regulations of Tonnage Measurement of Ships (1)	Application of the rule	L_s	20 (Regulations of Tonnage Measurement of Ships) (Simplified Regulations of Tonnage Measurement of Ships)	Simplified Regulations of Tonnage Measurement of Ships (1)
Ship Safety Law (3)	Loadline mark	L_s	24 Ships for coasting and wider service Ships for greater coasting and wider service	
Ship Safety Law (6)	Supervision and inspection	L_s	30 (Supervision during construction) (Voluntary inspection acceptable)	
Ship Stability Rules (1)	Application of the rule	L_s	24 Non-passenger ships for coasting and wider service	
Ship Provision Rules (134)	Power-driven steering gear	L_s	60 (Installation of power-driven steering gear)	Refer to Chapter V, 1.
Ship Provision Rules (137/2)	Location of steering gear	L_s	65 (Arrangement of steering gear (located aft) in enclosed space	
Ship Provision Rules (Tab.9)	Ship light and red light	L_s	19.8 (Provision of 1st class mast and side light) (Red light not required, one additional for tug)	Refer to Chapter V, 8.
Ship Provision Rules (143)	Gong	L_{oa}	106.75 (Provision of one gong)	
Rules for Life Saving Appliances of Ships (70)	No. of life buoy for class 4 ships	L_s	(2) 30 (4)	Refer to Chapter V, 7.
Rules for Life Saving Appliances of Ships (74)	No. of self-igniting lights and self-activating smoke signal for class 4 ships	L_s	30 (Two self-igniting lights and one self-activating smoke signal) (One self-igniting light)	
Rules for Life Saving Appliances of Ships (82)	Electric alarms for class 3 ships	L_s	47.5 (Electric alarm system in addition to emergency alarm system)	
Ship Subdivision Rules (65)	Arrangement for double bottom	L_{wl}	50 61 76 (Installation of complete double bottom) (Fore hold space) (Fore and aft hold spaces)	
NK Rules Part C 6.1.1	"	L_{pp}	100 (Installation of complete double bottom)	
Law for Preventing Collisions at Sea (2)	No. of mast lights	L_{oa}	(1) 45.75 (2)	Table 9 of Ship Provision Rules
Law for Preventing Collisions at Sea (11)	No. of anchor lights	L_{oa}	(1) 45.75 (2)	

Rule (Article)		Item	L	50 100 150	Note
LLC 1966	(5)	Application of the convention	L_f	24 ———	Refer to Chapter III, 2.
	(15)(16)	Load on hatch cover	L_f	24 (Gradually reduced) 100 (Constant)	
	(27)	Requirements on flooding calculation	L_f	For type "A" ship: (One compartment flooding other than the machinery space) 150 — 225; (Flooding into machinery space to be calculated as well) 225 — For type "B" ship with assigned freeboard less than that in Table B.: 100 — 225	
	(27)(28)	Range of freeboard table	L_f	24 (Correction table for wooden hatch) 200 24 (Table A and Table B 365	
	(29)	Correction for length	L_f	24 — 100	
	(40)	Winter north atlantic freeboard	L_f	24 — 100	

Note) L_f = Freeboard length L_R = Registered length
L_{WL} = Length on waterline L_{OA} = Overall length

——┤ Less than   ——┤ Not more than   ├—— Not less than   ├—— More than

(2) Restrictions by gross tonnage (Japanese ships) (Table 102)

Table 102 Restrictions by Gross Tonnage (Japanese Ships)

Rules (Article)	Item	5 10 20 50 100 150 200 300 500 1000 2000 3000 4000 5000	Note
Ship Law (5) (20) Government Ordinance for Registry and Tonnage Measurement of Small Ships (1)	Registration	5 … 20 (The Certificate of Nationality of the Ship to be issued by the Administrative office which governs the port of the ship after being registered on the Ship Register (book)) (Certificate of Nationality of the Small Ship to be issued by the governor of the port of the ship)	Fishing boats defined by the Fishing Boat Law (2-1) are excluded.
Ship Safety Law (3)	Marking of load water line	20 Fishing boat Passenger ship of coasting and wider service (Except those of coasting service not engaged in international voyage and under 100 GT) 300 Ships of coasting and wider service	
(4)	Radio telegraph	300 " 1600 (Wireless telephone acceptable) (Wireless telephone is acceptable for the ships of coasting service and not engaged in the internat'onal voyage) 100 Fishing boat	Exceptions are found in the Special Regulations for Fishing Vessels
Ship Stability Rules (1)	Application of the rule	5 Hovercraft & passenger ship 500 Non-passenger ship of coasting and wider service Small passenger ship 20 Fishing boat	
Ship Provision Rules (105) (115-3)	Accommodation ladder	Passenger ships (Omission is admitted for ships of coasting and smooth water service) 300 Non-passenger ship (Board or canvas at the back not required)	May be omitted only when admitted by the Administration.
(122-6)	Emergency lighting system	Passenger ship engaged in international voyage 500 Non-passenger ship engaged in international voyage	
(146)	Radio direction finder	Ships engaged in 1600 international voyage	Refer to Chapter V, 8.
(146-2)	Pilot ladder and ship side lighting system	(Omission is admitted for ships of coasting service) 5000 Ships engaged in international voyage 1000 All ships	Ditto
(169-4)	Application of the rule of cargo gear	300 All ships (Except the cargo gear of which rated capacity is less than 1 ton)	
(214)	Application of dead-front type electric distribution panel	Passenger ship engaged in international voyage 500 All ships (except fishing boat) engaged in international voyage	
(304)	Application of the rule on provisions for small ships	5 Towed passenger ship Small passenger ship	Class 5 ships in the Rules for Life Saving Appliances of Ships
		5 10 20 50 100 150 200 300 500 1000 2000 3000 4000 5000	

Rules (Article)		Item	5 10 20 50 100 150 200 300 500 1000 2000 3000 4000 5000	Note
Rules for Life Saving Appliances of Ships	(62)(63)	Life saving appliances for tankers	(Life boats to accommodate all complement shall be carried on each side of the ship.) — 1600 Tanker in class 3 ships	Refer to Chapter V, 7.
	(64)(83)		(At least one motor life boat with minimum speed of 6 knots shall be carried.) (Boat davit shall be of gravity type.)	
	(64)		(At least one motor life boat shall be carried.) — 1600 Class 3 ships other than tankers	
	(63)		(Not less than four life boats shall be carried. Two shall be carried aft and two amidships.) — 3000 Tankers in class 3 ships	Two life boats may be permitted provided that there is no amidships superstructure and no room to carry four life boats aft.
Rules for Fire Fighting Appliances of Ships	(36)	No. of fire pump	Class 1 ship and class 2 ship of greater coasting and wider service (2) 4000 (3) Class 2 ship of coasting and smooth water service 100 (1) 1000 (2) 4000 (3) (Omission is permitted)	Refer to Chapter V, 15. Omission is permitted provided that red fire buckets are arranged at suitable places.
	(53)	"	Class 3 ships (1) 1000 Class 3 ships and class 4 ships of greater coasting and wider service (2) Class 4 300 ships (1) 1000 Class 4 ships of coasting & smooth water service (1)	
	(43)	Fire fighting system for cargo area	(Fixed fire smothering gas system) 1000 Class 1 & 2 ships of greater coasting and wider service (Adequate fire extinguishing system) Class 1 ships and class 2 ships of coasting and wider service 1000 Class 1 ship of coasting service	
	(57)	"	(Fixed fire smothering gas system or fixed type steam system) 2000 Class 3 & 4 ships (Above system may be replaced by fixed foam fire extinguishing system or the system releasing foam on the outside of the tanks.) 2000 Tankers in class 3 & 4 ships	Ships with steel hatch covers, bulk carriers, lumber carriers, etc. are excluded.
	(45) (60)	Fire fighting system in engine room	(Installation of fixed fire fighting system (gas, foam or pressurized water)) Class 1 & 2 ships 1000 Class 3 & 4 ships	To be fitted where main engine or auxiliary engines with not less than 1000 BHP in total are installed.
	(61)	Pump room in tanker	(Ditto) 2000 Tankers in class 3 & 4 ships	
	(42)	Installation of international shore connection	1000 Class 1 ship	
Mariner's Law	(82)	Doctor	For ships of greater coasting and wider service and with 100 persons and above 3000	

Note) 1. —┤ Less than —┤ Not more than ├— Not less than ├— More than
2. Above are the tonnage calculated by the current Japanese Regulations of the Tonnage Measurement of Ships (1974).

10.10. Equipment Number and Classification Symbols and Notation

(1) Equipment number

(a) Equipment number by the Ship Provision Rules
(Legislated by Japanese Government) (Table 103)

Equipment number (E.N) = $N_1+N_2+N_3$

Table 103

Categories	Contents	E.N ≤975	E.N >975*
Main part of the hull N_1	Below the uppermost continuous deck L, B, D, and d are defined by the Rules of Hull Structure of Steel Ships	$N_1 = L(B+D)$	$N_1 = L(B+d) + 0.85L\times(D-d)$
Superstructures and similar structures N_2	(1) Superstructures, (2) Structures on and above upper deck of which side walls are within 30 cm from ship's sides, and (3) Continuous trunk ways of which side walls are within 30 cm from ship's sides l and h mean the length and height of the above structure respectively.	For superstructure $N_2 = \Sigma\frac{3}{4}lh$ For raised quarter deck and sunken forecastle deck $N_2 = \Sigma lh$	$N_2 = \Sigma 0.85lh$
Deck houses and similar structures N_3	Structures other than those defined by the above, l' and h' mean the length and height of the deck house and similar structure	$N_3 = \Sigma\frac{1}{2}l'h'$	$N_3 = \Sigma 0.75l'h'$

Note) 1. The parts of the ship excluded from the calculation are;
(1) Fore and aft part which exceeds L defined by the rule.
(2) Isolated superstructures etc. of which length, or width is less than half of ship's breadth.
(3) Isolated deck houses, etc. of which length or width is less than half of ship's breadth or height is not more than 1.22 m.

2. The mark * is according to the volume 2 of The Guideline for Ship Inspection.

(b) Equipment number by classification societies (Table 104)

Equipment number (E.N) = $\Delta^{2/3}+2Bh+0.1A$

Table 104

Classification Societies	Δ	B	$h=f+h'$		A
			f	h'	
NK LR AB NV (1974)	Molded displacement to the summer load waterline (t)	Maximum molded breadth (m)	Freeboard from the summer load waterline amidships (m)	Total height of superstructures and deckhouses having a breadth of greater than 1/4 B at ship's centerline. Screens and bulwarks more than 1.5 m in height shall be regarded as parts of houses. Sheer, camber and trim may be neglected.	Profile area (1)+(2) (m^2) (1) $f\times L$ (2) Sum of the product of length multiplied by breadth of the superstructures, deckhouses, etc. What should be considered in this calculation are superstructures, deckhouses and trunks of which breadth exceeds 1/4 B and screens or bulwarks of which height exceeds 1.5 m.

Note) 1. L defined by each classification society shall be used.
2. Superstructures and deckhouses within the range of L shall be included in the calculation.
3. NK allows to neglect deckhouses, trunks, screens and bulwarks of which length is not more than $B/2$.

(2) Classification symbols and notations (Table 105)

Table 105 Simbols and Notations of Principal Classification Societies

Society	Classification Symbols and Notations						Registered Notations			Highest Class
	Survey during Construction	Hull	Machinery	Equipment	Others	Examples of Notation	Machinery	Ref. Machinery and Insulation	Others	
NK (1974)	*	NS	MNS	Included in hull		Navigating range: Coasting Service, Smooth Water Service, etc. Purpose: Tanker, Oils-Flashing Point below 65°C, Bulk Carrier, Column Stabilized Drilling Unit, Fishing Purposes, etc. CoC ... When anti-corrosion system is applied MO .... Unattended engine room		RMC	FPA (Fire fighting system)	NS* MNS*
AB (1974)	●	A1	AMS	Ⓔ Ⓜ		Navigating range: Great Lakes Service, River Service, etc. Purpose: Oil Carrier, Ore Carrier, Bulk Carrier, Strengthened for the Carriage of Heavy Cargoes, Certain Holds Empty, Special Purpose Vessels ("Ferry Service", "Dredging", "Fishing", "Towing", "Barge", etc.), Drilling Unit, Column Stabilized Drilling Unit, Self-Elevating Drilling Unit, Ice Strengthening Class A, B, or C, Ice Strengthening Class IAA, IA, IB, or IC, etc. Reduced Scantling due to Corrosion Control. INERT SYS ... Inert Gas System Certified. RW ... Reduced Weight Anchor. ● ACC, ACC ... Automatic Control System Certified. ● ACCU, ACCU Automatic Control System Unattended Engine Room Certified.		RMC		● A1 Ⓔ ● AMS

Society	Classification Symbols and Notations						Registered Notations			Highest Class
	Survey during Construction	Hull	Machinery	Equipment	Others	Examples of Notation	Machinery	Ref. Machinery and Insulation	Others	
BV (1973)	●	I 3/3 Good	Included in hull	E	○ One compartment flooding	Navigating range: Deep Sea, Coastal Service, Sheltered Waters, etc.		R.M.C.	SF (Fire fighting system)	● I 3/3 E
	● Survey by other class society	II 5/6 Fairly good			○ Two compartment flooding	Purpose: Oil Tanker, Ore Carrier, Bulk Carrier, Bulk-Ore Carrier, Heavy Cargo, Liquefied Gas Carrier, Chemical Carrier, Container Ship, Roll On-Roll Off, Special Service, Fishing Vessel, Tug, Dredger, Floating Dock, Wine Carrier		R.M.C. - S.		
	● Fairly good			- Fairly good	☼ SOLAS	Ice Class 1A Super, 1A, 1B, or 1C, Glace 1-Super, 1, 11, or 111, etc. CL ... Limited Corrosion AUT, AUT ... Unattended engine room (AUT), (AUT)..Automatic control engine room		R.M.C. - V.		
CR (1972)	●	CR100	CMS	E		Navigating range: Coasting Service, Smooth Water Service or Harbor Service, Navigation in Ice				CR100 ● E
	● Survey by other class society					Purpose: Oil Carrier, Ore Carrier, Bulk Carrier, Lumber Carrier, Dredger, Tug, Fishing Service, Floating Crane, etc.		RMS		CMS ●

Society	Classification Symbols and Notations						Registered Notations			Highest Class
	Survey during Construction	Hull	Machinery	Equipment	Others	Examples of Notation	Machinery	Ref. Machinery and Insulation	Others	
LR (1974)	●	100 A A	LMC	1		Purpose: Oil Tanker, Liquefied Gas Carrier, Ore Carrier, Strengthened for Ore Cargoes, Strengthened for Ore Cargoes-Specified holds may be empty, Strengthened for Heavy Cargoes, Strengthened for Heavy Cargoes-Specified holds may be empty, Trawler, Tug, Barge, Pontoon, Special Cargoes, Special Features Icebreaker, Ice Class 1*, 1, 2, or 3, Ice Class IA Super, IA, IB, or IC, etc. CC ... Corrosion Control IGS .. Inert Gas System UMS .. Unattended Machinery Space		Lloyd's RMC		● 100A1 ● LMC
NV (1974)	●	1A	Included in hull	1		Navigating range: N ... Norwegian Coast, Baltic, North Sea, etc. I ... Enclosed Fjords, Lakes, or Rivers K,K Partly Sheltered, K Sheltered, K Except Finnmark 1/10-1/4, etc.	MV (Machinery)	KMC	F (Fire fighting system)	● 1A1
	● Registered after survey by other class society			2		Purpose: Tanker (for Oil, Chemical, Liquefied Gas or C), Ore Carrier, HC, HC (Holds No. ... empty), Drilling Vessel, Hydrofoil, Trawler, Fishing, Ferry A, or B, Ice Breaker, Ice 1A*, 1A, 1B, 1C, or C. CORR ... Corrosion Control INERT .. Inert Gas System EO ..... Unmanned Engine Room	KV (Boiler)			

10.11. Data on Crew and Passengers

(1) Required minimum floor area for crew (Table 106)

(2) Definition of a passenger
SOLAS 1960; Every person other than:

(a) The master and the members of the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship; and

(b) A child under one year of age

The Japanese Enforcement Regulation of the Ship Safety Law; Every person other than crew and other persons on board.
"Crew" means the captain, seamen and spare seamen that are regulated by the Japanese Mariner's Law.
"Other persons on board" means the persons regulated by the Japanese Enforcement Regulation of the Ship Safety Law or the Japanese Guideline for Ship Inspection.

(3) Definition of passenger ship and non-passenger ship (Table 107)

(4) Calculation base of certified numbers of passengers (Table 108)

(5) Escape means of passenger ships and car ferries

(a) Related rules, circulars, etc.

i) The Japanese Ship Provision Rules; legislated in 1934 - revised in June, 1973 (applied to general ships except those specially noted)
The Guideline for Ship Inspection concerning the above Rules (Volume 2); enforced in March, 1972. (applied to general ships except those specially noted)

ii) Structural Standard for Car Ferries (The Guideline for Ship Inspection, Annex 3); enforced in March, 1972. (applied to car ferries)

iii) The Guideline for Ship Inspection No. 367; enforced in Jul. 10, 1973
The Guideline for Ship Inspection No. 481; enforced in Sept.21, 1973
(put into force to assure more safety of car ferries)

(b) Escape means (Table 109)

Table 106 Required Minimum Floor Area, etc. of Crew

Navigating area	Japan*7 (1973) Floor*1 area m²/person	Japan*7 (1973) Volume*1 m³/person	D.O.T. (1953) GT	D.O.T. (1953) Floor*3 area ft²/person	D.O.T. (1953) Floor*3 area ft²/person, Special crew	U.S.C.G. (1973)	U.S.C.G. (1973) Floor area ft²/person	U.S.C.G. (1973) Volume ft³/person
Ocean going	1.10 (bed area)	2.75	less than 400	15	14	1 - 4 persons/room *4	30	210
Greater coasting	1.10	2.05	400 - 800	20	18			
*2 Coasting	0.55	1.15	800 - 3,000	25				
Smooth water	0.45	-	3,000 and above	30	20			

N.S.C. (1974) GT	N.S.C. (1974) Floor area*6 m²/person, 1 person/room *5	N.S.C. (1974) Floor area*6 m²/person, 2 persons/room
less than 200	(4.00) 3.00	2.10
200 - 500	(5.25) 3.40	2.60
500 - 3,000	(6.50) 3.75	2.75
3,000 - 10,000	(7.50) 4.25	3.25
10,000 and above	(7.50) 4.75	3.75

ILO No. 92 (1970) GT	ILO No. 92 (1970) Floor area m²/person
1,000 - 10,000	3.72
10,000 and above	4.65

*1 Certified numbers of crew shall be those calculated based on the floor area or volume, whichever is the less.
*2 Certified numbers of crew shall be calculated based on the floor area or volume of greater coasting area when the ship runs in not less than 12 hours between two most distant ports.
*3 Floor area shall be 24 cubic feet/person in case of four persons/room in a passenger ship.
*4 Numbers of crew shall not exceed 4 persons/room.
*5 The value in ( ) shall be applied to the officers with no other separate room.
*6 For the ship 3,000GT and above, total floor area of 9 m² is required for triple berth cabin and 12 m² for quadruple berth cabin.
*7 It is decided by the labor agreement between Japanese shipowners' association and all Japan seamen's union that:
1) The numbers of crew in one cabin shall be one in principle and shall not exceed two.
2) The floor area of one cabin shall be
   6.0 m² for the vessels of 3,000GT and above
   6.5 m² for the vessels of 5,000GT and above
   7.0 m² for the vessels of 8,000GT and above
   8.0 m² for the vessels of 15,000GT and above.

Table 107 Definition of Passenger Ship and Non-passenger Ship

<table>
<tr><th>Rule</th><th colspan="4">Passenger ship</th><th>Non-passenger ship</th></tr>
<tr><td>SOLAS 1960
Japanese Ship Safety Law
Merchant Shipping Act (England)</td><td colspan="4">Ships which carry more than 12 passengers</td><td rowspan="8">All ships other than passenger ships</td></tr>
<tr><td rowspan="7">USCG 1973*</td><td colspan="4">Kind of main engine</td></tr>
<tr><td colspan="2">Steam</td><td colspan="2">Motor</td></tr>
<tr><td>65' and below in ship length</td><td>Ships which carry more than 6 passengers</td><td>15 GT and below</td><td>Ships which carry more than 6 passengers</td></tr>
<tr><td rowspan="4">More than 65' in ship length</td><td>Ships (excl. yachts), engaged in international voyage, which carry more than 12 passengers</td><td rowspan="3">Over 15 GT (excl. sea going vessel not less than 300 GT)</td><td>Ships (excl. yachts), engaged in international voyage, which carry more than 12 passengers</td></tr>
<tr><td>Ships, not more than 15 GT, which carry over 6 passengers</td><td>Ships, not more than 65' in length, which carry over 6 passengers</td></tr>
<tr><td rowspan="2">Ships other than following ones
(a) Yachts
(b) Cargo or tank vessels which carry not more than 16 passengers
(c) Tow boats and fishing boats not more than 1 NT which carry persons other than crew, excluding for ocean going and coasting service</td><td>Ships more than 65' in length other than the following ones; Cargo or tank vessels which carry not more than 16 passengers</td></tr>
<tr><td>Sea going vessel 300 GT and over</td><td>Ships (excl. yachts), engaged in international voyage, which carry more than 12 passengers
Ships other than following ones
(a) Yachts
(b) Cargo or tank vessels which carry not more than 16 passengers</td></tr>
</table>

* Care should be taken that, in addition to the above, sailing boats and non-self-propelled ships are treated as passenger ships in some cases.

Table 108 Floor Area, Volume, etc. per Passenger

Japan

	Navigating area	Facility	Calculation base	
General passengers, immigrants and extraordinary passengers	Ocean going	Bed	One person/bed	Play ground 0.45 m^2
	Greater coasting	Bed	One person/bed	
		Space for seat *1	0.85 m^2 (1.00 m^2)	
	Coasting and Smooth water	Bed	One person/bed	
		Space for seat *1	Navigating time (hr)	Unit area (m^2)
			24 and above	0.85 (1.00)
			6 - 24	0.55 (0.65)
			1.5 - 6	0.45 (0.55)
			less than 1.5	0.30 (0.35)
		Space for chair *2	Navigating time (hr)	Unit breadth (front) (cm)
			6 - 24	50
			1.5 - 6	45
			less than 1.5	40
		Standing space	Navigating time (hr)	Unit area (m^2)
			1.5 - 3	0.35
			less than 1.5	0.30
Deck passengers			On exposed upper deck (m^2)	On other exposed decks (m^2)
	A		0.85	0.85
	B		0.85	-
	C		0.85	0.85
	D		1.10	-

*1 Numerals in ( ) show unit area without passages.

*2 In case of ships navigating 3 hrs. and over,
(1) The depth of chairs shall be not less than 40 cm.
(2) The front space of chair shall be not less than 30 cm.

England

For ships engaged in international voyage:

General passengers
- Bed one per person
- Floor area 36ft^2
- Airing space 24ft^2

Non-berth passengers (4th class passengers)
- Under exposed deck 15ft^2
- Airing space 6ft^2

Deck passengers
- On exposed deck 12 ft^2

Others

Pilgrim passenger
Passenger on board the pilgrim ship which is engaged in carrying pilgrims visiting Hejaz or navigating among the ports in Red Sea.

Indonesian Regulation of Pilgrim Ships
- Between decks 1.50 m^2 (16.2 ft^2)
- Airing space 0.56 m^2 (6 ft^2)

Merchant Shipping Act 1923 (Pakistan)
- Between decks 18 ft^2, 108 ft^3
- Airing space 6 ft^2

Non-berth passengers
The Indian Merchant Shipping Rules 1935
For one passenger in a room certified not less than seven persons, (for a ship engaged in international voyage)
- Between decks 15 ft^2, 90 ft^3
- Airing space 6 ft^2

Revised Philippine Merchant Marine Regulation 1957
Between decks
- 7 ft^2 for ferry boat, harbour, bay, lake & river vessels which navigate less than 4 hrs in the daytime.
- 10 ft^2 for passenger ships which navigate less than 12 hrs.
- 12 ft^2 for other coasting and ocean going passenger ships.

Airing space
- 90 ft^3 for 3rd grade compartment for spaces other than state rooms and cabins on main deck or all the decks on main deck.
- 108 ft^3 for accommodation quarters on all the decks under main deck
- 36 ft^2 or 110 ft^3 for state rooms or cabins on main deck or on all the decks above main deck
- (21 ft^2 or 110 ft^3 for ships less than 150 GT)
- 125 ft^3 for state rooms or cabins under main deck

Table 109 Escape Means

Item			Contents	Note	Rules
General			Escape means is a group of corridors, stairways, ladders and doorways to be arranged for escape to the embarkation deck in an emergency.		The Ship Provision Rules (122.2)
No. of escape routes to be installed	General Ships	Accommodations other than those for crew	Not less than 2	Engine room, boiler room and shaft tunnel(s) are not included in service spaces.	The Ship Provision Rules (122.2)
		Crew's accommodation and service spaces	Not less than 1		
		Engine room Boiler room Shaft tunnel(s)	Not less than 2, one of which shall not pass through the watertight door(s). All the escapes which do not pass through the watertight door(s) shall be as far away as possible.	For ships under 2000 GT, the requirements are lightened in some cases.	The Ship Provision Rules (122.3)
	Passenger ship engaged in international voyage	Watertight compartment under bulkhead deck	Not less than 2, one of which shall not pass through watertight bulkhead(s) or fire-proof bulkhead(s)		The Ship Provision Rules (122.3)
		Each vertical zone above bulkhead deck	Not less than 2, one of which shall be led in vertical direction via stairways. The other one shall be the easily accessible stairway of incombustible construction which is enclosed with enclosures and led to embarkation deck.	Vertical zone means the section into which the hull, superstructure and deck houses which are divided by "A" class divisions, the mean length of which on any one deck does not, in general, exceed 40 meters.	
Breadth			60 cm and above Breadth for each deck shall be as follows; First deck N_1 (cm) Second deck N_1+N_2 Third deck $N_1+N_2+0.5N_3$ Fourth deck $N_1+N_2+0.5N_3+0.25N_4$	N: Number of persons scheduled to escape (N_1 shows numbers of persons scheduled to escape from the first deck) N includes two-thirds of crew and all passengers. In case all persons in public rooms are included, N shall be one-third of the total accommodated persons. For the fifth deck and above, breadth shall be confirmed by the Administration.	The Guideline for Ship Inspection (122.4)
Ladders	Inclination		For crew only 60° or less For others 45° or less	Excluding engine room, boiler room and shaft tunnel	The Guideline for Ship Inspection (122.4)
	Direction		Lengthwise of ship	-	
	Arrangement		Straightly up to embarkation deck		
	Handrail		To be fitted at center of the ladder in case the breadth in 2m and above.		
Lighting system	Emergency light		Fitted at doorways of main compartment.	Applied to passenger ships engaged in international voyage only.	The Ship Provision Rules (122.5)
	Lighting equipment		Fitted at the location of life raft and places required from safety standpoint.		
	Electric source		To be supplied from emergency electric source as well as main one.		
Emergency lighting			To be fitted at corridors, stairways, ladders and doorways.	Ditto	The Ship Provision Rules (122.6)

Item	Contents		Note	Rules
Emergency notice	Notice board	Meaning of signals, what to do in an emergency shall be described.		The Ship Provision Rules (122.7)
	Notice by luminous paint	Route up to the embarkation deck shall be shown.	In case emergency lighting is not fitted.	The Guideline for Ship Inspection (122.4)
Others	Blind corridor	12 m and less		The Ship Provision Rules (122.4)
	Entrance door	To be always unlocked.		The Guideline for Ship Inspection (122.4)
	Storm rail	To be fitted at corridors and stairways		
	Ladders between embarkation decks	Suitable numbers of inclined ladders shall be fitted when two or more embarkation decks are installed.		

Note) 1. The Ship Provision Rules (122.2) means the regulation 122.2 of the Ship Provision Rules.

2. As for the accommodation facilities of passengers required by the rules, refer to Chapter V, 21.7.1 - 3.
3. As for the accommodation facilities of crew, refer to Chapter 5, 21.7.4.
4. Following requirements are made on emergency exits and meeting places.

Emergency exits (The Ship Provision Rules 100.1)	• Width shall be not less than 60 cm. • Doors shall be opened/closed from both sides of them. • Location of the said doors shall be clearly denoted. • In case the exit(s) is led to the other passenger room(s) only, it is requested to install emergency exit(s) without fail.
Meeting places in an emergency (The Ship Provision Rules 90)	• The places shall not be used as passenger rooms. • In case the meeting place(s) cannot be secured in addition to the said places, the exit(s), which are directly led from port side/starboard side of the said passenger room(s) to the sea, shall be installed.

(c) Special requirements on the safety of car ferries (Table 110)

Table 110 Special Requirements on the Safety of Car Ferries

(The Guideline for Ship Inspection No. 367 & 481,
The Structural Standard of Car Ferries)

Item	Contents	
Embarkation means	As for embarkation on life boats and life rafts, refer to Chapter V, 7.1.3 and 7.7.	
Notation of escape routes and facilities	Signs and arrangement shall be posted. Escape route from the place to embarking place shall be marked by luminous letters or signs.	
Escape means	In addition to the escape means specified in the Ship Provision Rules, Regulation 122.3, escape means not less than 2 shall be installed in accommodation spaces and service spaces under vehicle deck, one of which shall be by the passage, steel stairways and ladders enclosed by steel casing of A-30 construction and led to the embarkation deck.	
Escape deck	Escape deck shall be installed on open deck.	
Emergency stairways	On the fittings installed between meeting places and embarking places; 1) Not to be laid across the two decks and above and to be used exclusively. 2) Width shall be 0.5 x (No. of embarking persons), but not less than 90 cm. 3) Platform not less than 10 m^2 shall be installed.	Vehicle area in accommodation shall be separated from galley and machinery space. Insulation of floor, ceiling and casing. A-0 (Accommodation space) A-30 (Vehicle area) A-60 (Machinery space)
Embarking place	1) Large opening shall be fitted. 2) Openings shall not, in principle, be arranged on the side shell within 2 m from the one faced to embarkation equipment and on the steel walls of the other compartments. The cover made of metal or equivalent which can be closed from outside of the place is admitted.	
Alarms	Steam horn or electric siren shall be fitted.	
Emergency lighting	Emergency lighting shall be fitted on doorways, corridors, stairways and ladders, escape decks and other places wherever necessary.	
Vehicle area	Location	Vehicle area shall be arranged where the use of doorways, stairways, life-saving apparatus is not disturbed.
	Escape opening	Opening used as escape means shall not be arranged.

10.12. Loading Data

10.12.1. Loading Data for Main Cargoes

(a) Stowage factor (S.F.) of main cargoes (Table 111)
(b) Loading factor of lumbers (Table 112)
(c) Size of containers (Refer to Chapter V, 3.5)

Table 111 Stowage Factor (S.F.) of Main Cargoes

Kind of cargo	Form	S.F.	Repose angle	Note
Iron ore	Bulk	12 - 16	40° - 50°	Australian product
	"	11 - 16	35° - 60°	Brazilian product, Swedish product, water content 0 - 4%
	"	16	38°	Egyptian product, moisture content 3 - 5%
	"	19	38°	Ghana product
Bauxite	Bulk	27 - 32	{ 28°	Dry
	Bagged	38 - 40	{ 40°	Moisture content 8%
Lime stone	Bulk	27	33°	Powdery
	"	30	34°	Oita (Japan) product
	"	22 - 24		Split, South Australian product
Cement	Bulk	24 - 28	indefinite	Repose angle varies by the ratio of air in it
	Bagged	32 - 38		
	Bulk	35 - 36		Lump, loaded at Marseilles
Salt	Bulk	29 - 40	30° - 45°	
	"	33	45°	Low grade, without lump, moisture content 3%
Coal	Bulk	30 - 50	30° - 45°	Water content varies by the production area
	"	46 - 48		Small coal
Sand	Bulk	18 - 28	30° - 45°	
	Bagged	28		
Steel bar		20 - 30		
rail		15 - 35		
plate		8 - 16		
billet		10 - 14		
Scrap		40 - 55		#1 HMS $l<1$ m, $t>3$ mm
		50 - 80		#2 HMS $l<1$ m, $t<3$ mm
		32		Bundle (600 x 600 x 1300)
		50		Kaiser (scrap of thin plate)
		20		Plate end (thick plate)
White rice	Bulk	46 - 50		Standard 47 (Japanese product)
	Bagged	48 - 52		" 52
Wheat	Bulk	46 - 55		" 47
	Bagged	48 - 55		" 52
Barley	Bulk	53 - 59		" 54
	Bagged	60 - 66		" 60
Soyabean	Bulk	44 - 60		
	Bagged	48 - 59		
Sugar	Bulk	36 - 46	30° - 39°	
	"	57	35°	
	Bagged	40 - 55		Refind soft sugar
Chip	Bulk	100-160	45° - 58°	Loaded by pneumatic trimmer moisture content 40 - 50%

Note) 1. S.F. = Stowage factor (ft^3/LT) Virtual specific weight ρ' (t/m^3) = 35.9/S.F.
2. Selection of value of S.F. shall be fully discussed by the customer before start of design.
3. Repose angle of grain is 30° - 31° at dry condition and normally 35° - 37°.
4. As for liquid cargoes, refer to Chapter II, 1.2, Table 2.
5. As for refrigerated cargoes, refer to Chapter V, 18.4.4, Table 167 and Table 168.
6. Data for reference: Code of Safe Practice for Bulk Cargoes (IMCO)
General Information for Grain Loading (NCB)
Table of Stowage Factor and Loading Practice
(edited by N.Y.K. Line, Marine Division)

Table 112 Loading Factor of Lumber

Kind of Lumber		Log				Timber		Packaged timber		
		Log from pacific coast of North America		Lauan from the Philippines		Small size square timber	Large size square timber	Short size timber	Long size timber	
		2'~3' φ×13' 1'~2' φ×40'~60'				4"×4"×10'~20' 5"×5"×10'~20'	18"×18"×30'~40'	2'×4'×8'~16' 3'×4'×8'	4'×4'×18' 4'×4'×20' 4'×4'×26'	
Weight (long ton) per 1000 BM		Mean value for one vessel 1.5 - 1.6		Mean value for one vessel 2.0 - 2.5		1.5 - 1.6		Hemlock spruce 1.86		
Location		In hold	On deck	In hold	On deck	In hold	On deck	In hold and on deck	In hold	On deck
Space required for loading 1000 BM (ft^3)	(Minimum)	(170)	(140)	(180)	(160)					
		175 ~ 190	155 ~ 165	185 ~ 200	170 ~ 180	120	136	100 ~ 110	140 ~ 165	120 ~ 145
	(Maximum)	(208)	(200)	(220)	(210)					
$K = \frac{\text{Loading volume } (ft^3)}{\text{Required volume } (ft^3)}$	(Maximum)	(0.49)	(0.60)	(0.46)	(0.52)					
		0.48 ~ 0.44	0.54 ~ 0.51	0.45 ~ 0.42	0.49 ~ 0.46	0.69	0.61	0.84 ~ 0.76	0.60 ~ 0.51	0.69 ~ 0.58
	(Minimum)	(0.40)	(0.42)	(0.38)	(0.40)					

Note) 1. BM: Board measure foot, which is also denoted as BF.
2. $1\ BM = 1' \times 1' \times \frac{1}{12}' = 0.0835\ ft^3 = 0.00236\ m^3$
3. $K = 83.5$ /(space required for loading 1000 BM, ft^3)
4. Required volume in the above table is only for the design and it varies according to the size and shape of the hold. Actual results in the operation are sometimes reported to exceed the design value.
5. Lumber from North America is the log with rind but is measured to the inside of the rind for the determination of BM.
6. Lauan from the Philippines is normally loaded aboard the ship after being barked.

10.12.2. Rules on Loading Special Cargoes

(1) Loading of bulk grain
Summary of IMCO Resolution A.264 (Carriage of Grain), which is scheduled to be incorporated in SOLAS (1974), is described below.

(a) Definitions (Regulation 2)

i) The term "grain" includes wheat, maize (corn), oats, rye, barley, rice, pulses, seeds and processed forms thereof, whose behavior is similar to that of grain in its natural stage.

ii) The term "filled compartment" refers to any compartment in which, after loading and trimmings, the bulk grain is at its highest possible level.

iii) The term "partly filled compartment" refers to any compartment wherein bulk grain is not loaded in a manner as stated in ii), but surface of the grain shall be trimmed to level.

iv) The term "Angle of flooding" (θ_f) means an angle of heel at which openings in the hull, superstructures or deckhouses, which cannot be closed watertight, immerse. Small openings through which progressive flooding cannot take place need not be considered as open.

(b) Intact stability requirements (Regulation 4)
The intact stability characteristics of any ship carrying bulk grain shall meet, throughout the voyage, at least the following criteria.

i) The angle of heel due to shift of grain shall be not greater than 12 degrees except that an Administration may require lesser angle of heel, which, for example, permissible angle of heel might be limited to the angle of heel at which the edge of the weather deck would be immersed in still water.

ii) In the statical stability diagram (Fig. 217), the net or residual area (residual dynamical stability) between the heeling arm curve and the righting arm curve up to the angle of heel of maximum difference between the ordinates of two curves, or 40 degrees or the "angle of flooding (θ_f)", whichever is the least, shall in all conditions of loading be not less than 0.075 meter-radians.

iii) The initial metacentric height, after correction for the free surface effects of liquid in tanks, shall be not less than 0.30 m.

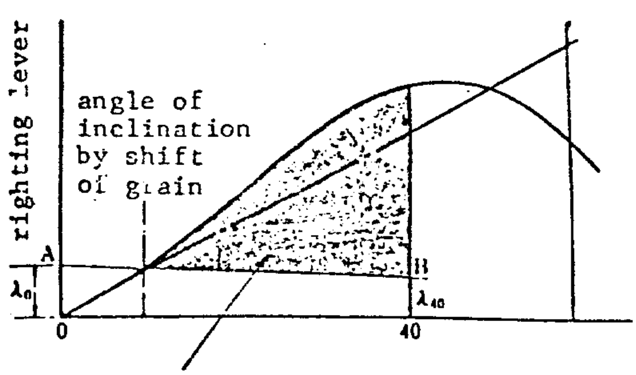


Fig. 217 Statical stability diagram

$$\lambda_0 = \frac{\text{Assumed volumetric heeling moment by shift of grain}}{\text{Stowage factor (S.F.)} \times \text{displacement}}$$

$$\lambda_{40} = 0.80 \times \lambda_0$$

Note) 1. Stability diagram, as much accuracy is required, shall be made up based on as many cross curves as practicable including those of 12 degrees and 40 degrees.

2. Heeling moment curve by shift of grain is approximately represented by straight line AB.

(c) Longitudinal divisions and saucers (Regulation 5)

In both "filled compartments" and "partly filled compartments", longitudinal divisions may be provided as a device either to reduce the adverse heeling effect of grain shift or to limit the depth of cargo used for securing the grain surface. Such divisions shall be fitted grain-tight and constructed in accordance with the requirements.

In a "filled compartment", a division, if fitted to reduce the adverse effects of the grain shift, shall

i) in a 'tween-deck compartment extend from deck to deck and

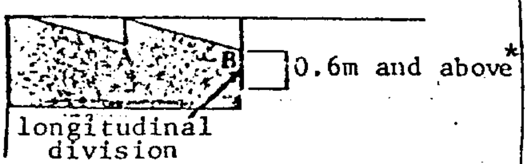
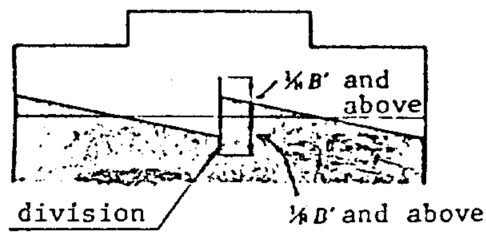
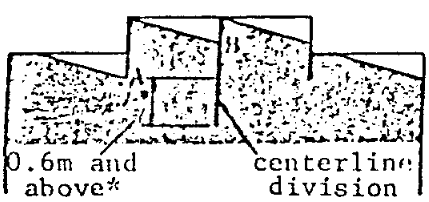
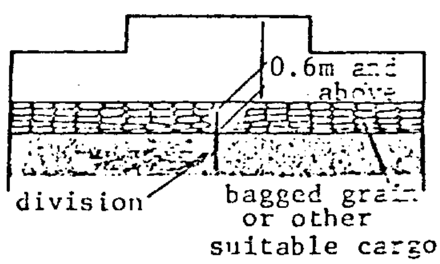
ii) in a hold be in accordance with Table 113.

Except in the case of linseed and other seeds having similar properties, a longitudinal division beneath a hatchway may be replaced by a saucer or bundling of bulk.

In a "partly filled compartment", a division, if fitted shall be in accordance with Table 113.

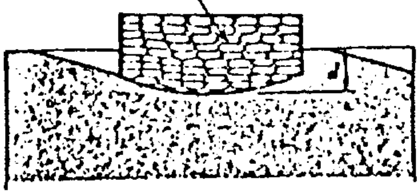
Furthermore, the adverse heeling effects of grain shift may be reduced by tightly stowing the wings and ends of compartment with bagged grain or other suitable cargo adequately restrained from shifting.

Table 113 Longitudinal Divisions

Filled compartment	Partly filled compartment
1. Before and abaft hatchways 	1. When free surface of grain is not secured.  B' is the maximum breadth of the compartment.
2. In and abreast hatchways 	2. When free surface of grain is secured. 
* The centerline division shall extend to at least 0.6 m below A or B whichever gives the greater depth.	

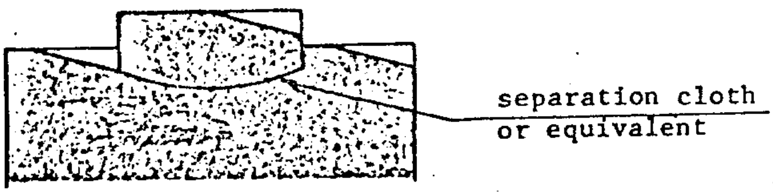
Filled compartment	Partly filled compartment

3. Saucers



B (molded breadth) $\leq$ 9·1m d = 1.2 m
B (molded breadth) $\geq$ 18·3m d = 1.8 m
9·1m $< B <$ 18·3m to be calculated by interporation method.

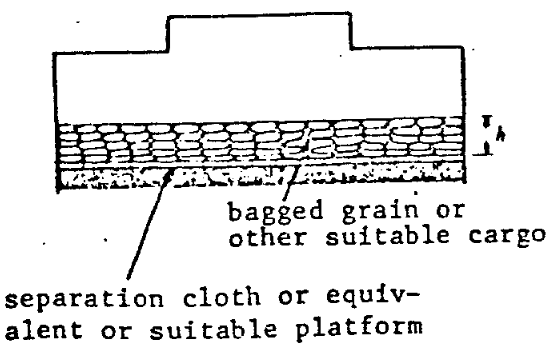
4. Bundling of bulk



(d) Securing (Regulation 6) (Fig. 218 & 219)
The surface of the bulk grain in any "partly filled compartment" shall be level and topped off with bagged grain tightly stowed. Instead of bagged grain, other suitable cargo exerting at least the same pressure may be used. The bagged grain or such other suitable cargo shall be supported in a manner described in the rule. Alternatively, the bulk grain surface may be secured by strapping or lashing.

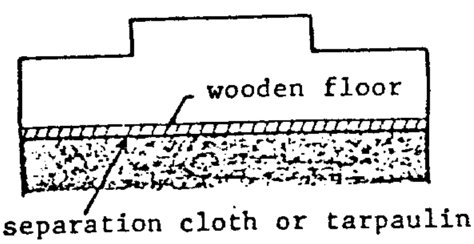
(e) Feeders and trunks (Regulation 7)
If feeders and trunks are fitted, proper account shall be taken of the effects thereof when calculating the heeling moments.

(f) Combination arrangements (Regulation 8)
Lower holds and 'tween-deck spaces in way thereof may be loaded as one compartment provided that, in calculating transverse heeling moments, proper account is taken of the flow of grain into the lower spaces.



h is 1.2 m or 1/16 of the breadth of the free grain surface, whichever is the greater.

Fig. 218 Securing of grain surface by bagged grain



Steel wire rope, doubled steel strapping or chain of equivalent strength is used for lashing.

Fig. 219 Securing of grain surface by strapping or lashing

(g) Calculation of assumed heeling moment

i) Assumed void in "filled compartment" (Fig. 220)

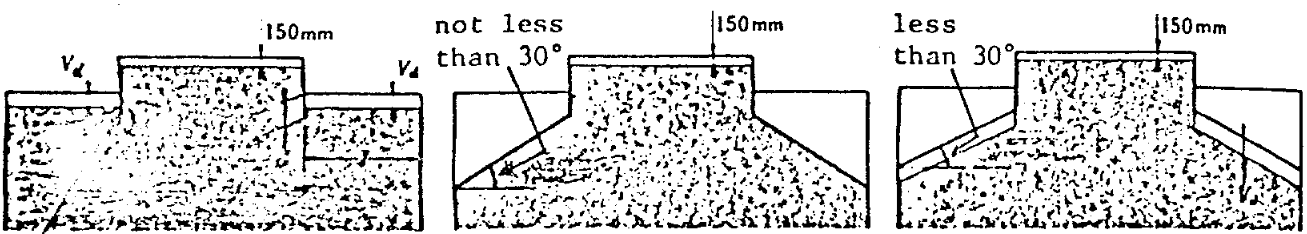
A void is assumed to exist under all boundary surfaces having an inclination to the horizontal less than 30 degrees and that the void is parallel to the boundary surface having an average depth calculated according to the following formula.

$$V_d = V_{d1} + 0.75\ (d - 600)\quad (\text{mm})$$

where, V_d = Average void depth (mm)
V_{d1} = Standard void depth from table 114 (mm)
d = Actual girder depth (mm)

In no case shall V_d be assumed to be less than 100 mm.

Within filled hatchways and in addition to any open void within the hatch cover, there shall be assumed to be a void of average depth of 150 mm measured down to the grain surface from the lowest part of hatch cover or the top of the hatchside coaming, whichever is the lower.



(1) General

(2) In case of boundary surface having an inclination to the horizontal not less than 30°

(3) In case of boundary surface having an inclination to the horizontal less than 30°

Fig. 220 Typical example of a void defined by the rule

Table 114 Standard Void Depth

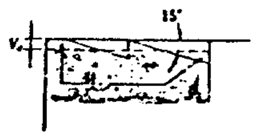
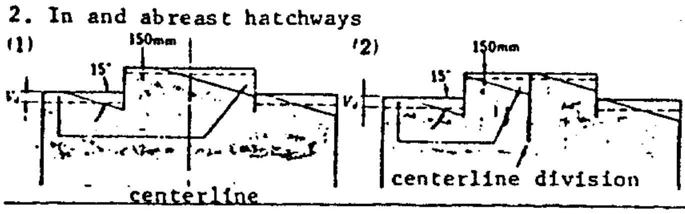
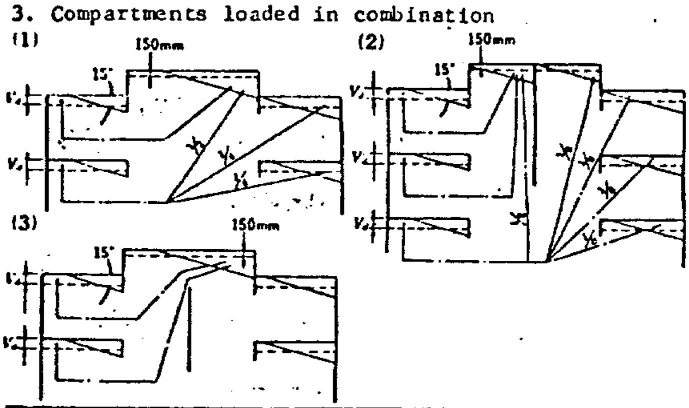
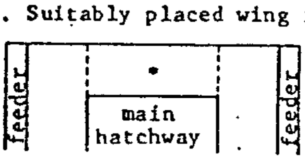
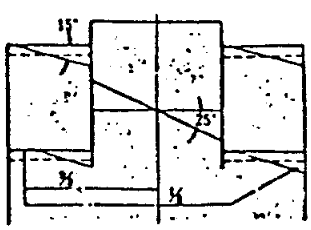
l (m)*	V_{d1} (mm)	Note
0·5	570	For l greater than 8.0 m, V_{d1} shall be linearly extraporated at 80 mm increase for each 1.0 m increase in distance. Where there is a difference in depth between the hatchside girder or its continuation and the hatchend beam the greater depth shall be used except that; 1) When the hatchside girder or its continuation is shallower than the hatchend beam the void abreast the hatchway may be calculated using the lesser depth; 2) When the hatchend beam is shallower than the hatchside girder or its continuation the void fore and aft of the hatchway inboard of the continuation of the hatchside girder may be calculated using the lesser depth; and 3) Where there is a raised deck clear of a hatchway the average void depth measured from under side of the raised deck shall be calculated using the standard void depth (V_{d1}) in association with a girder depth (d) of the hatchend beam plus the height of the raised deck.
1·0	530	
1·5	500	
2·0	480	
2·5	450	
3·0	440	
3·5	430	
4·0	430	
4·5	430	
5·0	430	
5·5	450	
6·0	470	
6·5	490	
7·0	520	
7·5	550	
8·0	590	

* l is the distance from hatchend or hatchside to boundary of compartment.

ii) Assumed volumetric heeling moment of a filled compartment (Table 115)
The resulting grain surface after shifting shall be assumed to be at 15 degrees to the horizontal. A discontinuous longitudinal division shall be considered effective over its full length. The ship's stability calculations shall be normally based upon the assumption that the center of gravity of cargo in a "filled compartment" is at the volumetric center of the whole cargo space. In those cases where the Administration authorizes account to be taken of the effect of assumed under deck voids on the vertical position of the center of the gravity of the cargo in "filled compartment", it will be necessary to compensate for the adverse effect of the vertical shift of grain surfaces by the following formula.

Total heeling moment = 1.06 x calculated transverse heeling moment

Table 115 Assumed Volumetric Heeling Moment of a Filled Compartment

Assumptions	Note
1. Before and abaft hatchways  *--- shows the shift of excess void area.	If a compartment has two or more main hatchways through which loading may take place the depth of the underdeck void for the portion(s) between such hatchways shall be determined using the fore and aft distance to the mid-point between the hatchways.
2. In and abreast hatchways 	
3. Compartments loaded in combination 	In figure (1), the void area under the third deck and lower decks available for transfer from the low side of each of these decks shall be assumed to transfer in equal quantities to all the voids under the decks on the high side and the void in the upper deck hatchway. In figure (2), the void area under these decks available for transfer from the low side of each of those low decks shall be assumed to transfer in equal quantities to the voids in each of the two halves of the upper deck hatchway on each side of the division and the voids under the decks on the high side.
4. Suitably placed wing feeders  The portion marked * is included in the calculation.	Provision of feeders 1. The feeders shall extend for the full length of the deck and the perforations therein shall be adequately spaced. 2. The volume of each feeder shall be equal to the volume of the under deck void outboard of the hatchside girder and its continuation.
5. Trunks situated over main hatchways  centerline	If the wing spaces in way of the trunk cannot be properly trimmed it shall be assumed that a 25 degree surface shift takes place.

iii) Assumed volumetric heeling moment of partly filled compartments (Fig. 221 & 222)

When the free surface of bulk grain has not been secured, it shall be assumed that the grain surface after shifting shall be at 25 degrees to the horizontal. In a compartment in which the longitudinal divisions are not continuous between the transverse boundaries, the length over which any such divisions are effective as devices to prevent full width shifts of grain surfaces shall be taken to be actual length of the portion of the division under consideration less two-sevenths of the greater of the transverse distances between the division and its ajacent division or ship's side. This correction does not apply in the lower compartments of any combination loading in which the upper compartment is either a "filled compartment" or a "partly filled compartment".

The adverse effect of the vertical shift of grain surfaces shall be calculated as follows.

Total heeling moment = 1.12 x calculated transverse heeling moment

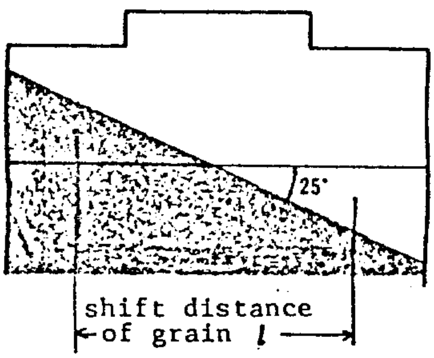


Fig. 221 When grain surface is not secured

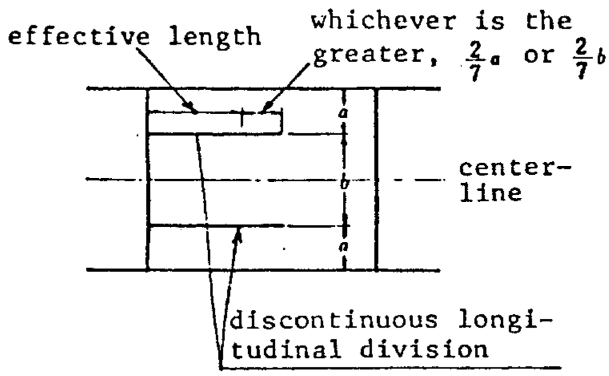


Fig. 222 When longitudinal divisions are provided

(h) Alternative loading arrangements for existing ships

A ship loaded in accordance with the following requirements shall be considered to have intact stability characteristics at least equivalent to the requirements of this regulation. "Existing ship" means a ship, the keel of which is laid before the date of coming into force of this regulation.

i) Stowage of specially suitable ships

Bulk grain may be carried without regard to the requirements specified in (g) in ships which are constructed with two or more vertical or sloping grain-tight longitudinal divisions suitably disposed to limit the effect of any transverse shift of grain under the following conditions.

i-i) as many holds and compartments as possible shall be full and trimmed full;

i-ii) for any specified arrangement of stowage the ship will not list to an angle greater than 5 degrees at any stage of the voyage where:

- in holds and compartments which have been trimmed full, the grain surface settled 2 percent by volume from the original surface and shifts to an angle of 12 degrees with that surface under all boundaries of these holds and compartments which have an inclination of less than 30 degrees to the horizontal.

- in "partly filled compartments or holds" free grain surfaces settle and shift as mentioned above or to such larger angle as may be deemed necessary by the Administration, or by a Contracting Government on behalf of the Administration, and grain surfaces if overstowed in accordance with the Regulation 5 shift to an angle of 8 degrees with the original levelled surfaces. Shifting boards, if fitted, will be considered to limit the transverse shift of the surface of the grain.

ii) Ships without documents of authorization
A ship not having on board documents of authorization may be permitted to load bulk grain under the requirement mentioned i) or the following requirements.

ii-i) All "filled compartments" shall be fitted with centerline divisions extending for the full length of such compartments which extend downwards from the underside of the deck or hatch covers to a distance below the deck line of at least one-eighth of the maximum breadth of the compartment or 2.4 m, whichever is the greater except that saucers may be accepted in lieu of a centerline division in and beneath a hatchway.

ii-ii) All hatches to "filled compartments" shall be closed and covers secured in place.

ii-iii) All free grain surfaces in "partly filled compartments" shall be trimmed level and secured.

ii-iv) Throughout the voyage the metacentric height after correction for the free surface effects of liquids in tanks shall be 0.3 m or that given by the following formula, whichever is the greater:

$$GM_R = \frac{lBV_d(0{\cdot}25B - 0{\cdot}625\sqrt{V_d B})}{S.F. \times \Delta \times 0{\cdot}0875}$$

where, l = Total combined length of all full compartments (m)
B = Molded breadth (m)
S.F. = Stowage factor (m^3/t)
V_d = Calculated average void depth (mm)
Δ = Displacement (t)

(2) Loading of ore concentrate* in bulk (by The Japanese Regulations concerning the Carriage of Special Cargoes such as Grain by Ships)

(a) Loading of bulk ore concentrate in ships with freeboard mark shall be in accordance with Table 116 except that in foreign port.

(b) Installation of longitudinal bulkhead or shifting board and transverse shifting board (or dike with bagged ore) in general cargo ships (steel ships) shall be in accordance with Table 117.

(c) Requirements for single-purpose ships shall be as follows.

i) Longitudinal bulkheads symmetrical to ship centerline with the distance of $0{\cdot}60B$ and less which will be extended from the hold bottom to the deck and from the foremost bulkhead to the aftermost bulkhead of the hold shall be installed in the hold where bulk cargo is loaded.

ii) Ballast tank(s) with enough capacity shall be provided outside of the longitudinal bulkheads and also ballast pumps sufficient for loading and discharging shall be installed to enable the ship at upright condition when she lists to an angle that the edge gets to the water level at the full loaded condition (or 10 degrees, whichever is the smaller) and also the ore concentrate inclines to that angle.

Note) * Ore concentrate means such ore as sulphide ore concentrate, zinc ore concentrate and copper ore concentrate processed by floatation.

Table 116 Loading Instructions of Ore Concentrate

Steel ships w/free-board mark \ Item	Moisture in fine concentrate		Limitation of draft	Limitation of loading space	Longitudinal bulkhead or shifting board*2	Transverse shifting board or dike by bagged ore
Passenger ship	less than 8%		Not restricted (up to the freeboard mark)	Not restricted	Unnecessary	Unnecessary
General cargo ship	less than 8%		Not restricted (up to the freeboard mark)	Not restricted	Unnecessary	Unnecessary
	Moist ore concentrate	8% & above but under 9%	Up to the freeboard of that corresponding to the freeboard mark multiplied by C*1	Weight of ore concentrate loaded in other spaces than lower holds and deep tanks shall be 20% or less of the displacement corresponding to the freeboard described left.	Necessary, except that;: 1. Ore concentrate is divided by the shifting device made of wood and bagged ore and enclosed by the bagged ore. 2. The surface of ore concentrate is levelled and wood is loaded on it up to the under side of the deck. 3. Ore concentrate of which weight*3 is 20% or less of the displacement corresponding to the freeboard described left is loaded in the lower holds.	Unnecessary
		9% & above but under 12%			Necessary, except measures described above 2 or 3 is applied.	Necessary, except measures described above 2 or 3 is applied.
Industry carriers	less than 8%		Not restricted (up to the freeboard mark)	Cargo shall be loaded evenly in the space between longitudinal bulkheads	Special requirements other than for industry carriers are not made.	Unnecessary
	Moist ore concentrate	8% & above but under 9%				
		9% & above but under 12%				
		12% & above				

*1 C is equal to $\left(1.15-\frac{L}{600}\right)$ or 1.0, whichever is the greater.
*2 Longitudinal bulkhead or shifting board is not required provided that maximum width is $B/2$ or below.
*3 The weight of the cargo loaded in the deep tanks divided so that the maximum breadth of the tank is $B/2$ or below may be excluded.

Table 117 Location of Longitudinal Bulkhead (Shifting Board) and Transverse Shifting Board

<table>
<tr><th colspan="5">Longitudinal bulkhead or shifting board</th><th colspan="2" rowspan="2">Transverse shifting board or dike by bagged ore</th></tr>
<tr><th>Number</th><th>Breadth-wise</th><th colspan="2">Depthwise</th><th>Length-wise</th></tr>
<tr><td>One</td><td>To be placed at ship center-line.</td><td rowspan="2">To be placed from the bottom where the ore is loaded to the place high enough upward from the ore surface.</td><td>$h \geq B/15$*</td><td rowspan="2">To be placed from the foremost bulkhead to the aftermost bulkhead.</td><td rowspan="2">To be placed longitudinally at suitable interval.</td><td>$GT < 500T$
Maximum interval $= \frac{\text{Total hold length}}{2}$</td></tr>
<tr><td>Two</td><td>To be placed between 0.6B or less symmetrical to ship center-line.</td><td>$h \geq B/10$*</td><td>$GT \geq 500T$
Maximum interval $= \frac{\text{Total hold length}}{3}$</td></tr>
</table>

* h means the distance from the surface of ore concentrate which is trimmed even to the top of the longitudinal bulkhead(s) or shifting board(s).

(3) Loading of lumbers on deck
(By the Japanese Regulations concerning Carriage of Special Cargoes such as Grain by Ships)

The loading of lumbers on upper deck or exposed superstructure decks shall be in accordance with the following requirements. As for the details refer to the said regulations.

(a) In case logs are loaded to the height much over the bulwark, stanchions having enough strength shall be firmly fixed at the deck stringer plate with the intervals not more than 3.05 m. The stanchions arranged on superstructure decks shall be tightly supported by lashing wire.

(b) Lumbers on deck shall be fastened by lashing wire at the appropriate interval not more than 3.05 m.

(c) The necessary space for opening and closing the doors shall be assured around the door opening faced to the passages for crew.

(d) Enough care shall be taken of ship stability. The loading height of lauan logs and similar large size logs from the upper deck upward shall be limited to one-third of the deck breadth at the place or of the ship's breadth, if deck breadth exceeds ship's breadth, whichever is the smaller.

(e) As for loading of lumbers on deck up to the assigned lumber freeboard condition, refer to 2.9.1 and 2.9.2 in addition to the above requirements. In combined loading of lauan logs or similar large size logs and ore concentrate, the logs shall be laid on the ore concentrate up to the under side of the deck.

(4) Regulations concerning the carriage of dangerous goods
Some major regulations are listed below.

(a) Stowage Conditions and Precautions Required for the Carriage of Dangerous Goods or Explosives in Ships

(b) USCG, CFR 46, part 146 - 149

(c) DOT, The Merchant Shipping (Dangerous Goods) Rules

(d) Suez, Rules of Navigation (Appendix for vessels carrying dangerous cargo)

(e) Panama, Rules and Regulations Governing Navigation of the Panama Canal and Adjacent Waters (Chapter 8)

(f) SOLAS, Chapter 7, Carriage of Dangerous Goods

(g) IMCO Resolution (A.81, A.230 and A.289)