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Introduction

This booklet provides the basic outline of lectures on stability, load-line, trim and longitudinal strength in accordance with the requirements of Chapter II of the STCW-Code, in particular with the tables A-II/1 and A-II/2 in this Code.

Assisting material:

- Loading and Stability Manual, MV. Nautilus,
- Loading and Stability Manual (Extract), MV. Bockenheim,
- DOS compatible diskette with a loading and stability program for MV. Bockenheim,
- See-BG: Bekanntmachung über die Anwendung der Stabilitätsvorschriften für Frachtschiffe, Fahrgastschiffe und Sonderfahrzeuge vom 24. Oktober 1984,
- IMO: Extract of the Intact Stability Code:
  Chapter 3 - Design Criteria applicable to all ships (Subchapters 3.1 and 3.2 only).

Students attending these lectures should have a sound knowledge of basic algebra and geometry as well as basic physics, in particular static's.

The abbreviations and symbols used in this booklet and in the Manuals are in line with a proposed standard currently under consideration in the ISO. The publications by See-BG and IMO however show somewhat different abbreviations and symbols.

For successfully passing the examination provided at the end of the course it is strongly recommended to make use of the exercises given in this booklet, above the minimum of exercises required for admittance to the examination.

May, 2003 H. Kaps

1. Stability

1.1 Parameters of stability

Stability of a ship is its property to float upright and to offer resistance against external heeling moments. This general property can be described more precisely by the parameters **metacentric height** and **righting levers**.

1.1.1 Initial stability and metacentric height

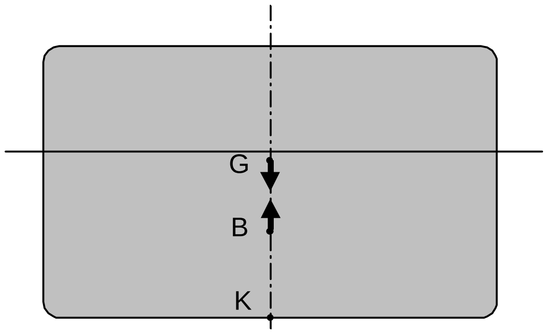


Figure 1: Ship in upright condition

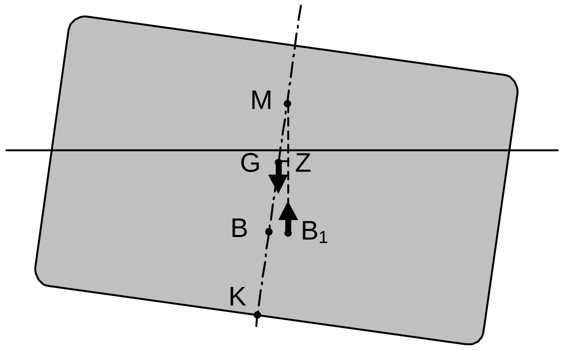


Figure 2: Ship in heeled condition

Figure 1 shows the centre of mass G with the gravity vector pointing down and the centre of buoyancy B with the buoyancy vector pointing up.

Figure 2 shows the ship slightly listed by the angle ϕ. The shift of immersed volume has moved the centre of buoyancy from B to B_1. Weight and buoyancy now provide a pair of vectors, which upright the ship again. The appropriate righting lever is $GZ = GM \cdot \sin \phi$ [m].

This is only true if the intersection M of the buoyancy vector with the midship plane is placed above the centre of mass G. M is called the metacentre and is defined as the intersection of neighbouring vectors of buoyancy within a range of heel of about ± 5° (i.e. to starboard or port). The **metacentric height** GM is the first and most important parameter of stability. It should be positive, i.e. M should be situated over G at all times.

The position of M depends on the draught of the vessel and is pre-calculated and tabulated as KM by the naval architect and provided to the mariner in the Loading and Stability Manual.

The position of G depends on the vertical distribution of masses in the ship (hull, equipment, cargo bunkers, ballast) and is at the full disposal and responsibility of the mariner. The supervision and control of KG is the main issue of the management of ship's stability. The relation between GM and KG is shown in Figure 2: $KG = KM - GM$ or $GM = KM - KG$.

1.1.2 Righting lever curve

Figure 3 shows a heel of more than 5° where typically the intersection of the buoyancy vector intersects the midship plane in N, which is above M. This increase of the metacentric height is generally referred to as "additional form stability". The righting lever GZ exceeds the appropriate value of $GM \cdot \sin \phi$.

It should be noted, however, that with increasing heeling angles, in particular after the deck edge is immersed, N starts moving downwards again, passes M and reaches G at large angles of heel. At this heeling angle the righting lever GZ is equal to zero.

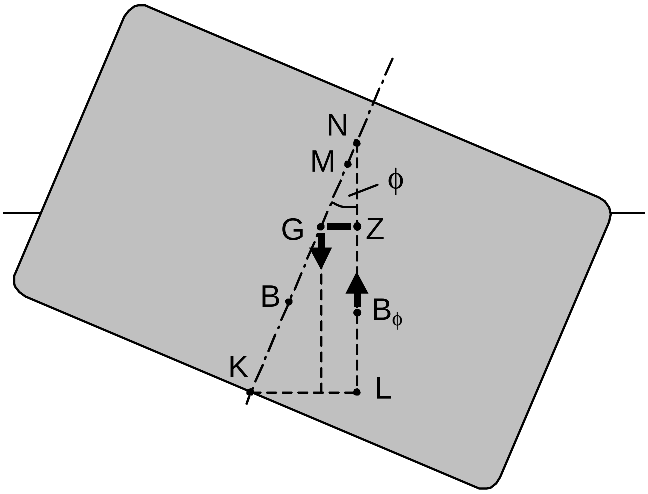


Figure 3: Heel of more than 5°

The **righting levers** GZ (ϕ) are the second important parameters of stability at heeling angles above 5°. GZ is calculated by the formula:

$$GZ(\phi) = LK(\phi, T) - KG \cdot \sin\phi \quad [m]$$

LK equals KN · sinϕ and is provided by the naval architect in form of tables or diagrams with the entry parameters draught T and angle of heel ϕ in the Loading and Stability Manual. LK-values are commonly referred to as cross curve-values.

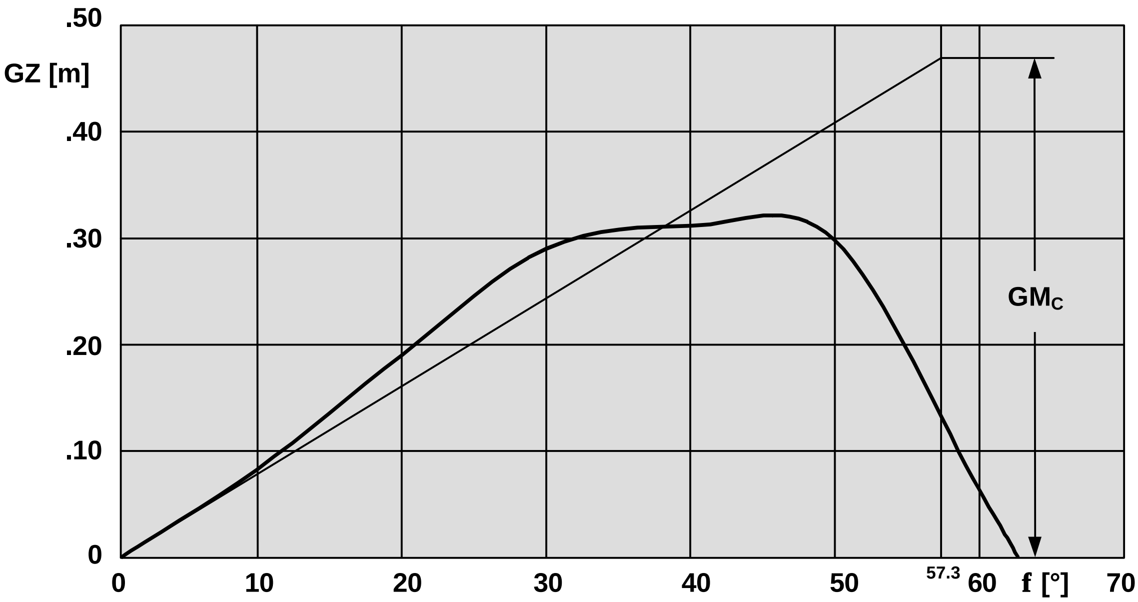


Figure 4: Typical righting lever curve

Although righting lever curves can be precisely calculated using the LK-values and a given KG, there is no simple formula for obtaining GZ-values. There are however approximations for righting lever curves:

up to 5° heel: $GZ(\phi) = GM \cdot \sin\phi \quad [m]$

up to 15° heel: $GZ(\phi) = \left(GM + \frac{BM}{2} \cdot \tan^2\phi\right) \cdot \sin\phi \quad [m]$

(with BM ≈ KM – 0.53 · mean draught)

The gradient of the righting lever curve at zero degrees heel is found by the first derivation of the equation GZ = GH · sin ϕ:

$$\frac{dGM}{d\phi} = \tan \alpha_{(\phi = 0)} = GM \cdot \cos 0° = GM$$

The triangle showing the gradient angle has a base of 1 radian = 57.3°. This triangle can be used to draw the righting lever curve in the vicinity of 0° heel.

1.1.3 Influence of liquid free surfaces

Any liquid free surfaces in tanks or other spaces on board will move athwartship as the ship heels and thus increase the heel. Liquid free surfaces have an adverse effect to stability and should therefore be generally avoided.

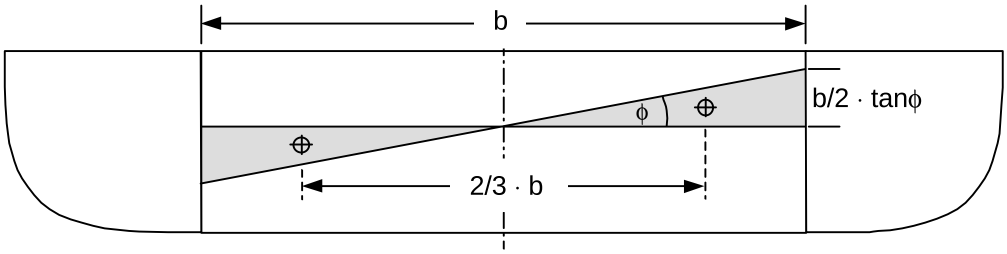


Figure 5: Liquid free surface in a double bottom tank of length l and breadth b

The heeling moment from a liquid free surface acting at a tiny angle of heel ϕ can be calculated from the prism of liquid moving athwartship.

$$\text{volume} = \frac{b}{2} \cdot \frac{b}{2} \cdot \tan\phi \cdot \frac{1}{2} \cdot l \quad [m^3]$$

$$\text{distance} = \frac{2}{3} \cdot b \quad [m]$$

$$\text{mass moment} = \frac{l \cdot b^3}{12} \cdot \rho \cdot \tan\phi \quad [t \cdot m]$$

This transverse mass moment causes the ship's centre of mass to shift by

$$GG_1 = \frac{l \cdot b^3 \cdot \rho}{12 \cdot DISM} \cdot \tan\phi \quad [m]$$

Figure 6 shows the remaining righting arm G_1Z. Figure 6 shows further

$$GG_1 = GG_c \cdot \tan\phi \quad [m]$$

Combining the two equations for GG_1 provides a formula which shows the influence of liquid free surfaces independent from the angle of heel.

$$GG_c = \frac{l \cdot b^3}{12 \cdot DISM} \cdot \rho = \frac{i_B \cdot \rho}{DISM} \quad [m]$$

The term $l \cdot b^3 / 12$ is the moment of inertia for a rectangular area l · b. It is referred to as i_B.

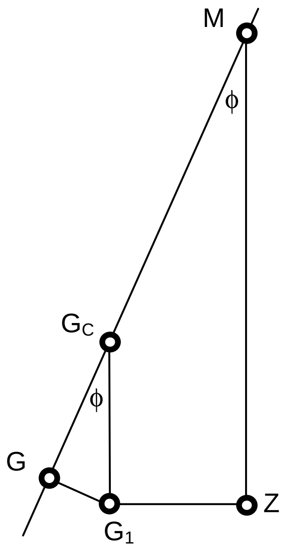


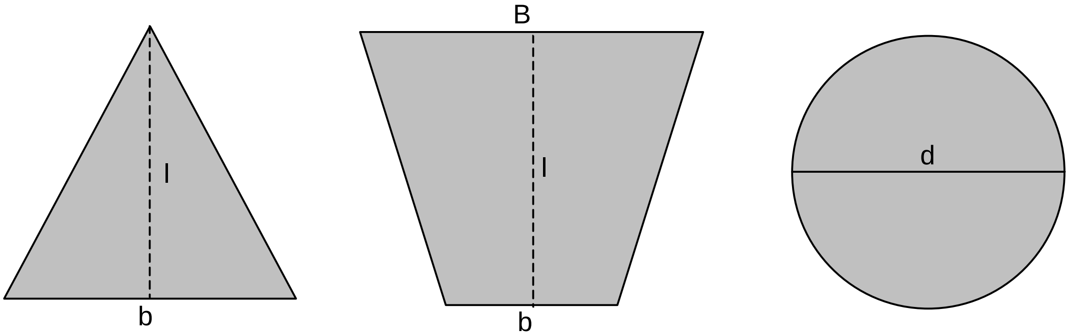
Figure 6: Correction for liquid free surfaces GGc

The term i_B can be obtained for any shape of free surface by adding narrow stripes of rectangular shape. Values of i_B are provided for the ship's tanks in the Loading and Stability Manual. The calculation of GG_c for a number of liquid free surfaces is:

$$GG_c = \frac{\sum (i_B \cdot \rho)}{DISM}$$

The vertical position of the tank, i.e. is it a double bottom tank, side tank, top tank or swimming pool, has no influence on the free surface effect.

Special terms of i_B are given for surfaces of triangular, trapezoid and circular shape.



$$i_B = \frac{l \cdot b^3}{48} \qquad i_B = \frac{l \cdot (B^4 - b^4)}{48 \cdot (B - b)} \qquad i_B = \frac{\pi \cdot d^4}{64}$$

Figure 7: Moments of inertia for special shapes

The free surface effect can be interpreted as an apparent lifting of G which increases KG to KG_c or reduces GM to GM_c. The apparent centre of mass G_c is relevant to all practical considerations within the management of ship's stability.

Homework exercises No. 1

For the following exercises the ship is assumed to be immersed in seawater. Recommended scale for GZ-curves:

ϕ-axis:	10°	$\Rightarrow$	2 cm
GZ-axis:	0.1 m	$\Rightarrow$	1 cm

.1 MV. Nautilus: draught T_{KC} = 7.60 m; KG = 8.60 m; $\Sigma i_B \cdot \rho$ = 328 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.2 MV. Nautilus: draught T_{KC} = 6.25 m; KG = 8.24 m; $\Sigma i_B \cdot \rho$ = 433 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.3 MV. Nautilus: draught T_{KC} = 5.12 m; KG = 6.48 m; $\Sigma i_B \cdot \rho$ = 659 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.4 MV. Nautilus: draught T_{KC} = 4.84 m; KG = 8.73 m; $\Sigma i_B \cdot \rho$ = 244 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.5 MV. Nautilus: draught T_{KC} = 8.31 m; KG = 8.45 m; $\Sigma i_B \cdot \rho$ = 572 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.6 MV. Bockenheim: draught T_{KC} = 10.55 m; KG = 9.40 m; $\Sigma i_B \cdot \rho$ = 936 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

.7 MV. Bockenheim: draught T_{KC} = 8.64 m; KG = 7.35 m; $\Sigma i_B \cdot \rho$ = 571 t·m
Determine DISV, DISM, GM_C, KG_C and draw the GZ-curve.

1.2 Loading and Stability Manual

Loading and Stability Manuals are required by the SOLAS Convention and the International Load Line Convention ILLC. They shall contain all necessary information to enable the master and his officers to load and operate the ship in a safe manner.

IMO has developed a Model Loading and Stability Manual and published it by MSC/Circ. 920 in June 1999, with the aim to promote a world-wide uniform layout and terminology of such information. The manual for MV. Nautilus, Version 2.0, follows the proposed draft layout. It contains symbols and abbreviations being currently under consideration within Standards Organizations (CEN and ISO).

It is of utmost importance for any master or cargo officer to get familiarised with the arrangement and details of information contained in the Loading and Stability Manual of his present ship. For the purpose of training the following questions and exercises should be worked with reference to the manual of MV. Nautilus.

Homework exercises No. 2

.1 Give the principal dimensions of the ship.

.2 Give the winter-, summer- and the tropical draught.

.3 The after peak is filled with sea water to 3.6 m sounding. Give volume, mass, free surface moment and the co-ordinates of the after peak contents.

.4 Draught T_{KC} = 6.95 m. Give DISV, DISM, TPC, KM, MTM, XB and XF.

.5 Draught T_{KC} is 7.25 m. Give the LK-values for this draught.

.6 Explain the Information Category 1A.

.7 Give the co-ordinates of a 20'-container in Bay 15, Tier 84, Row 01 with ZG at 50% h_c.

.8 Give the co-ordinates of a 40'-container in Bay 20, Tier 06, Row 06 with ZG at 40% h_c.

.9 Give the maximum stack load for Bay 08, Row 03 on deck.

.10 Give the maximum stack load for Bay 17, Row 02 in hold.

.11 Explain the difference between the figures of DISV and DISM within Table 6 for any given draught T_{KC}.

.12 How many 9.5' high cube containers can be stowed in Bay 13 under deck?

.13 Which density of HFO is used in the manual?

.14 What is the total capacity of HFO tanks?

.15 Which ballast tank shows the most severe free surface effect?

.16 Which "angle of flooding" appears at 7 m draught and 1 m trim by stern?

.17 Which is the maximum permissible KG_c at 7 m draught and 3 tiers containers on deck with regard to the IMO Intact Stability Code?

.18 Give the mass and the co-ordinates of the "light ship".

.19 Give the minimum operational draughts forward and aft.

.20 Bay 03 is loaded on deck with 4 tiers. Give the maximum permissible stern trim with 8 m mean draught due to SOLAS sight line requirements.

1.3 Determination of KG_c

KG_c can be found by two methods. The first method is the calculation of masses and moments. This can be done at any early planning stage in a complete synthetic way.

The second method is the direct measurement of GM_c by an in-service inclining test or by evaluation of the ship's natural period of roll. From this GM_c the KG_c is obtained. It is obvious that for the measurement method the ship must be available and loaded to the actual condition.

1.3.1 Calculation of masses and moments

The principle of this calculation is demonstrated by the task to find the centre of mass of a number of heavy balls of different weights lined up on a weightless rod.

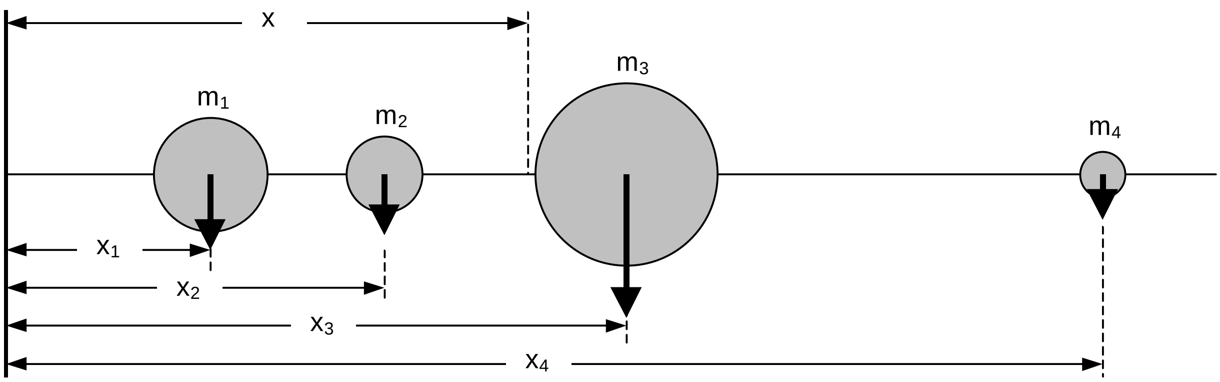


Figure 8: Centre of mass of lined up balls

Figure 8 shows 4 balls of different masses and different distances from an arbitrary reference line. The right turning mass moments can be described as:

$$\sum_{i=1}^{4}(m_i \cdot x_i)$$

The counter-balancing left turning moment will be:

$$x \cdot \sum_{i=1}^{4} m_i$$

So the distance of the counter-balancing force (at the centre of mass) from the reference line is:

$$x = \frac{\sum_{i=1}^{4}(m_i \cdot x_i)}{\sum_{i=1}^{4} m_i}$$

This formula can be converted for the calculation of KG_c as follows:

$$KG = \frac{\sum(m_i \cdot ZG_i)}{DISM} \qquad [m]$$

$$KG_c = KG + \frac{\sum(i_B \cdot \rho)}{DISM} \qquad [m]$$

$$KG_c = \frac{\sum(m_i \cdot ZG_i) + \sum(i_B \cdot \rho)}{DISM} \qquad [m]$$

The practical calculation uses a clearly arranged calculation pattern which can be seen in the Loading and Stability Manual of MV. Nautilus.

For a single added or subtracted mass in the system a simple formula can be derived from the above formula:

$$\Delta KG_C = \frac{\pm m \cdot (ZG - KG_C)}{DISM \pm m} \qquad [m]$$

Example: DISM = 12500 t; KG_c = 8.50 m; m = 130 t to be loaded in ZG = 14.35 m. Calculate the change of KG_c:

$$\Delta KG_c = \frac{130 \cdot (14.35 - 8.50)}{12500 + 130} = 0.06\,m$$

Even more simple is the formula obtained for the change of KG_c from a vertical shift of a single mass:

$$\Delta KG_c = \frac{m \cdot e}{DISM} \qquad [m]$$

The distance e should be taken as the vertical component of any true distance of shifting.

Example: DISM = 2580 t; shifting of 45 t from ZG = 12.4 m to ZG = 2.5 m. Calculate Δ KG_c:

$$\Delta KG_c = \frac{45 \cdot (2.5 - 12.4)}{2580} = -0{,}17\,m$$

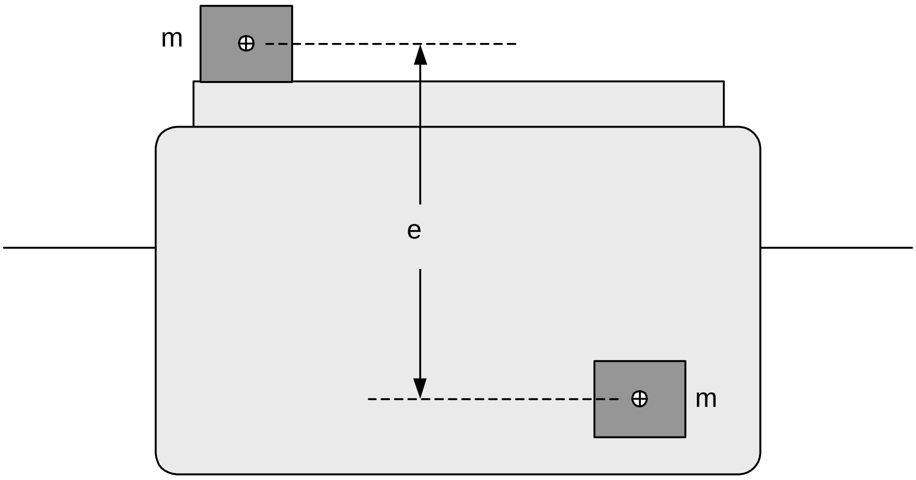


Figure 9: Vertical shift of a single mass

Homework exercises No. 3

.1 MV. Bockenheim shall be loaded as follows:

FO deep tanks P+S 98%

FO bunker tanks P+S 98%

FO settling tanks each 50%

DO tanks 8 P+S 80%

LO tanks 10,11 C 98%

FW engine room 100%

Hold 1 full with 3753 t

Hold 2 full with 4158 t

Hold 3 full with 4161 t

Hold 4 full with 4166 t

Hold 5 full with 4161 t

Hold 6 full with 4166 t

Hold 7 full with 4130 t

Stores: 75.0 t, ZG = 16.76 m

Calculate KG_c, GM_c, DISM, GZ-curve

Note: Don't forget the light ship mass!

.2 MV. Nautilus is loaded as in Condition 8.1:

Calculate KG_c, GM_c and the righting levers after filling the swimming pool.

.3 MV. Nautilus is loaded as in Condition 5.1:

Calculate KG_c, GM_c and the righting levers for the following changes in container masses:

all containers in tier 84 have an average mass of 10 t each,

tier 86 is completely loaded with empty containers of 2 t each.

.4 MV. Nautilus is loaded as in Condition 4.1:

Calculate KG_c, GM_c and the righting levers for the assumption that c.o.g. of all containers is at 43% of container height.

.5 Calculate Δ KG_c and the new KG_c:

DISM = 7365 t;	KG_c = 6.53 m;	m = 1135 t in ZG = 12.40 m
DISM = 8269 t;	KG_c = 8.55 m;	m = 263 t in ZG = 0.75 m
DISM = 12327 t;	KG_c = 7.23 m;	m = 628 t in ZG = 9.77 m
DISM = 4225 t;	KG_c = 5.83 m;	m = - 317 t in ZG = 2.15 m
DISM = 2218 t;	KG_c = 4.66 m;	m = 212 t shifting 4.30 m up
DISM = 9712 t;	KG_c = 6.89 m;	m = 519 t shifting 10.20 m down
DISM = 18725 t;	KG_c = 9.22 m;	m = 1830 t shifting 6.20 m up

1.3.2 In-service inclining test

The in-service inclining test is aimed to determine the actual metacentric height of the vessel by measuring the reaction of the ship to a defined heeling moment. Assumed the ship was upright at the beginning there will be a heeling angle ϕ after the shift of mass m.

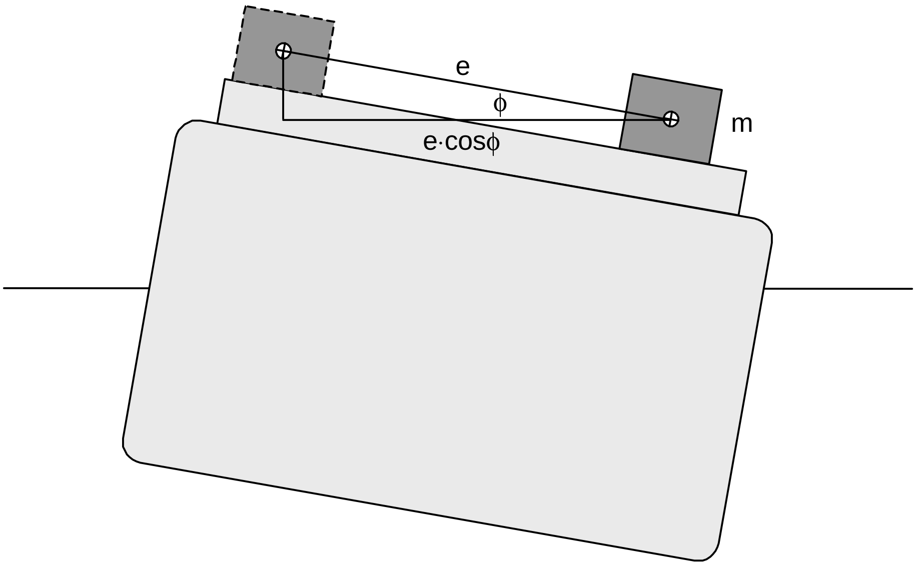


Figure 10: Defined heeling moment m · e

The effective heeling moment is $m \cdot e \cdot \cos\phi$. The righting moment is $DISM \cdot GM_C \cdot \sin\phi$ for $\phi \le 5°$.

$$DISM \cdot GM_C \cdot \sin\phi = m \cdot e \cdot \cos\phi \quad [t \cdot m]$$

$$GM_C = \frac{m \cdot e}{DISM \cdot \tan\phi} \quad [m]$$

In practice there is rarely a perfect upright ship at the beginning of the test. Therefore the angle of heel must be measured before and after the shift of mass and the $\tan\phi$ replaced by $\tan\Delta\phi$.

Other practical aspects of this test are described in detail under chapter 5 of this paper. A sound description is found in the "Bekanntmachung von 1984" by See-BG, pages 4 and 5.

Homework exercises No. 4

.1 MV. Nautilus: mean draught 7.20 m in seawater; shifting an 18.6 t container from 178208 to 178205 produces a change of heel of 2.3° to SB. Determine DISM, GM_c, KG_c.

.2 MV. Nautilus: mean draught 8.15 m in water of 1.018 t/m^3; shifting a 20.4 t container from 098407 to 078606 produces a change of heel of 1.9° to PS. Determine DISM, GM_c, KG_c.

.3 MV. Nautilus: mean draught 7.68 m in water of 1.009 t/m^3; shifting a crane boom from port to starboard at 10° boom angle produces a change of heel of 4.1° to SB. Determine DISM, GM_c, KG_c.

.4 MV. Nautilus: mean draught 6.85 m in fresh water; shifting a crane boom from longitudinal position to 90° starboard at 10° boom angle produces a change of heel of 2.4° to SB. Determine DISM, GM_c, KG_c.

Note: DISM in dock-water must be calculated by the Archimedian law: DISM = DISV · ρ

1.3.3 Evaluation of period of roll

The natural period of roll T_ϕ of the vessel can be used to calculate the metacentric height GM_c. The theory of this method is based on the physical pendulum.

$$T_\phi = 2\pi \sqrt{\frac{\text{moment of inertia}}{\text{nominal righting moment}}}$$

Moment of inertia = $\sum \left(m_i \cdot r_i^2 \right)$

Nominal righting moment = $DISM \cdot g \cdot GM_c$

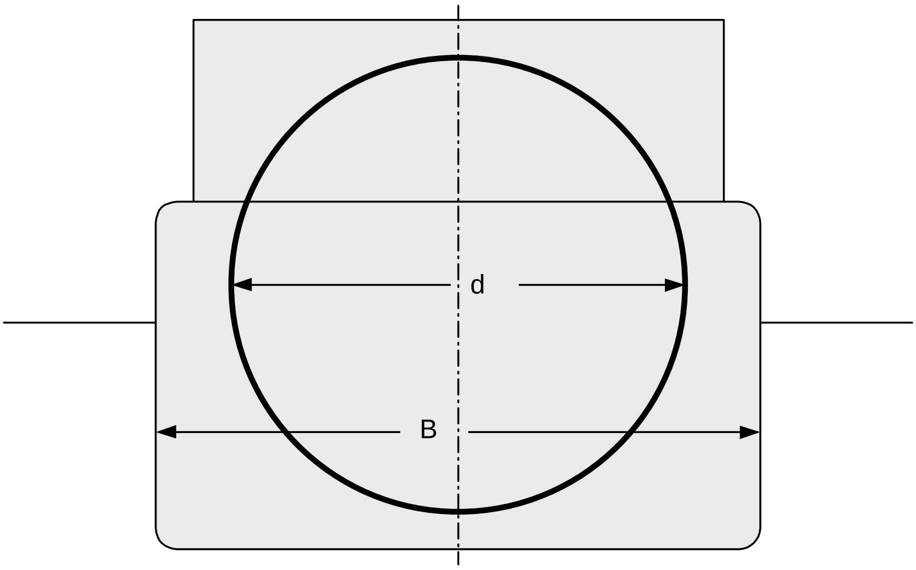


Figure 11: Tube of equivalent moment of inertia

The moment of inertia of the ship about its longitudinal axis can be expressed by the equivalent moment of inertia of a tube with the diameter d and the mass equal to DISM.

With this assumption the formula for T_ϕ reads:

$$T_\phi = 2\pi \sqrt{\frac{DISM \cdot d^2/4}{DISM \cdot g \cdot GM_c}}$$

This equation can be simplified to:

$$T_\phi = \frac{d}{\sqrt{GM_c}} \quad \text{or} \quad GM_c = \left(\frac{d}{T_\phi}\right)^2$$

Usually d is expressed as a proportion of the ship's breadth B with the appropriate co-efficient C_ϕ:

$$d = C_\phi \cdot B$$

So the final version of the formula reads:

$$T_\phi = \frac{C_\phi \cdot B}{\sqrt{GM_c}} \quad \text{or} \quad GM_c = \left(\frac{C_\phi \cdot B}{T_\phi}\right)^2$$

The dimensions are no longer correct since π has been simplified against the square-root of g. The value of C_ϕ can only be estimated. It should be taken as 0.76 for homogeneously loaded vessels. It tends to be greater up to 0.82 with large peripheral masses like ballast in double bottom and side tanks or high deck cargo. It tends to be smaller up to 0.70 with masses concentrated to the centre of the ship's hull like iron ore cargo.

The measurement of rolling periods must be done in port. Rolling motions at sea are disturbed by forced oscillations from waves and offset by the influence of ship's speed.

Practical aspects of this method are described under chapter 5 of this paper as well as in the "Bekanntmachung von 1984" by See-BG, pages 5 to 7.

Homework exercises No. 5

.1 MV. Nautilus is loaded to reference draught 6.83 m in dock-water of 1.018 t/m^3. 1.5 roll-oscillations are observed taking 26.4 seconds. C_ϕ is estimated to 0.78. Calculate DISM and KG_c.

.2 MV. Nautilus is loaded to reference draught 8.29 m in seawater. 2 full roll-oscillations are observed taking 43.6 seconds. C_ϕ is estimated to 0.82. Calculate DISM and KG_c.

.3 MV. Bockenheim is loaded to reference draught 10.85 m in dock-water of 1.020 t/m^3. 1 roll-oscillation is observed taking 18.8 seconds. C_ϕ is estimated to 0.72. Calculate DISM and KG_c.

.4 Explain conditions of a ship influencing the C_ϕ-value.

.5 Explain the method of triggering and observing roll-oscillations in a practical way.

1.4 Stability criteria

Stability criteria are established to describe minimum requirements. They originate from research on ship losses and stability accidents. Observing such minimum requirements does not provide absolute safety in any condition of weather and seaway. There is only a high probability that the ship will survive.

The so-called **IMO-criteria**, laid down in the Intact Stability Code, are commonly accepted world-wide. Also ships under German flag will be operated under IMO-criteria after 1999.

Existing ships under German flag may however still be operated with the **See-BG-criteria** laid down in the "Bekanntmachung von 1984". See-BG-criteria are more stringent. They provide a higher margin of safety, and consequently less deck cargo capacity.

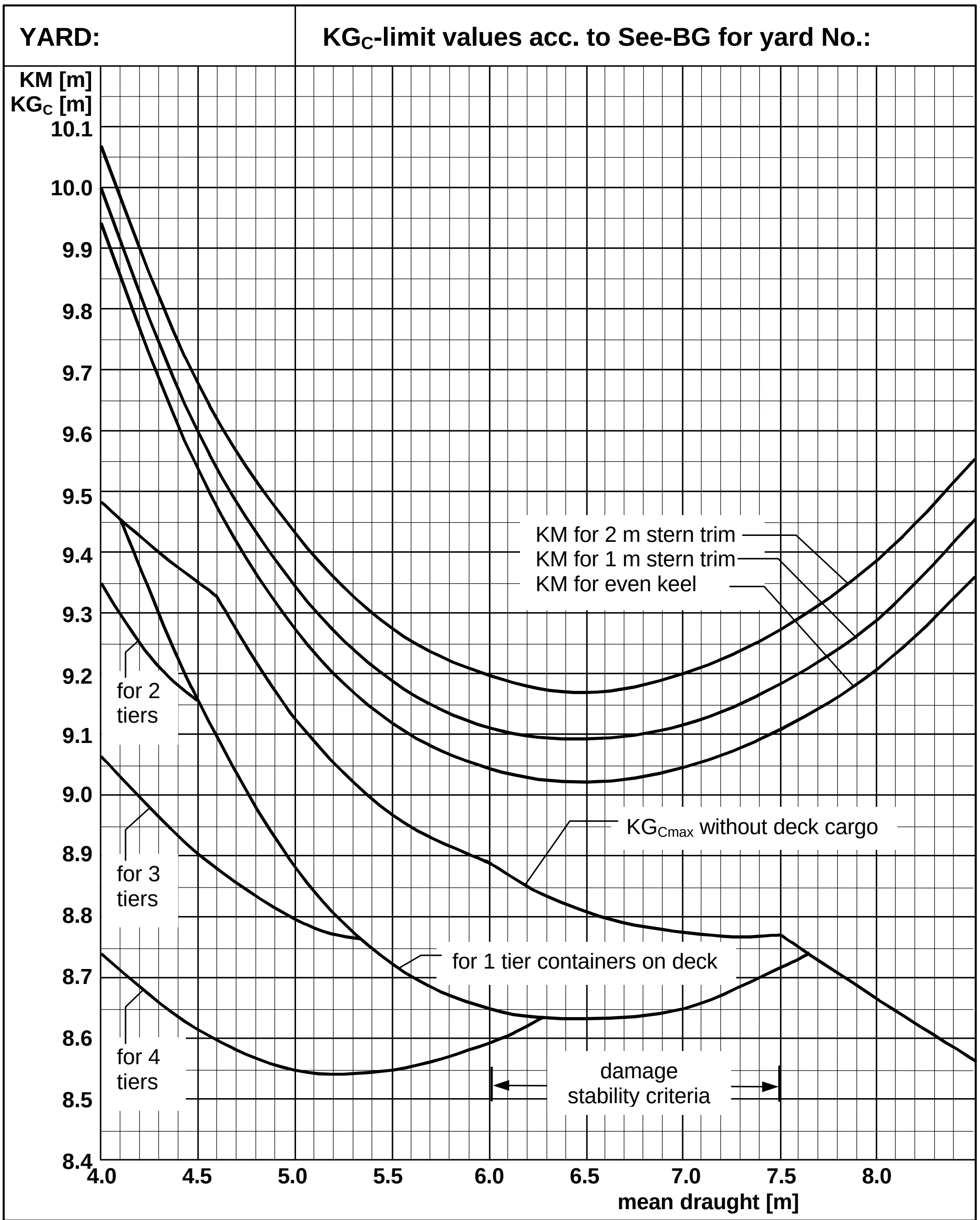
The following overview is applicable for normal dry cargo ships including container ships:

See-BG-criteria	**IMO-criteria**
$GZ_{30} \geq 0.20$ m for $L \leq 100$ m	$GZ \geq 0.20$ m at $\phi \geq 30°$
$GZ_{30} \geq 0.002 \cdot L$ for $100 < L \leq 200$ m	GZ_{max} at $\phi \geq 25°$
$GZ_{30} \geq 0.40$ m for $L > 200$ m	
$GM_c \geq 0.15$ m	$GM_c \geq 0.15$ m
$A_{30} \geq 0.055$ m·rad	$A_{30} \geq 0.055$ m·rad
$A_{40} \geq 0.090$ m·rad	A_{40} or $A_F \geq 0.090$ m·rad
$A_{30\text{-}40} \geq 0.03$ m·rad	$A_{30\text{-}40}$ or $A_{30\text{-}F} \geq 0.03$ m·rad
Range of positive GZ values ≥ 50°	
GZ_{30} to be increased if range < 60°	Weather criterion to be used in addition to the above criteria: area **b** ≥ area **a** (see IS-Code)
Deck cargo:	
heel from wind pressure less than 18° or less than an angle producing 10% residual freeboard on the low side and	
$GM_c \geq 0.30$ m for $L \leq 100$ m	
$GM_c \geq 0.005 \cdot L - 0.2$ for $100 < L \leq 120$ m	A_F = area under the righting lever curve up to the angle of flooding
$GM_c \geq 0.40$ m for $L > 120$ m	

This overview does not provide all details. The original text must be used for individual application of the criteria. The following calculation scheme may be used for calculating the areas under the righting lever curve, provided, the angle of flooding is greater than 40°.

f	**GZ(f) [m]**	**Area up to 30°**		**Area up to 40°**	
		Factor	Product	Factor	Product
10°		3		2	
20°		3	+	1	+
30°		1	+	2	+
40°				0,5	+
		Σ_1 =		Σ_2 =	
Areas [m·rad]		Factor 0,0654 $A_{30°}$ =		Factor 0,1164 $A_{40°}$ =	
				$-A_{30°}$ =	
				$A_{40°} - A_{30°}$ =	

Both, See-BG- and IMO-criteria, are not very comfortable for practical use. They are intended as approval criteria to be used by the flag State Administration in the first place. Their use in daily shipboard practice requires pre-calculated curves or tables of limiting values of KG_C or GM_C in relation to the mean draught. This information is mandatory by SOLAS regulation. Such a table of limiting KG_C-values is given in the Loading and Stability Manual of MV.Nautilus. Height of deck cargo may be a separate parameter as it influences the wind pressure.



By observing the above KG_C limit values the stability criteria according to the See-BG "Bekanntmachung von 1984" will be complied with.
The lower KG_C limit values for deck cargo must be observed, if the mass of containers loaded on deck exceeds 10 % of the mass of containers loaded in the cargo holds. Between the limit curves for one to four tiers of containers on deck should be interpolated as appropriate. The KG_C limit values remain valid also with stern trim and thereby greater KM values.

Figure 12: KG_C-limit curves for MV. Nautilus by See-BG

Another aspect of judgement regards the ship's behaviour in a seaway. A ship is considered as

- **stiff** with $T_\phi \le 0.75 \cdot B$,
- **normal** with $0{,}75 \cdot B < T_\phi \le 1.25 \cdot B$,
- **weak** with $1.25 \cdot B < T_\phi \le 2 \cdot B$,
- **tender** with $2 \cdot B \le T_\phi$. (B in metres compared to T_ϕ in seconds)

Homework exercises No. 6

.1 Criteria by See-BG:

A ship of L = 98 m shows the following stability parameters: GM_C = 0.58 m; GZ_{10} = 0.09 m; GZ_{20} = 0.16 m; GZ_{30} = 0.20 m; GZ_{40} = 0.19 m; GZ_{50} = 0.12 m; GZ_{60} = 0.01 m. Check the suitability of these parameters with regard to the minimum criteria by See-BG.

.2 Criteria by IMO:

A ship of L = 128 m shows the following stability parameters: GM_C = 0.40 m; GZ_{10} = 0.08 m; GZ_{20} = 0.17 m; GZ_{30} = 0.32 m; GZ_{40} = 0.17 m; GZ_{50} = 0.04 m. Check the suitability of these parameters with regard to the minimum criteria by IMO.

.3 Determine the stability parameters of MV. Nautilus at TKC of 8.20 m and KGc of 8.84 m. Check which of the parameters is at its limits.

Note: MV. Nautilus is operating with IMO criteria.

1.5 Effects on stability

The stability of a ship may be affected in various ways. For the general understanding of such effects on stability the most common phenomena are explained below.

1.5.1 Transverse shifting of mass

If a mass within a ship shifts transversely the centre of mass of the whole ship shifts as well.

$$GG_1 = \frac{m \cdot e}{DISM} \qquad [m]$$

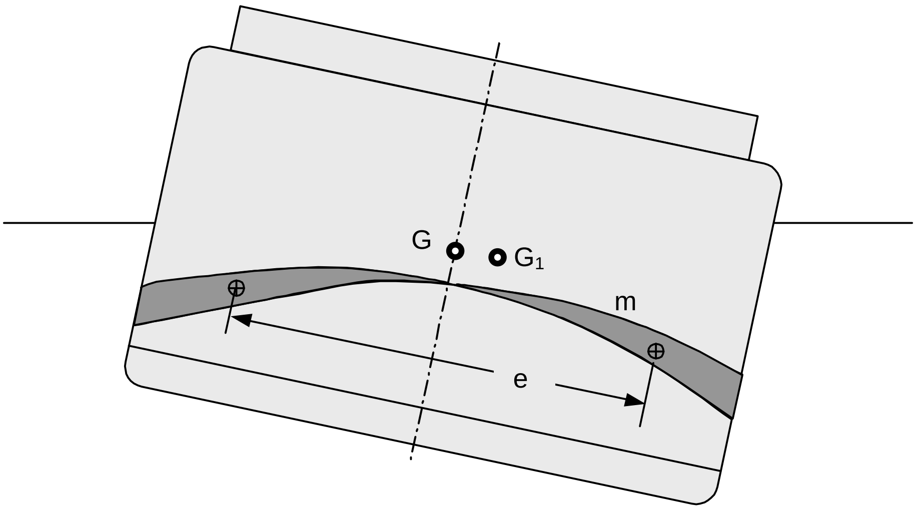


Figure 13: Transverse shifting of mass

This transverse shift of G acts as a heeling lever k_o at 0° heel. For any other heeling angle this heeling lever is reduced to $k_\phi = k_o \cdot \cos \phi$. In this way a complete heeling lever curve can be drawn into the current righting lever diagram.

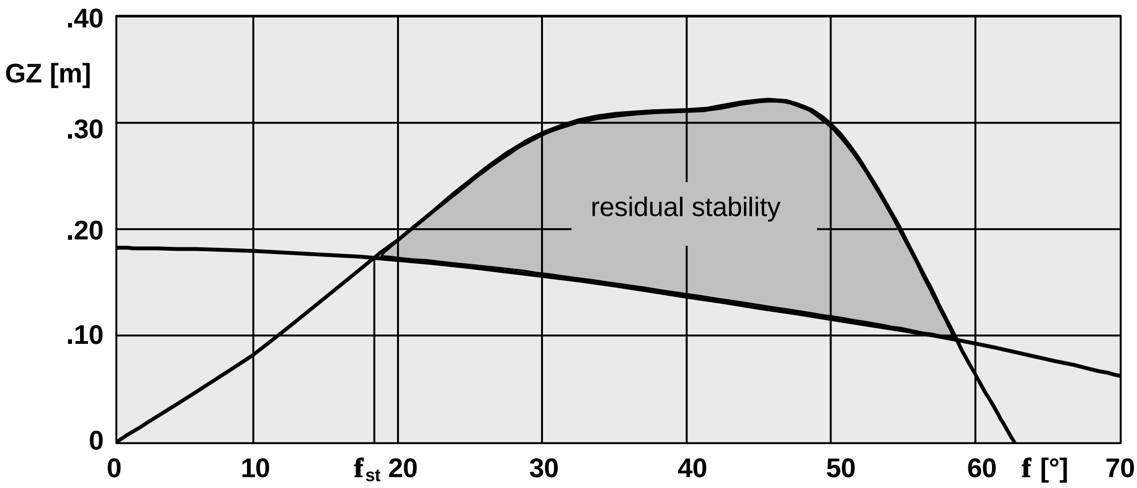


Figure 14: Diagram of righting and heeling levers

From this diagram two important information's can be taken:

- the statical angle of heel,
- the residual stability (hatched area).

There are no commonly agreed criteria as when to abandon ship in such a case. This depends largely on the existing seaway and on remaining chances to reduce the heeling moment quickly by appropriate measures. However, the Grain Code and the Survival Criteria for damaged tankers make use of this balance of righting and heeling levers.

As general advice can be taken: The situation has become critical if the hatched area, presenting the residual stability, is less than the area under a minimum GZ-curve in the upright condition.

If the heeling moment m·e is unknown after a shifting of cargo has occurred, it can be estimated from the observed statical angle of heel. The heeling lever k_ϕ is taken from the righting lever curve at ϕ_{st},

$$k_o = \frac{k_\phi}{\cos \phi_{st}}$$

$$m \cdot e = k_o \cdot DISM$$

The heeling lever curve can be drawn with $k_\phi = k_o \cdot \cos \phi$. In a real distress condition, the heeling lever curve can be replaced by a simple horizontal line, drawn through the intersection of the righting lever curve with a vertical line erected at the angle of heel ϕ_{st}.

1.5.2 Wind pressure

The pressure of wind to a ship's side and deck cargo may result into a considerable list of the ship and is therefore considered as a threat to stability.

A simplified formula for the determination of this list assumes an even pressure distribution over the height of the affected area and a wind direction beam to the ship's course.

Typical wind pressures are given by See-BG in the "Bekanntmachung von 1984" with

$p = 1.0$ kN/m^2 at approximately Bft 12
$p = 0.6$ kN/m^2 at approximately Bft 10
$p = 0.3$ kN/m^2 at approximately Bft 8

The IMO Code on Intact Stability uses 0.504 kN/m^2 for the "weather criterion".

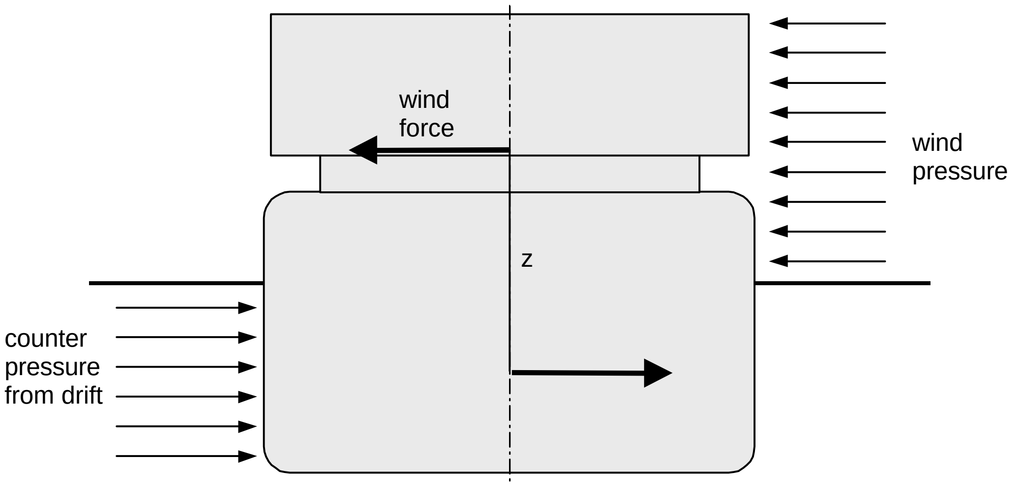


Figure 15: Heeling moment by wind pressure

The wind heeling lever z is defined as the vertical distance from the centre of the projected area of wind attack above the waterline to the centre of the underwater lateral area. The latter can be taken as a point at one half the mean draught.

With the area A of wind attack and the pressure p the heeling moment is $p \cdot A \cdot z$ [kN·m] at 0° heel. This moment is considered not to change remarkably with increasing heel according to the IS-Code. See-BG however assumes a reduction with the cos ϕ or moreover with $(0{,}25 + 0{,}75 \cdot \cos^3 \phi)$.

The corresponding heeling levers, which can be balanced with the righting levers, are calculated as follows (See-BG version).

$$k_\phi = \frac{p \cdot A \cdot z}{9.81 \cdot DISM} \cdot \cos\phi \quad [m]$$

1.5.3 Hard rudder

A ship running at full speed heels to port in a hard rudder turn to starboard and vice versa. The heeling force is the centrifugal force acting in the centre of mass G.

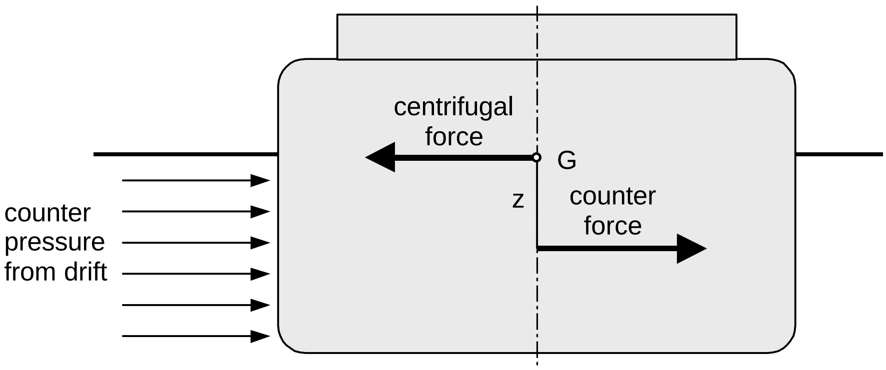


Figure 16: Heeling moment by hard rudder turn

The centrifugal force F is calculated as follows:

$$F = DISM \frac{v^2}{r} \quad [kN]$$

v = ship's speed [m/s] r = radius of turning circle [m]

The heeling lever z is the difference between KG and about one half the draught (KG – T/2).

With the assumption r = 5 · L (IS-Code and See-BG) the heeling moment is:

$$M_F = 0.2 \cdot \frac{v^2}{L} \cdot DISM \cdot \left(KG - \frac{T}{2} \right) \quad [kN \cdot m]$$

or approximately

$$M = 0.02 \cdot \frac{v^2}{L} \cdot DISM \cdot \left(KG - \frac{T}{2} \right) \qquad [t \cdot m]$$

The corresponding heeling levers, related to the ship's displacement DISM, can be balanced with the righting levers:

$$k_\phi = 0.02 \cdot \frac{v^2}{L} \cdot \left(KG - \frac{T}{2} \right) \cdot \cos\phi \quad [m]$$

The assumption of r = 5 · L appears very large for new ships. It is justified to some degree by the fact that the formula is entered with the initial speed of the ship. The better solution would be to introduce observed turning characteristics from the manoeuvring tests of the particular ship. In that case the formula would read, with Adv = measured advance in turning circle test trial:

$$k_\phi = 0.12 \cdot \frac{{v_0}^2}{Adv} \cdot (KG_C - 0.5 \cdot T + 0.25 \cdot B \cdot \tan\phi) \cdot \cos\phi$$

The above formula also considers the increase of the heeling lever by the breadth component of ships with a large B/T-relation, like ferries or passenger vessels.

1.5.4 Negative metacentric height

Negative metacentric height is already the result of certain effects to stability from excessive liquid free surfaces or wrong decisions regarding loading or ballasting the ship, or from water soaking or icing of deck cargo. Nevertheless the behaviour of a ship with negative metacentric height is worth a closer look.

Example: It is assumed that MV. Nautilus has a draught of 7.2 metres and a negative GM_C of – 0.15 m. Then the following righting levers can be found:

KM	=	9.064	m
GM_c	=	– 0.150	m
KG_c	=	9.214	m

f	**10°**	**20°**	**30°**	**40°**	**50°**	**60°**
LK	1.587	3.199	4.707	5.998	6.922	7.437
KG_C x sin f	1.600	3.151	4.607	5.923	7.058	7.980
GZ	– 0.013	0.048	0.100	0.075	– 0.136	– 0.543

From the curve in Figure 17 can be found:

- an unstable condition at zero degree heel,
- two stable conditions at about ± 13.5° heel,
- poor values of positive righting levers and range of stability.

Note: The scale of GZ-values and angle of heel in Figure 17 has been changed against other GZ-curve figures in this booklet.

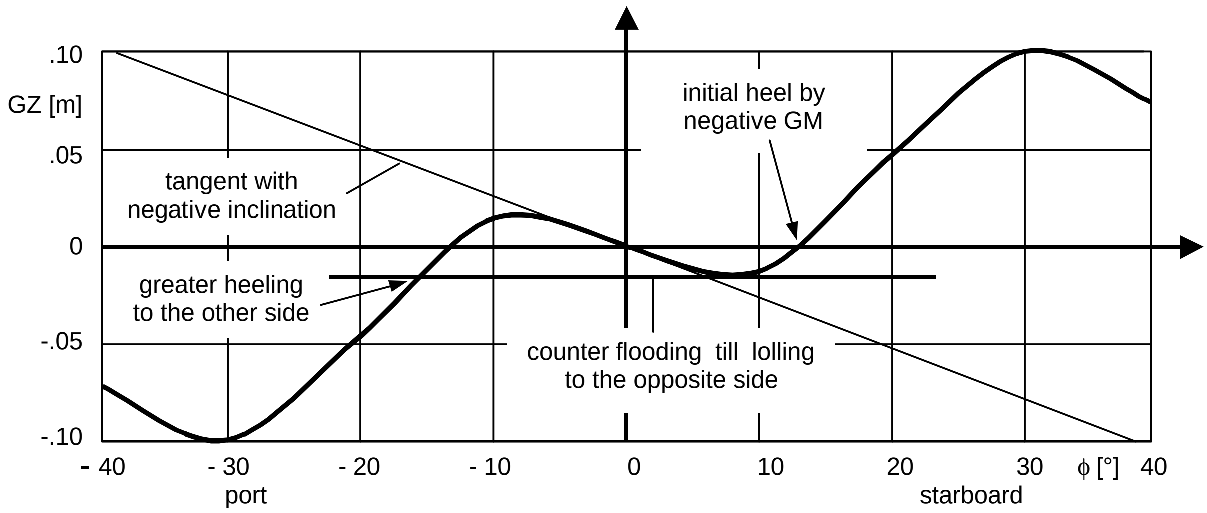


Figure 17: Righting lever curve with negative GM_c

The heeling angles of the two stable conditions can be found more easily by using the approximation for the righting lever curve up to 15° heel from chapter 1.1.2:

$$GZ\,(\phi) = \left(GM + \frac{BM}{2} \cdot \tan\phi^2 \right) \sin\phi$$

In the stable conditions GZ (ϕ) must be equal to zero.

$$0 = GM + \frac{BM}{2} \cdot \tan^2\phi$$

$$\tan\phi = \pm\sqrt{\frac{-2 \cdot GM}{BM}}$$

For the above example ϕ is found by:

$$\tan\phi = \pm\sqrt{\frac{-2 \cdot (-0.15)}{9.064 - 0.53 \cdot 7.2}} = 0.239$$

$$\phi = \pm 13.45°$$

If a ship has a list due to negative metacentric height, any attempt to right the ship by the transverse shift of a mass will result in a sudden heel to the other side to a greater angle than before. During this motion the ship will gather kinetic energy which causes her to swing even further than the new angle of stable condition. This increases the risk of capsizing.

Therefore, any list in port or at sea which cannot be well explained by asymmetrical positioning of masses should be treated as a list from negative metacentric height. This however can only be cured by improving the stability, i.e. by reducing top masses or increasing bottom masses. It should be borne in mind that the development of low positive or even negative values of GM_c can be kept undetected for a while if, in port, the ship is tightly moored to the jetty, or at sea, the weather is calm and the sea smooth.

1.5.5 Heavy seaway

Heavy seaway causes the ship to roll and pitch and there is in principle a risk of cargo shifting which is a threat to stability. Also heavy masses of seawater on deck may impair the stability for a certain time.

Apart from these effects a high breaking wave may throw a small vessel abeam and roll her over. This is called "capsizing by broaching to".

Large vessels however are liable to sustain a considerable "loss of stability" when riding on a wave crest with the direction of the seaway. This effect is severest with waves of the length of the ship and with high ship's speed because then the time span of reduced stability may be sufficient for a capsize. Remarkable reduction of speed is necessary.

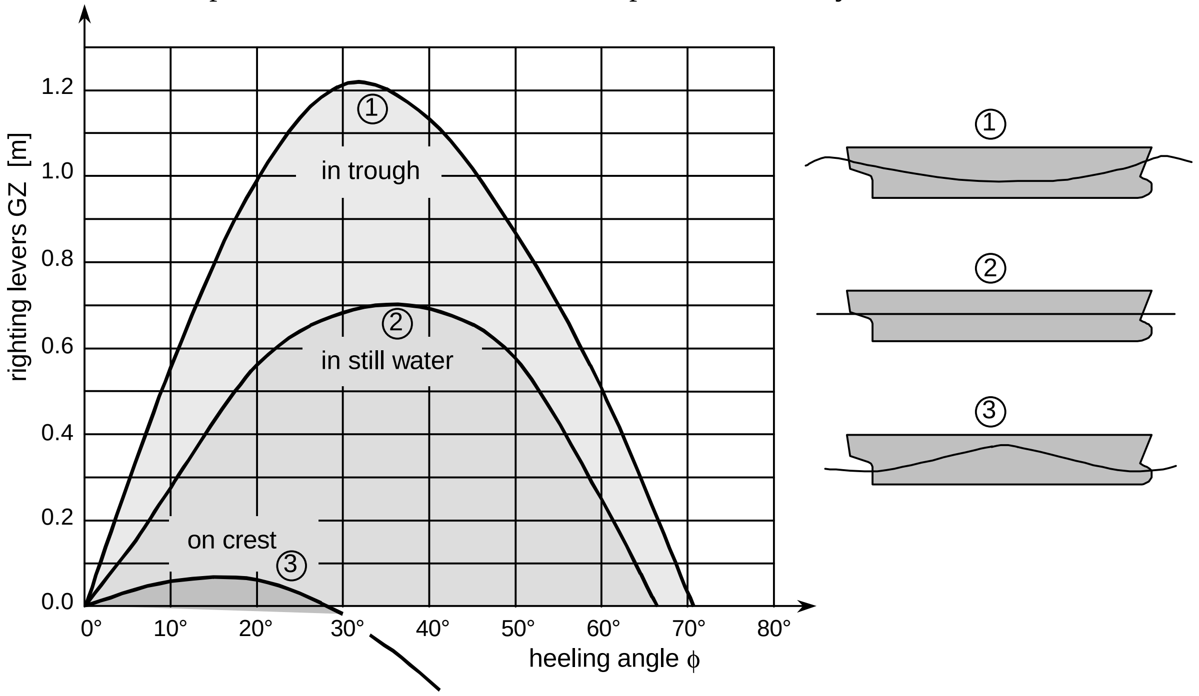


Figure 18: Righting levers in still water, on a wave crest and in a wave trough

The change of, e.g., GZ_{30} between stillwater, crest and trough in absolute figures increases with the size of the ship. Therefore large vessels are suffering from this influence more than small vessels ("scale effect"). For this reason the See-BG-criteria require increased GZ_{30}-values for vessels of 100 m and above.

1.5.6 Resonance with encountered waves

If waves encounter with the ship at intervals which are equal to the rolling period or equal to one half of the rolling period of the ship then there is the risk of resonance. Resonance causes the rolling motions to increase until there is some reason for running out of phase due to change of T_ϕ in high amplitudes or due to irregularity in the seaway. Pure capsizes due to resonance are very rare but shift of cargo with subsequent loss of stability is the more common consequence.

The period of encounter T_E can be pre-estimated by the following formula:

$$T_E = \frac{q \cdot T_w^2}{q \cdot T_w + v \cdot \cos\beta} \quad [s]$$

Tw	=	wave period [s] (to be measured by the foam patch method)
q	=	wave factor = 1.56 m/s^2
v	=	ship's speed [m/s]
β	=	angle of encounter (β = 0 if ship is running against the sea)

Note: $q \cdot T_w^2$ = wave length [m]
$q \cdot T_w$ = wave speed [m/s]

The period of encounter can be largely influenced by changing course and/or speed.

Since the rolling period of the ship may change considerably with the amplitude of roll, depending of the ship's form characteristics, the pre-estimation of resonance may not be very accurate. The method however gives a good basis for on-board observations and the gathering of experience with a particular ship.

1.5.7 Ingress of water

Ingress of water through a leak from bottom damage or collision has four basic effects on stability:

- Added mass with an effect on KG.
- Reduced freeboard with effects on KM and cross-curves.
- Possible free surfaces from the entered water.
- Possible heeling moment if flooding is asymmetrical.

In addition there may be effects to KM and cross-curves if the ship is heavily trimmed by the incoming water. These additional effects cannot readily be accounted for by usual ship-board stability documents.

The other four effects can be easily understood and pre-calculated. Pre-calculation may be time consuming since the final stage of flooding can only be found by iterative calculations. The aim of such pre-calculation however should be the identification of instant remedial measures, in particular counter-flooding or jettisoning of masses in high positions, or the immediate abandoning of the ship if a capsize is to be expected.

Therefore the ISM-Code requires that pre-planned emergency procedures should contain also a set of instructions to the master for appropriate measures in cases of ingress of water.

The general scope of such instructions should include the following aspects:

- Damage to ship's tanks in double bottom or double side will generally require appropriate counter flooding to avoid heavy list of the ship.
- Damage to a cargo hold of the ship in a loaded condition will cause a list in the beginning due to free surfaces. This list may increase to a capsize if the stability was at certain limits. Pre-calculated cases are necessary to demonstrate these limits to the master.
- If this critical phase is overcome without a capsize the metacentric height will become positive again due to the mass of water low in the hold. The righting levers however will become very poor in the end due to the reduced freeboard. Therefore the ship will be sensitive to even small heeling moments. These must be compensated carefully by appropriate counter-flooding into low tanks.
- Damage to the engine room with subsequent water ingress causes heavy trim and increasing free surface effect towards the end of flooding. Counter-flooding of forward tanks may reduce this trim but increase the bending moment. Pre-calculations are necessary for identifying limits to these measures.

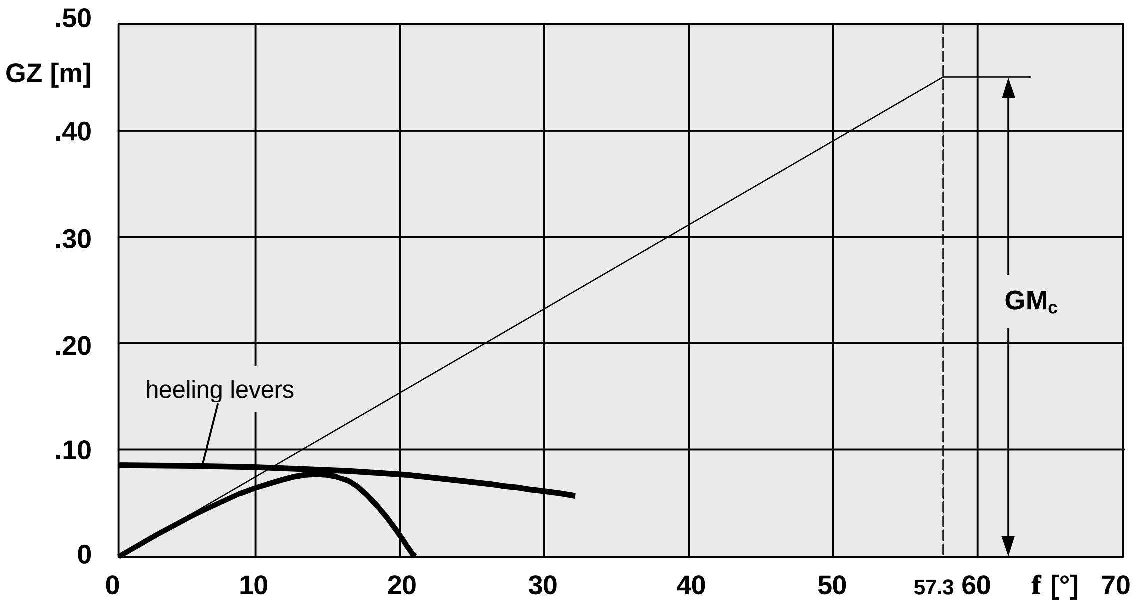


Figure 19: Typical righting levers after flooding a cargo hold on a loaded vessel

Homework exercises No. 7

.1 MV. Nautilus is sailing with break bulk cargo and containers on deck. DISM = 10180.0 t; KG_c = 8.62 m. A heavy cargo unit of 92 t in hold No. 2 shifts by 6 m to port. Show the righting lever curve and the curve of heeling levers. Value the residual stability.

.2 Same as above: DISM = 8225.6 t; KGc = 8.70 m; shifted mass = 160 t cement; distance = 5 m.

.3 MV. Nautilus is sailing as in loading condition 7.1. In very heavy weather the following containers are lost over board:

Position 018201

Position 018203

Position 018401

Position 018403

Position 018405

Show the righting lever curve and the curve of heeling levers. Value the residual stability.

.4 MV. Nautilus is sailing with a cargo of dry fertiliser in bulk. DISM = 13240.0 t; KG_c = 7.80 m. In very heavy weather the ship develops a list of 15° to starboard. Value the residual stability of the ship.

.5 MV. Nautilus is sailing as in condition 7.1. Determine the expected list in a wind of 10 Bft from the starboard side.

.6 MV. Nautilus is sailing as in condition 7.2. Calculate the expected heel in a hard rudder turn to starboard (speed = 15 knots); r = 300 m.

.7 MV. Nautilus has a draught of 7.40 m and a negative GM_c of – 0.12 m. Calculate the expected angle of loll.

.8 MV. Nautilus is sailing as in condition 2.1. After a collision water is entering the empty cargo hold No. 2. Examine the initial stability (GM_C) at the following stages of flooding:

0.5 m water in hold 2

1.5 m water in hold 2

2.5 m water in hold 2

4.5 m water in hold 2

final stage of flooding (water inside at draught level)

.9 MV. Nautilus is sailing in a strong wind and sea from 280° with a course of 155° and 14 knots. Determine the period of encounter with an observed period of 8.5 seconds.

.10 Same as above: T_w = 9.2 s; wind and sea from 225°; course 350°; speed 12 knots.

.11 A ship of 160 m length is running with 18 knots before a seaway with waves with T_w = 10.7 s. Calculate the wave length. Calculate the wave speed. Calculate the time which an overtaking wave crest requires to pass from L/4 to 3 · L/4 of the ship.

2. Draught and trim

2.1 Pre-calculation of draught and trim

Similar to the calculation of the vertical distance KG of the centre of mass above the base line, also the longitudinal distance from an agreed reference plane can be obtained. This plane is generally the aft perpendicular AP.

$$XG = \frac{\Sigma\left(m_i \cdot XG_i\right)}{DISM}$$

The distance of the centre of buoyancy XB from AP is shown for the ship on even keel in the hydrostatic table. The following calculation gives the expected trim of the vessel:

$$\text{trimming lever} = (XG - XB) \qquad [m]$$

$$\text{trimming moment} = DISM \cdot (XG - XB) \qquad [t \cdot m]$$

$$\text{trim} = \frac{\text{trimming moment}}{\text{moment to trim one metre}} \qquad [m]$$

$$t = \frac{DISM\left(XG - XB\right)}{MTM} \qquad [m]$$

The trim t is the difference of draughts at AP and FP: $t = T_{KF} - T_{KA}$ [m]

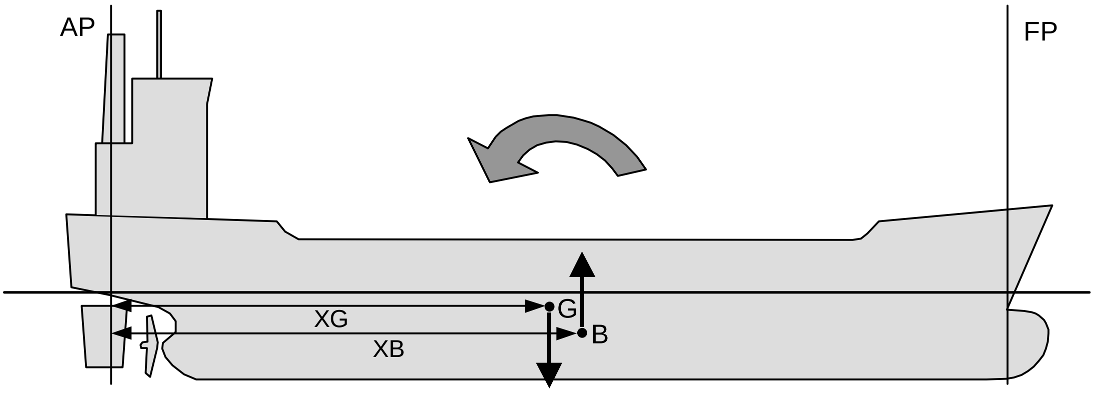


Figure 20: Trimming lever and trimming moment

The trimming moment will cause the ship to rotate about a transverse axis until B has moved under G. The position of this transverse axis is the centre of flotation F. Only this position provides that the immersed volume of the ship remains unchanged during the trimming motion. The shaded volumes forward and aft of F in Figure 21 will then be equal.

The keel draught at AP, FP and MP is thus obtained by:

$$T_{KA} = T_{KC} - t \cdot \frac{XF}{L} \qquad [m]$$

$$T_{KF} = T_{KC} - t \cdot \left(\frac{XF - L}{L}\right) \qquad [m]$$

$$T_{KM} = \frac{(T_{KA} + T_{KF})}{2} \qquad [m]$$

The mean draught T_{KM} is usually not equal to the reference draught T_{KC}.

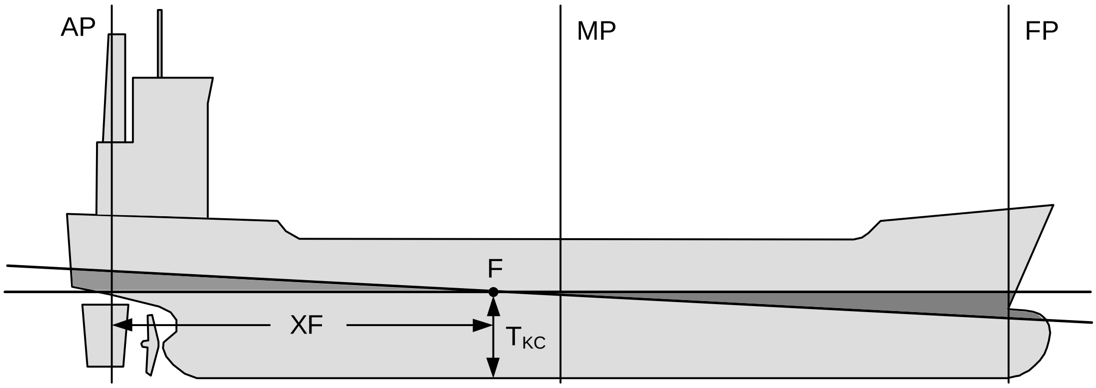


Figure 21: Trimming about the axis through F

Example: MV. Nautilus has a calculated DISM = 11815.0 t and an XG = 57.88 m. From the hydrostatic table is taken:

T_{KC} = 7.60 m
XB = 59.03 m
MTM = 13569 tm/m
XF = 56.41 m

$$t = \frac{11815 \cdot (57.88 - 59.03)}{13569} = -1.00\,\text{m}$$

$$T_{KA} = 7.60 + 1.00 \cdot \frac{56.41}{117.6} = 8.08\,\text{m}$$

$$T_{KF} = 7.60 + 1.00 \cdot \frac{(56.41 - 117.6)}{117.6} = 7.08\,\text{m}$$

$$T_{KM} = \frac{(8.08 + 7.08)}{2} = 7.58\,\text{m}$$

If XG for a ship in a given loaded condition is unknown, but required for a further calculation of draught and trim, a reasonably accurate value of XG can be obtained by reading draughts fore and aft and entering the reversed formula for the trim.

$$XG = \frac{t \cdot MTM}{DISM} + XB \qquad [\text{m}]$$

This method may be somewhat inaccurate if DISM, MTM and XB are taken from the hydrostatic table using T_{KM} instead of T_{KC}. Another error may be introduced when draught readings at marks are used instead draught values at perpendiculars (refer to chapter 3.2).

2.2 Calculation of change of trim

During cargo operations the question for an expected change of trim due to loading or unloading or longitudinal shifting a mass may arise. Loading or unloading at the centre of flotation F will cause no change of trim but a parallel immersion or emersion only.

Any longitudinal shifting a mass m by the distance e will cause the trimming moment m·e. The produced change of trim will be:

$$\Delta t = \frac{m \cdot e}{MTM} \qquad [m]$$

For loading or unloading a mass the distance e must be referred to the position of F.

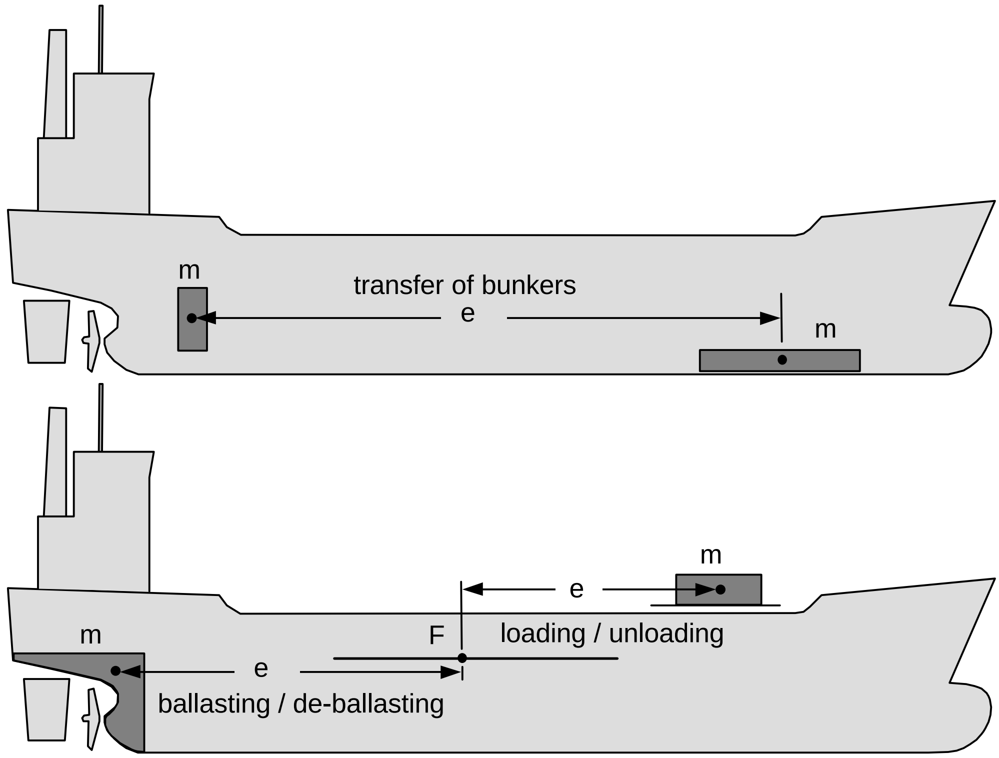


Figure 22: Change of trim by longitudinal transfer, loading or unloading

The sign of Δt should be determined by observing the plausibility. The result Δt is accurate for small values of m only. In shipboard practice m should not be greater than 0.05 · DISM.

Example: MV. Nautilus is loading containers with the present draught T_{KF} = 5.28 m and T_{KA} = 6.74 m. The present trim is – 1.46 m. What will be the change of trim after loading 65 t into bay 01?

T_{KM} = 6.01 m; XF = 58.83 m; XG of bay 01 = 106.9 m; MTM = 10714 tm/m

$$\Delta t = \frac{65 \cdot (106.9 - 58.83)}{10714} = 0.29\,\text{m forward}$$

The residual trim will be – 1.46 + 0.29 = – 1.17 m.

Example: MV. Nautilus is underway with about 8.10 m draught and – 1.20 m trim. What will be the change of trim after a transfer of 50 t HFO from bunker tank No. 1.3 to the settling tanks aft?

XG of bunker tank No. 1.3 = 58.52 m; XG of settling tanks = 28.23 m; MTM = 14936 tm/m

$$\Delta t = \frac{50 \cdot (58.52 - 28.23)}{14936} = 0.10\,\text{m aft}$$

The residual trim will be – 1.20 – 0.10 = – 1.30 m.

Another change of trim will be observed when a ship passes from seawater to fresh water or vice versa. The reason for this is the change of draught and the following change of XB. This change of trim is small but may be of importance when draught is critical due to restrictions in the water depth of a harbour.

Example: MV. Bockenheim is bound for Bremen with a full cargo of grain. The permissible draught at the berth is 10.80 metres in fresh water where the ship shall arrive exactly on even keel. What must be the trim at the Weser entrance in seawater notwithstanding the additional change of trim due to fuel consumption?

Draught in fresh water =	10.80 m;	XB = 88.81 m
Draught in seawater =	10.56 m;	XB = 88.89 m
DISM = 38645 t;		MTC = 467 tm/cm

$$\Delta t = \frac{38645 \cdot 0.08}{467} = 6.6\,\text{cm forward}$$

The consumption of about 8 t fuel under way at x = 27.8 m gives an additional change of trim with XF = 85.6 m:

$$\Delta t = \frac{8 \cdot (85.6 - 27.8)}{467} = 1.0\,\text{cm forward}$$

The ship must have a trim by stern of about 8 cm at the Weser entrance in seawater in order to arrive in Bremen on even heel.

Homework exercises No. 8

.1 MV. Nautilus: DISM = 8324 t; XG = 56.83 m; water density = 1.019 t/m^3.
Determine T_{KF} and T_{KA}.

.2 MV. Nautilus: DISM = 10728 t; XG = 59.68 m; water density = 1.008 t/m^3.
Determine T_{KF} and T_{KA}.

.3 MV. Nautilus: DISM = 12918 t; XG = 57.10 m; water density = 1.022 t/m^3.
Determine T_{KF} and T_{KA}.

.4 MV. Bockenheim: DISM = 41712 t; XG = 86.82 m; water density = 1.016 t/m^3.
Determine T_{KF} and T_{KA}.

.5 MV. Bockenheim: DISM = 38798 t; XG = 89.12 m; water density = 1.024 t/m^3.
Determine T_{KF} and T_{KA}.

.6 MV. Bockenheim: T_{KF} = 10.29 m; T_{KA} = 10.81 m; water density = 1.020 t/m^3.
Determine approximate DISM and XG.

.7 MV. Nautilus: T_{KF} = 7.24 m; T_{KA} = 8.42 m; water density = 1.010 t/m^3.
Determine approximate DISM and XG.

.8 MV. Nautilus: at 6.60 m T_{KC} in dock water of 1.018 t/m^3.
Determine the change of trim after loading 64 to in Bay 03 deck.

.9 MV. Nautilus: at T_{KC} = 7.84 m in seawater.
Determine the change of trim after discharging 138 to from Bay 05 hold.

.10 MV. Nautilus: at T_{KC} = 8.25 m in fresh water.
Determine the change of trim after filling tank 1.6 from tank 1.1.

.11 MV. Nautilus is partly loaded bound for a dry dock for bottom repairs. DISM = 9220 t; KG_C = 8.60 m; trim = – 2.50 m. Calculate the required bearing load on the ship's heel (x = 10 m fwd AP) for trimming the ship to even keel whereupon the side supports can be put in place (refer to chapter 2.2). Calculate the loss of stability due to this bearing load executed in the keel level. Advise on reasonable remedial measures.

3. Freeboard and dead weight

3.1 Control of freeboard

The observance of sufficient freeboard is a fundamental contribution to the survival probability of ships at sea in several ways:

- freeboard provides reserve buoyancy needed when heavy seas flood the main deck,
- freeboard provides additional form stability when the ship is heeled (see chapter 1.1.2),
- freeboard provides protection against the destructive power of breaking seas.

3.1.1 Basic facts around the Archimedian law

The term mass displacement DISM has been explained in chapter 1.3 as the sum of all masses in the ship including the light ship mass.

$$\text{DISM} = \sum m_i$$

By the law of Archimedes it is also the mass of the displaced water.

$$\text{DISM} = L \cdot B \cdot T \cdot C_B \cdot \rho$$

L	=	length	[m]
B	=	breadth	[m]
T	=	draught	[m]
C_B	=	block co-efficient	
ρ	=	water density	[t/m^3]

The waterplane area A_W can be described as:

$$A_W = L \cdot B \cdot C_{WP} \quad [\text{m}^2]$$

C_{WP} = waterplane co-efficient

C_B varies from 0.55 (fast fruit carrier) to 0.85 (bulker, tanker) while C_{WP} shows 0.75 to 0.92 within the same range of ships.

If a vessel with any given draught is further loaded and thereby given a parallel immersion of exactly one centimetre the required mass for this immersion is called **tonnes per centimetre (TPC)**. The values of TPC are tabulated in hydrostatic tables for immersion in seawater.

$$\text{TPC} = L \cdot B \cdot C_{WP} \cdot 1.025 / 100 \quad [\text{t/cm}]$$

A vessel having the draught T in seawater will immerse by ΔT when entering water of less density (dock water) **without** any change of her mass displacement DISM.

volume displaced in dock-water	=	DISM / ρ	[m^3]
volume displaced in seawater	=	DISM / 1.025	[m^3]

$$\Delta T = \frac{\text{difference of volumes}}{\text{waterplane area}} = \frac{\left(\frac{\text{DISM}}{\rho} - \frac{\text{DISM}}{1.025}\right)}{L \cdot B \cdot C_{WP}} \quad [\text{m}]$$

$$\Delta T = \frac{\text{DISM}\,(1.025 - \rho)}{L \cdot B \cdot C_{WP} \cdot 1.025 \cdot \rho} \quad [\text{m}]$$

This immersion is generally called **dock water allowance (DWA)** and given in cm. By this the above formula reads:

$$DWA = \frac{DISM\,(1.025 - \rho)}{TPC \cdot \rho} \quad [cm]$$

If the dock water density is taken as 1 (fresh water) the formula for the **fresh water allowance (FWA)** can be obtained:

$$FWA = \frac{DISM}{40 \cdot TPC} \quad [cm]$$

Sometimes loading and stability manuals do not provide in their hydrostatic tables the immersed volume DISV but only the mass displacement DISM over the draught in seawater. If in such a case the immersed volume in seawater, dock water or fresh water is required for a given mass displacement the Archimedian law should be used:

$$DISV_{seawater} = \frac{DISM}{1.025} \quad [m^3]$$

$$DISV_{dock\ water} = \frac{DISM}{\rho} \quad [m^3]$$

$$DISV_{fresh\ water} = \frac{DISM}{1} \quad [m^3]$$

With these changes of displaced volumes the draught will change accordingly against the tabulated draught in seawater.

If however the mass displacements in seawater, dock water and fresh water are required for a given draught from such a table, the following rules use the tabulated value of DISM in seawater:

$$DISM_{seawater} = \frac{tab.value}{1.025} \cdot 1.025 \quad [t]$$

$$DISM_{dock\ water} = \frac{tab.value}{1.025} \cdot \rho \quad [t]$$

$$DISM_{fresh\ water} = \frac{tab.value}{1.025} \cdot 1 \quad [t]$$

The tabulated value of mass displacement serves in this case only to obtain the immersed volume at the given draught. The different displacements are then found by the Archimedian law.

These two approaches may easily lead to confusions with the use of such tables not showing the immersed volume. Care should be taken to make clear what is required as constant, the mass or the draught.

Note: The mass of a vessel never changes due to the density of the liquid wherein she floats, unless the vessel's speed approaches the speed of light (Albert Einstein).

Example: The hydrostatic table shows for T_{KC} = 6.80 m a DISM in seawater of 10274.4 t.

a) Give the immersed volume for this DISM in seawater.
b) Give the immersed volume for this DISM in dock water of 1.016 t/m^3.
c) Give the immersed volume for this DISM in fresh water.
d) Give the DISM for this T_{KC} in seawater.

e) Give the DISM for this T_{KC} in dock water of 1.016 t/m^3.
f) Give the DISM for this T_{KC} in fresh water.

The correct answers are (refer to the manual of MV. Nautilus):

a)	10023.8 m^3	with T_{KC} = 6.80 m	in seawater.
b)	10112.6 m^3	with T_{KC} = 6.85 m	in dock water of 1.016 t/m^3.
c)	10274.4 m^3	with T_{KC} = 6.94 m	in fresh water.
d)	10274.4 t	with T_{KC} = 6.80 m	in seawater.
e)	10184.2 t	with T_{KC} = 6.80 m	in dock water of 1.016 t/m^3.
f)	10023.8 t	with T_{KC} = 6.80 m	in fresh water.

3.1.2 The International Load Line Convention

This international convention is the present state of the meritorious efforts of Mr. Samuel Plimsoll who achieved in 1876 as a member of the British parliament against stiff opposition the first effective load line regulation on a national basis. This was followed by other maritime nations towards the end of the 19th century.

The International Load Line Convention (ILLC 66/88) applies to all seagoing vessels except:

- military vessels,
- new vessels of less than 24 m length,
- existing vessels of less than 150 gt,
- non-commercial pleasure vessels,
- fishing vessels.

Article 12 of LLC 66/88 requires that the loading marks of a vessel, appropriate to the season or the area as shown in the agreed chart, shall never be submerged while at sea, from departure until arrival.

A vessel operating in dock water or fresh water may however load deeper according to the appropriate DWA or FWA.

When leaving a port in a river or other inland water the vessel may be loaded deeper to the amount of the emersion by consumption of fuel and other consumables until reaching the open sea.

Loading a vessel to the appropriate mark is only allowed if this is compatible with the strength of the ship and with the ship's stability. Thus a vessel loaded to her mark with overstressing the hull or with insufficient stability is considered as **overloaded** in the legal sense.

Load line marks are given to the ship under the supervision of the national administration and attested by the International Load Line Certificate.

The position of the load line marks corresponds to the minimum freeboards. The minimum freeboard for Summer, Tropical, Winter, Winter North Atlantic and Fresh Water is calculated according to Regulation 40 of Annex I to ILLC 66/88.

tropical draught	= summer draught · (1 + 1/48)
winter draught	= summer draught · (1 – 1/48)
WNA draught	= winter draught – 50 mm (for ships up to 100 m length only)
fresh water draught	= summer draught + FWA

All draughts are related from top of keel to the upper edge of the appropriate horizontal line.

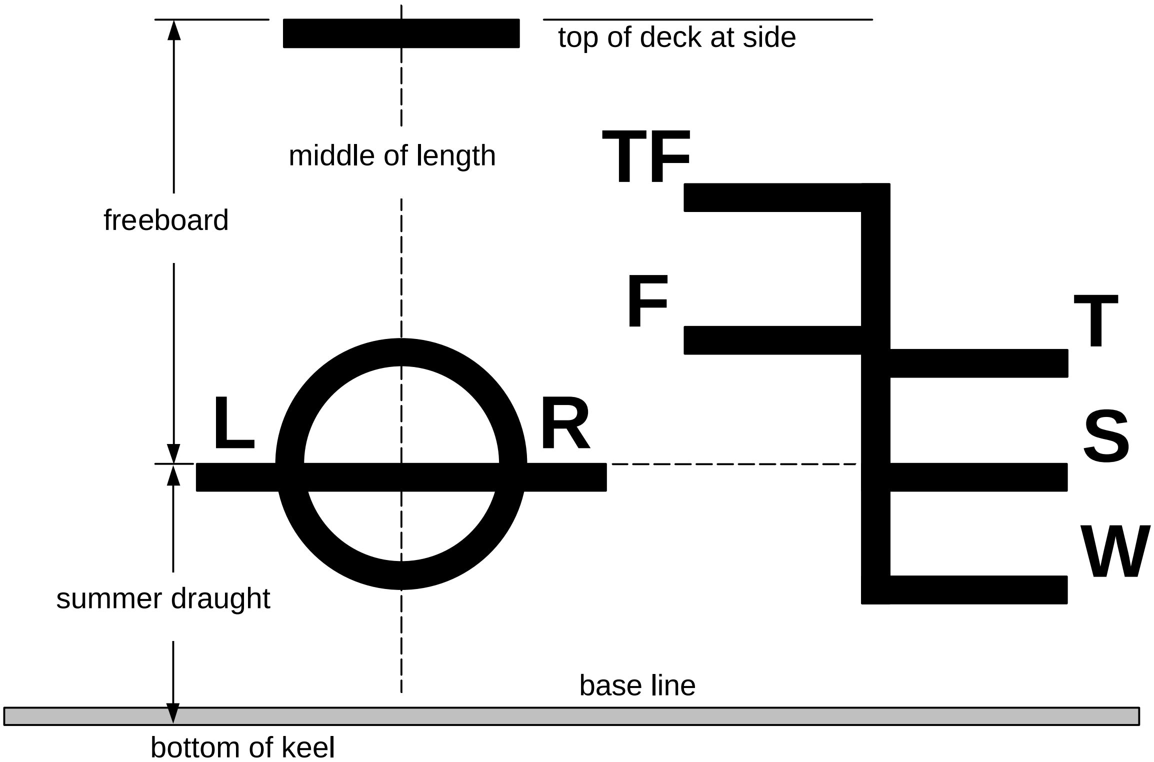


Figure 23: Load line marks for cargo vessels

3.1.3 Compliance with ILLC 66/88

The load line regulations are based on the ship on even keel without hull deflection. These preconditions however will almost never be met in real practice.

Most modern ships have the centre of flotation aft of MP due to the out-raking stern frames. If this ship is loaded to her summer displacement and trimmed by the stern, she will lift the load line out of the water by the amount:

$$\Delta T = t \cdot \frac{(XF - L/2)}{L} \quad [m]$$

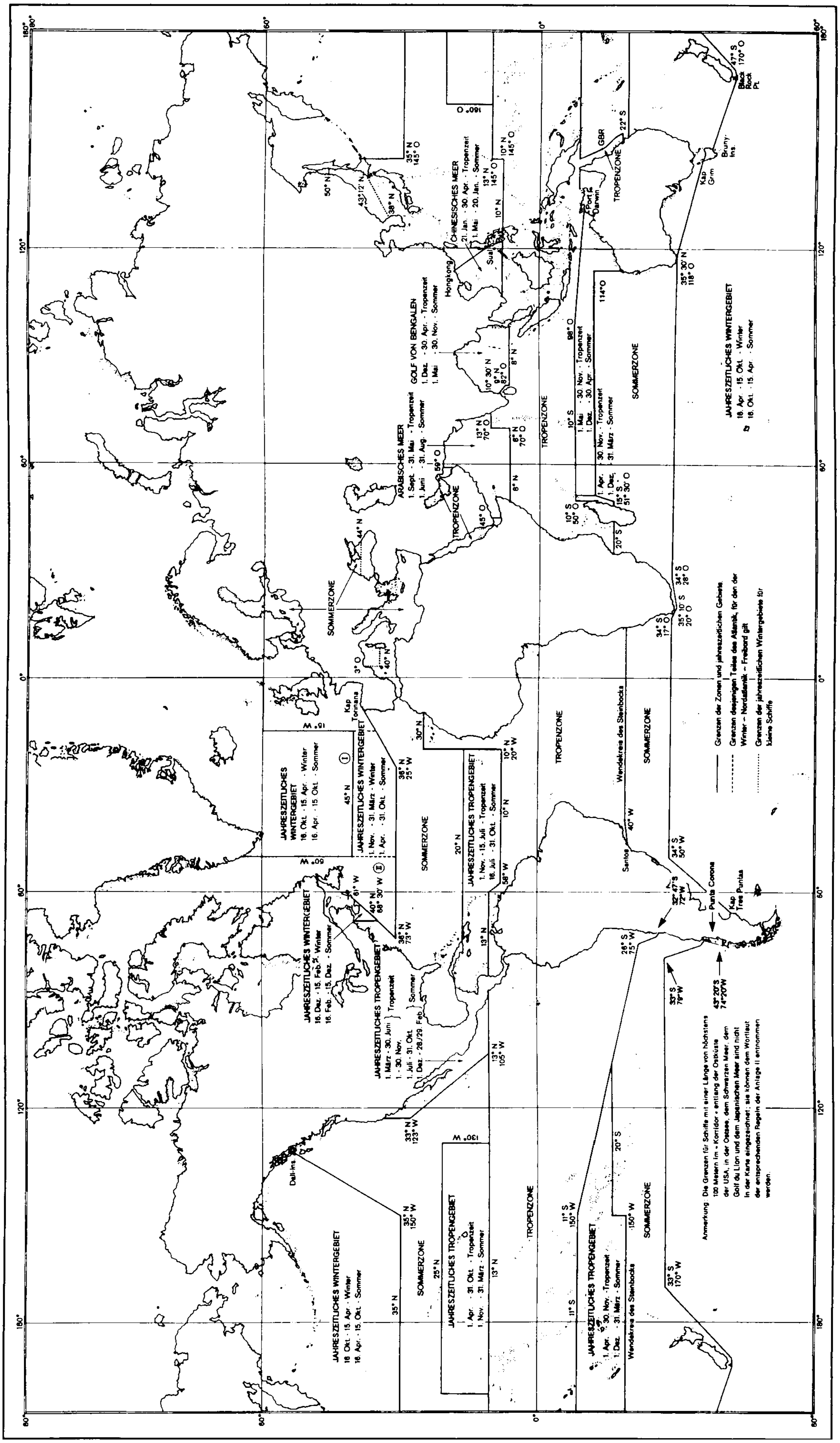
Most ships under 200 m length with fine lines show a hogging deflection of the hull with homogeneous distribution of cargo. Although this deflection shall never exceed Lpp/1000 as a rule of thumb when at sea the load line will be additionally lifted out of the water by a noticeable amount:

$$\Delta T = 0.3 \cdot hog \qquad [m]$$

Both values of ΔT may be added and used for further down loading without offending against the text of the load line convention. This practice should however be considered as violating the spirit of this convention.

LLC 66/88

KARTE DER ZONEN UND JAHRESZEITLICHEN GEBIETE



Karte der Zonen und Jahreszeitlichen Gebiete

Example: MV. Nautilus is loaded to a DISM of 13251 t in seawater with a trim by stern of 1.5 m and 0.07 m hog. XF = 55.02 m.

$$\Delta T = -1.5 \frac{(55.02 - 58.8)}{117.6} + 0.3 \cdot 0.07 = 0.07\,\mathrm{m}$$

This emersion of the summer mark corresponds to 143.8 t of apparent additional loading capacity which is often used by intention or by negligence.

Large ships however may suffer from the same insufficiency of the load line convention. They will often show a sagging deflection and may be slightly trimmed by head for compensating the consumption from forward bunker tanks during the voyage. On these ships the appropriate deductions from the cargo carrying capacity have to be made in order to keep the load line in the water line on departure.

Example: MV. Bockenheim shall be loaded to her summer mark. The planned departure condition shows a trim by head of 0.8 m and a sagging deflection of 0.08 m. L = 172.2 m; XF = 85.2 m; TPC = 40.0 t.

$$\Delta t = 0.8 \frac{(85.2 - 86.1)}{172.2} - 0.3 \cdot 0.08 = -0.028\,\mathrm{m}$$

This corresponds to a loss of dead weight of 112 t.

On large oil tankers with a sagging deflection of 0.25 m and a TPC of 200 t/cm the loss of dead weight will be as much as 1500 t.

The transition from one freeboard zone to another or sailing in a zone while its status changes with the date may generally happen during ocean passages and requires due consideration when planning the loading of the vessel.

To obtain the maximum permissible displacement at departure the controlling zone during the voyage should be identified and, as the next step, the number of sailing days to arrive at this zone or date should be calculated. The ship may then be loaded deeper by the expected emersion due to consumption of fuel and other consumables until arriving at the identified zone or date, provided the permissible load line draught at the zone of departure is not exceeded.

Homework exercises No. 9

.1 DISM = 18725 t; TPC = 32.4 t/cm; ρ = 1.018 t/m^3.
Calculate DWA.

.2 DISM = 420385 t; TPC = 202.5 t/cm; ρ = 1.009 t/m^3.
Calculate DWA.

.3 Calculate DWA for MV. Nautilus at 7.50 m draught for ρ = 1.012 t/m^3.

.4 Calculate FWA for MV. Nautilus at summer draught.

.5 Calculate FWA for MV. Bockenheim at summer draught.

.6 Calculate the loss of dead weight due to 0.18 m sagging on a large bulker with TPC = 82.5 t/cm.

.7 MV. Nautilus is loading in Rotterdam bound for New Foundland and shall sail on 10th October late evening. Daily consumption is 19.8 t. Identify the permissible displacement at departure.

.8 MV. Nautilus is delayed by repairs and can sail not earlier than 15th October early morning. Identify the permissible displacement at departure when the latitude of 15° W is reached after 2.8 days.

.9 A ship with summer draught 10.24 m is loading in a tropical port. Daily consumption at sea is 62.5 t; TPC = 38.4 t/cm.

a) Which is the tropical draught and the winter draught?

Calculate the permissible departure draught if the summer zone is reached after:

b) 6 days,

c) 14 days.

3.2 Determination of displacement

A draught survey is the procedure of obtaining, from draught readings, the immersed volume of the ship and from that the mass displacement. After deduction of light ship mass, bunkers, ballast and stores the net dead weight, i.e. the mass of cargo on board may be identified.

The normal practice, however, is to convey two draught surveys, one before and one after loading or unloading. The difference of displacements found is the amount of cargo loaded or unloaded, after correction for consumption and ballast changes between surveys.

The main difficulties of draught surveys are:

- correct measurement of draught,
- correct measurement of water density,
- correct survey of consumption and ballast changes between two correlated surveys.

3.2.1 Comprehensive draught survey

This survey is mainly used on bulk carriers and always carried out by an independent surveyor acting on behalf of the shipper or consignee. The ship's cargo officer should participate in the survey for the interest of the charterer and/or the owner. A full draught survey consists of the following steps:

1. Readings at all six marks: T_{KFR}, T_{KR}, T_{KAR} port and starboard,
2. Measure the water density ρ,
3. Calculate means of port and starboard: T_{KFR}, T_{KR}, T_{KAR},
4. Make corrections for trim and deflection to obtain T_{KF}, T_{K}, T_{KA},
5. Make corrections for deflection and trim to obtain T_{KC},
6. Obtain with T_{KC} the immersed volume DISV,
7. Obtain the mass displacement DISM = DISV · ρ.
8. Obtain the cargo loaded or unloaded by considering the previous survey results.

Steps 4 and 5 need some explanation:

Step 4:

The ship will be trimmed and deflected at the time of the draught readings. The function of the water line along the ship's lateral projection is approximated by:

$$T_K(x) = T_{KA} + t\,\frac{x}{L} - d\left(1 - \left(\frac{L-2x}{L}\right)^{1.7}\right) \quad \text{for } 0 < x \leq L/2$$

$$T_K(x) = T_{KA} + t\,\frac{x}{L} - d\left(1 - \left(\frac{2x - L}{L}\right)^{1.7}\right) \quad \text{for } L/2 < x \le L$$

$$d = T_{KM} - T_K$$

Since draught marks are placed in the vicinity of AP (x = 0), MP (x = L/2) and FP (x = L), it is necessary to find the gradients of the function at AP, MP and FP to obtain linear corrections for the readings taken.

gradient for x = 0: $\frac{d\,T_K}{dx} = \left(\frac{t}{L} - \frac{3.4 \cdot d}{L}\right)$

gradient for x = L/2: $\frac{d\,T_K}{dx} = \left(\frac{t}{L}\right)$

gradient for x = L: $\frac{d\,T_K}{dx} = \left(\frac{t}{L} + \frac{3.4 \cdot d}{L}\right)$

Since the trim is unknown before having obtained T_{KF} and T_{KA} the expression t/L is replaced by $(T_{KFR} - T_{KAR})/(X_3 - X_1)$. The deflection must be approximated by $(T_{KAR} + T_{KFR})/2 - T_{KR}$. The draught at AP, MP and FP is then found by:

$$T_{KA} = T_{KAR} + (0 - x_1)\cdot\left(\frac{T_{KFR} - T_{KAR}}{x_3 - x_1} - \frac{3.4 \cdot d}{L}\right)$$

$$T_K = T_{KR} + \left(\frac{L}{2} - x_2\right)\cdot\left(\frac{T_{KFR} - T_{KAR}}{x_3 - x_1}\right)$$

$$T_{KF} = T_{KFR} + (L - x_3)\cdot\left(\frac{T_{KFR} - T_{KAR}}{x_3 - x_1} + \frac{3.4 \cdot d}{L}\right)$$

These three results allow to obtain a better estimation for the deflection d. With this second figure of d the same formulae can be used a second time for obtaining more precise draught figures.

Having obtained these draughts the correct trim t can be calculated:

$$t = T_{KF} - T_{KA}$$

as well as the exact deflection:

$$d = T_{KM} - T_K$$

with $T_{KM} = \frac{(T_{KF} + T_{KA})}{2}$

Step 5:

This step actually presents a calculated removal of the deflection providing the draught at MP of the undeflected ship, and the correction of this draught for trimming the ship to even keel. This trim correction takes account of the fact that the ship is trimming about an axis through the centre of flotation F. An additional correction, the "Nemoto correction", accounts for the increase of the waterplane area with the draught and should be used only for trim values greater than 1% of Lpp.

$$T_{KC} = (T_{KM} - e \cdot d) + t\left(\frac{XF - L/2}{L}\right) + t^2\left(\frac{MTM_2 - MTM_1}{200 \cdot L \cdot TPC}\right) \quad [m]$$

The co-efficient ε is given as a function of C_{WP} as follows:

C_{WP}	0.700	0.750	0.800	0.850	0.900	0.950
ε	0.754	0.740	0.724	0.705	0.684	0.658

For container vessels the co-efficient ε can be taken as 0.7 in general.

MTM_2 = moment to change trim 1 metre at (T_{KM} + 0.5 m)
MTM_1 = moment to change trim 1 metre at (T_{KM} – 0.5 m)

The expression $T_{KM} - \varepsilon \cdot d$ is equal to $(1 - \varepsilon) \cdot T_{KM} + \varepsilon \cdot T_K$. The latter form shows clearly the dominating influence of the mid mark reading, as corrected, into the draught of the undeflected ship.

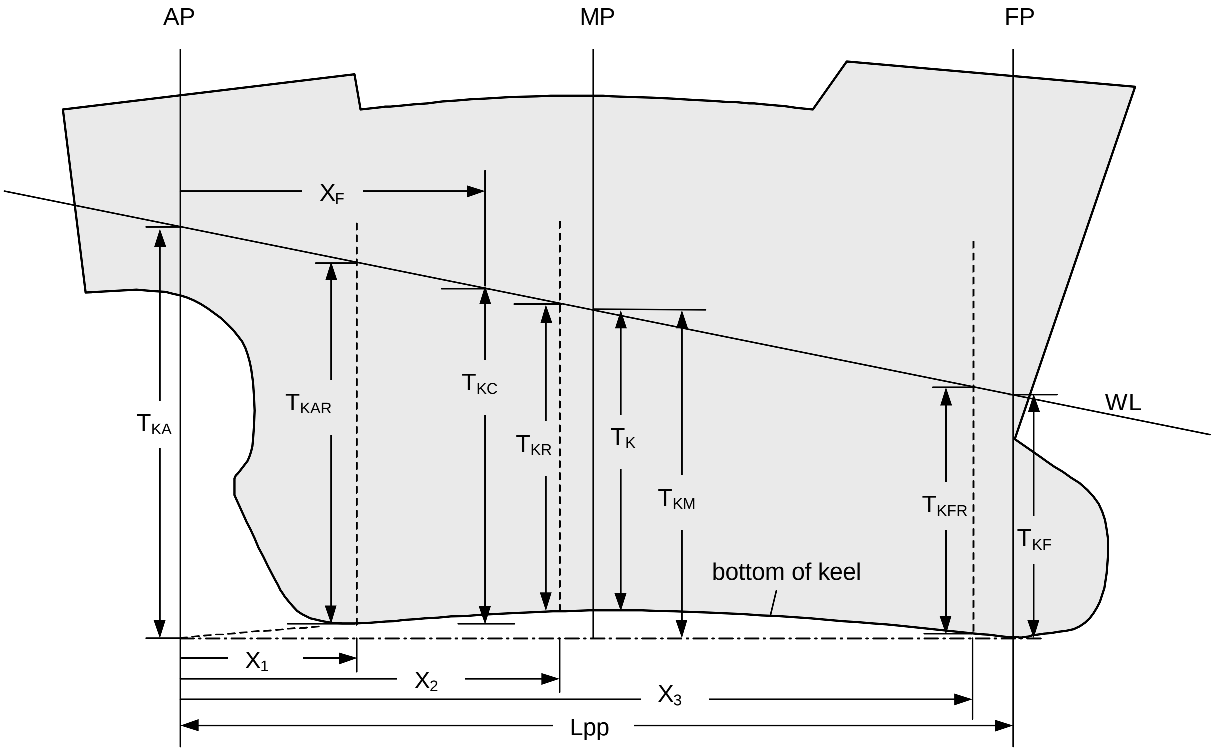


Figure 24: Definition of draughts and mark positions

Example: A full draught survey is carried out for MV. Bockenheim. x_1 = 5.0 m; x_2 = 85.1 m; x_3 = 171.2 m; L = 172.2 m.

Step 1: Readings taken at all six marks as follows:

T_{KAR}	=	9.24 m SB	T_{KAR}	=	9.29 m PS
T_{KR}	=	7.84 m SB	T_{KR}	=	8.29 m PS
T_{KFR}	=	7.10 m SB	T_{KFR}	=	7.11 m PS

Step 2: Measured water density = 1.018 t/m^3.

Step 3: Means of port and starboard calculated:

T_{KAR} = 9.265 m
T_{KR} = 8.065 m
T_{KFR} = 7.105 m

Step 4: approx. deflection = 0.120 m (hogging)

$T_{KFR} - T_{KAR}$ = – 2.160 m

$x_3 - x_1$ = 166.2

$$T_{KA} = 9.265 - 5 \cdot \left(\frac{-2.160}{166.2} - \frac{3.4 \cdot 0.120}{172.2} \right) \quad = \quad 9.342 \text{ m}$$

$$T_{K} = 8.065 + 1 \cdot \left(\frac{-2.160}{166.2} \right) \quad = \quad 8.052 \text{ m}$$

$$T_{KF} = 7.105 + 1 \cdot \left(\frac{-2.160}{166.2} + \frac{3.4 \cdot 0.120}{172.2} \right) \quad = \quad 7.094 \text{ m}$$

A better estimation of the deflection gives now: d = (9.342 + 7.094) / 2 – 8.052 = 0.166 m and a second calculation provides:

$$T_{KA} = 9.265 - 5 \cdot \left(\frac{-2.160}{166.2} - \frac{3.4 \cdot 0.166}{172.2} \right) \quad = \quad 9.346 \text{ m}$$

$$T_{K} = 8.065 + 1 \cdot \left(\frac{-2.160}{166.2} \right) \quad = \quad 8.052 \text{ m}$$

$$T_{KF} = 7.105 + 1 \cdot \left(\frac{-2.160}{166.2} + \frac{3.4 \cdot 0.166}{172.2} \right) \quad = \quad 7.095 \text{ m}$$

Step 5: T_{KM} = 8.221 m; ε = 0.705; d = 0.166 m; t = – 2.251 m

X_F = 87.46 m; MTM_2 = 42800 tm/m; MTM_1 = 40900 tm/m; TPC = 38.4 t/cm

$$T_{KC} = 8.221 - 0.705 \cdot 0.166 - 2.251 \left(\frac{1.36}{172.2} \right) + 2.251^2 \left(\frac{42800 - 40900}{200 \cdot 172.2 \cdot 38.4} \right)$$

T_{KC} = 8.221 – 0.117 – 0.018 + 0.007 = 8.093 m

Step 6: DISV = 28264.4 m^3

Step 7: DISM = 28264.4 · 1.018 = 28773.2 t

It seems advisable to use an appropriate computer programme for this calculation procedure.

3.2.2 Simplified draught survey

On small container vessels it may be advisable to take frequent draught readings to check the actual intake of cargo, since cargo documents may be not timely provided or of doubtful reliability. Due to the usual time pressure on such vessels the reading of all six marks will be not feasible. Therefore a reading fore and aft, with any list of the ship eliminated by the anti-heeling system, will be sufficient. Any deflection of the ship, usually hogging, may be estimated from the bending moments shown by the ship's loading and stability computer.

The procedure of this simplified draught survey is shown under chapter 5 of this booklet.

Homework exercises No. 10

.1 Complete a full draught survey for MV. Bockenheim:

T_{KAR}	=	11.56 m SB	T_{KAR}	=	11.54 m PS
T_{KR}	=	11.28 m SB	T_{KR}	=	11,20 m PS
T_{KFR}	=	11.03 m SB	T_{KFR}	=	10.97 m PS

ρ = 1.022 t/m^3.

.2 Complete a simplified draught survey for MV. Nautilus:

T_{KAR} = 7.28 m at x = 7.8 m
T_{KFR} = 6.52 m
ρ = 1.021 t/m^3.

The loading computer shows bending moments of 205000 kN·m at frame 64 and 223800 kN·m at frame 82

.3 MV. Nautilus is loaded down to her summer marks in seawater. Estimated hog = 0.08 m. Trim by stern is approximately 1.6 m. Determine the displacement.

.4 MV. Bockenheim is loaded down to her winter marks in seawater. Estimated sag = 0.06 m. Trim by the stern is approximately 1.4 m. Determine the displacement.

4. Hull strength consideration

This chapter is not intended to provide the theory of the structural strength of ships in depth. It shall rather give guidance on the use of information in loading and stability manuals for the avoidance of structural failure as required by Regulation 10 of the Annex to LLC 66/88.

4.1 Local strength

Local strength limits are usually given as mass per square metre and are applicable for a homogeneous surface load over the full area of the particular double bottom, tank top, tween deck, weather deck or hatch cover. Typical values of this maximum permissible surface loads are given in the manual of MV. Nautilus.

When loading break bulk into such a space the permissible stowage height can be easily calculated by:

max. stowage height = max. surface load x stowage factor

Example: The 'tween-deck of an old dry cargo ship has a permissible load per area of 1.9 t/m^2. The cargo to be loaded stows 1.2 m^3/t. The permissible stowage height is 2.3 m.

Stack loads of containers on deck or on hatch covers may be much higher than the surface load over the same area because the stacking points are specially strengthened.

Example: 20'-container stack load = 60 t on hatch covers of MV. Nautilus, while the corresponding surface load on 8' · 20' = 14.9 m^2 is 26 t with 1.75 t/m^2.

If the projected surface load of a heavy unit is higher than the permissible surface load of the stowage place, the stowage area must be appropriately enlarged and timber squares or steel beams used to spread the load.

***Example**:* A transformer of 108 t and a bottom area of 2 · 3 m shall be stowed into hold No. 2 of MV. Nautilus. Permissible load per area = 10 t/m^2. Required stowage area = 10.8 m^2. An area of 3.6 · 3 m must be sufficiently laid with timber squares of 20 · 20 cm.

Another restriction regarding local strength is found on bulk carriers, where the permissible amount of cargo in a hold increases with the draught of the vessel. For this reason it will not be possible to load the full allocated quantity into a hold with one pour while the ship as a whole is still partly loaded. The "half hatch rule" should be observed, notwithstanding restrictions from longitudinal strength criteria.

4.2 Longitudinal strength

4.2.1 Theoretical background

The Archimedian law, if applied to a floating ship, requires the equilibrium of weight and buoyancy or mass of the ship and mass of displaced water. This is valid for the ship as a whole but not necessarily for individual sectional compartments of the ship.

The pontoon in Figure 25 has the dimensions: L = 100 m, B = 20 m, T = 6 m. It is loaded to even keel in fresh water as follows:

Item	**mass [t]**	**XG [m]**	**long. mom. [t^{x}m]**
mass of hull	1500	50	75000
cargo in hold 5	2200	10	22000
cargo in hold 4	2300	30	69000
cargo in hold 3	1700	50	85000
cargo in hold 2	1900	70	133000
cargo in hold 1	2400	90	216000
Total	**12000**	**50**	**600000**

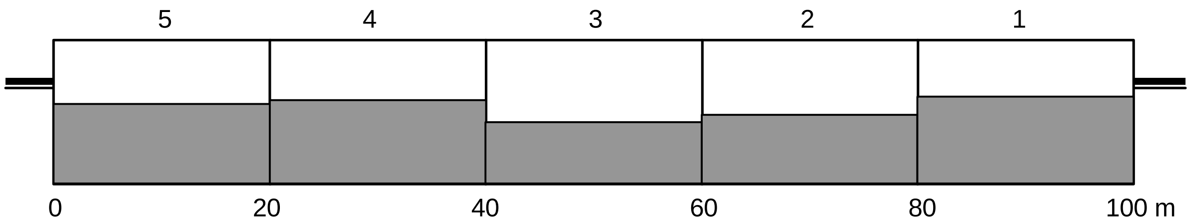


Figure 25: Pontoon with different loads in holds

Balance forces

The mass of displaced water of each section is 2400 t at 6 m draught in fresh water. The analysis of each hold or section of the pontoon shows differences between masses of load and displaced water which are expressed as balance forces:

hold	**5**	**4**	**3**	**2**	**1**	
mass of hull	300	300	300	300	300	t
mass of cargo	2200	2300	1700	1900	2400	t
mass of displ. water	– 2400	– 2400	– 2400	– 2400	– 2400	t
balance	+ 100	+ 200	– 400	– 200	+ 300	t
balance	+ 981	+ 1962	– 3924	– 1962	+ 2943	kN

The balance forces are the reason for stresses in the hull structure. In this particular case a hogging situation is given.

Shear forces

If a vertical cut would be made between hold 4 and hold 5 the latter would sink down by the force of 981 kN. As there is no cut, the same force must act as a vertical shear force between hold 4 and hold 5 to keep the latter in place. This principle applies to all sections along the length of the pontoon.

Definition: The shear force at a given position in the length of a ship is equal to the algebraic sum of all balance forces from weight and buoyancy to the left of this position.

Example: The shear force between hold 3 and hold 2 of the pontoon would be 981 + 1962 – 3924 = – 981 kN.

Bending moments

If a vertical cut would be made between hold 4 and hold 3, but fitting a hinge into the bottom of the pontoon, the two after compartments would tilt down due to the surplus of weight with the appropriate levers of 10 and 30 metres. This tilting moment is 10 · 1962 + 30 · 981 = 49050 kN·m. As there is no cut with a hinge, the same moment must act as a bending moment in this section to prevent the tilting.

Definition: The bending moment at a given position in the length of a ship is equal to the algebraic sum of all balance forces multiplied with their levers from this position to the left of this position.

Bending moments cause normal forces (pressure and tension) in the upper and lower girders (deck and bottom) of a ship's hull.

With these two definitions the shear forces and bending moments can be drawn as curves along the length of the pontoon.

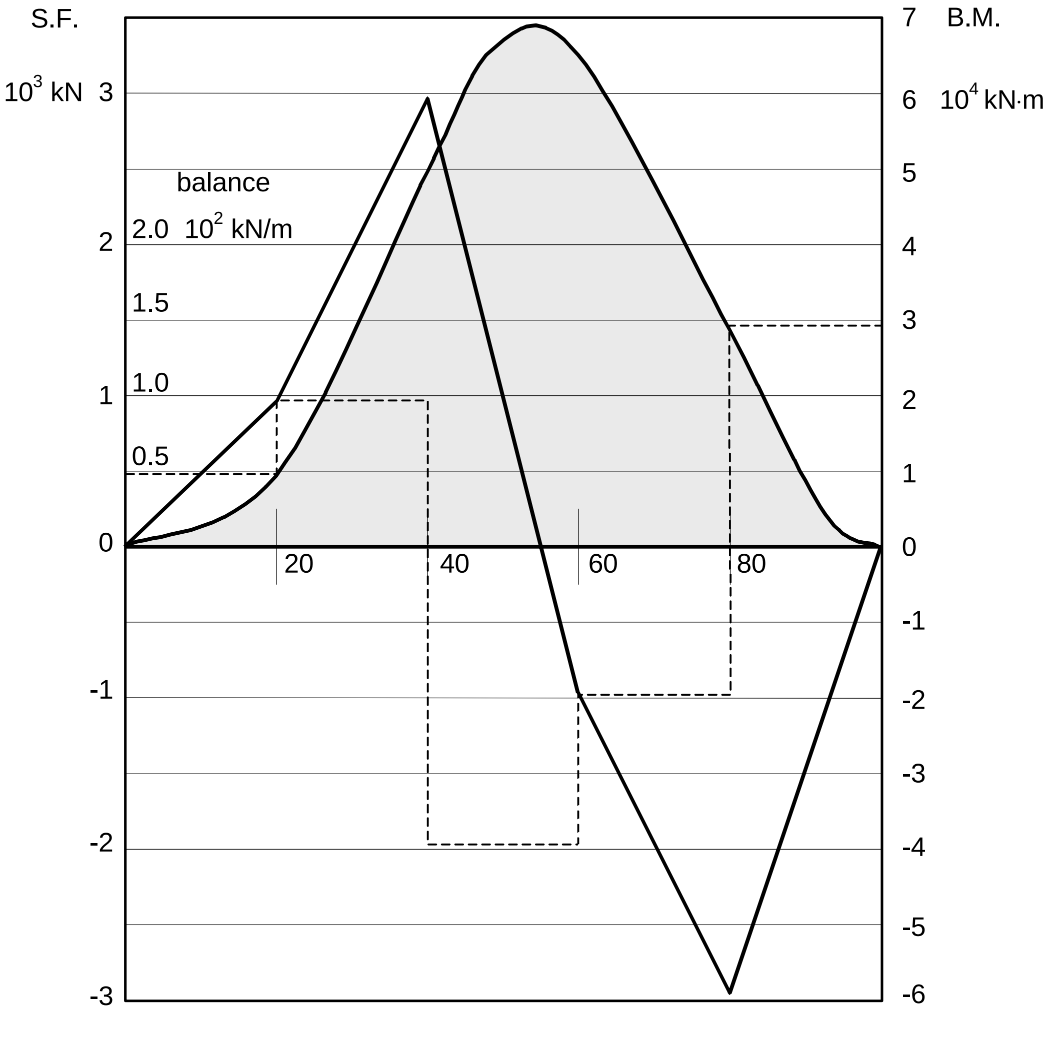


Figure 26: Curves of shear forces and bending moments

The shear force curve shows positive gradients in compartments of surplus of weight and negative gradients in compartments of surplus of buoyancy.

The bending moment curve is fully in the positive (upper) range of the diagram which coincides with the hogging situation of the pontoon. A bending moment curve in the negative range of the diagram would present a sagging situation.

These conclusions depend on the definition of signs, i.e. weight to be positive and buoyancy to be negative, as applied in naval architecture.

Mathematical analysis

For the ease of reference to specific literature another mathematical description of the curves of shear forces and bending moments is given.

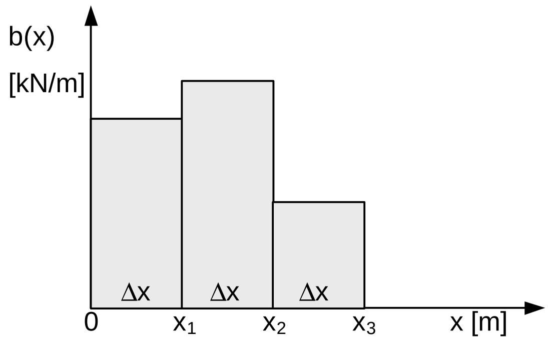


Figure 27: Balance curve

Balance function: b(x)
Shear force function: S(x)
Bending moment function: M(x)

The definition of shear forces above provides:

$S(0) = 0$
$S(x_1) = b(x_1) \cdot \Delta x$
$S(x_2) = b(x_1) \cdot \Delta x + b(x_2) \cdot \Delta x$
$S(x_3) = b(x_1) \cdot \Delta x + b(x_2) \cdot \Delta x + b(x_3) \cdot \Delta x$
(and so on)

For $\Delta x \rightarrow dx$ the shear force at any x_i is:

$$S(x_i) = \int_0^{x_i} b(x) \cdot dx$$

The definition of bending moments above provides:

$M(0) = 0$
$M(x_1) = b(x_1) \cdot \Delta x \cdot 0.5\, \Delta x$
$M(x_2) = b(x_1) \cdot \Delta x \cdot 1{,}5\, \Delta x + b(x_2) \cdot \Delta x \cdot 0.5\, \Delta x$
$M(x_3) = b(x_1) \cdot \Delta x \cdot 2.5\, \Delta x + b(x_2) \cdot \Delta x \cdot 1.5\, \Delta x + b(x_3) \cdot \Delta x \cdot 0.5\, \Delta x$
(and so on)

The difference between $M(x_3)$ and $\left(S(x_1) + S(x_2) + S(x_3)\right) \cdot \Delta x$ disappears for $\Delta x \rightarrow dx$. Thus the bending moment at any x_i is:

$$M(x_i) = \int_0^{x_i} S(x) \cdot dx$$

With these relations the curves of bending moments and shear forces can be more easily understood and identified by the appropriate rules:

zero shear force ® maximum or minimum bending moment,

extreme shear force ® point of inflexion in bending moment curve.

Limit values

Loading and stability manuals, which contain shear forces and bending moments for calculated loading conditions, will always present appropriate limit curves. These curves are given for the positive and the negative range of the diagram and may be distinguished into sea condition and harbour condition. They must never be exceeded as appropriate.

The limit curves for sea condition are narrower because there must be about 50% of the full strength capacity of the ship kept in reserve for additional stresses due to waves and dynamic shocks at sea. The limit curves for harbour condition are spread somewhat wider to provide more flexibility for cargo and ballast operation in port.

Deflection of hull

The accurate deflection curve can be calculated from the bending moments by the naval architect using the structural strength parameters. An estimation of the deflection at MP is however possible by means of a rule of thumb which is applicable for hogging and sagging:

$$\text{deflection d} = \frac{\text{B.M. at MP}}{\text{B.M. limit}_{\text{SEA}}\text{ at MP}} \cdot \frac{L}{1000} \qquad [\text{m}]$$

This rule of thumb applies to a more or less symmetrical, bell-shaped bending moment curve and implies that the maximum permissible deflection at sea should not exceed ± L/1000 in metres.

The absolute limit of deflection in port is ± L/500 m as a rule of thumb.

An undulated or asymmetrical bending moment curve should be replaced by an equivalent bell-shaped curve for using the above estimation formula.

Bulkhead correction

Bulk carriers with longitudinal girders in their bottom structure have the advantage that, in particular with alternate loading, the extreme positive and negative loads in full and empty holds are only partially transferred to the side shell and there accumulated to impressive shear forces. Another considerable part of the load is directly transferred from the longitudinal girders into the cross bulkheads where they are largely compensated by opposite loads from the other side.

This structural advantage is referred to as bulkhead correction and reflected in the appropriate loading computers on board and also in loading and stability manuals.

4.2.2 Examples of shear forces and bending moments

The following examples are typical presentations of shear forces and bending moments in modern loading and stability manuals.

Figure 28 shows the ballast condition of a container vessel of L = 167 m. Due to heavy weights in the ends (full fore peak, deck house plus engine) at a light draught the bending moments come close to the permissible sea-going limit.

Figure 29 shows the same vessel with a typical homogeneous distribution of containers. There is still a hogging condition due to containers stowed over the full length of the deck. Ships of this layout are referred to as "hogging ships".

Figure 30 shows the light ship condition of a modern product tanker of L = 168 m. The graphs present not only shear forces and bending moments but also the distribution of weight and buoyancy. The deflection is hogging.

Figure 31 shows the same vessel in ballasted condition with MARPOL draught. The stress condition is hogging for the same reason as in Figure 28, but the bending moments are far from the limit due to more full lines fore and aft.

Figure 32 shows the same vessel with homogeneously loaded cargo tanks. The stress condition is now a slight sagging due to surplus buoyancy fore and aft.

Figure 33 shows the same vessel with cargo only in tanks 2, 4 and 6. The stress condition is sagging with the typical zig-zag of the shear force curve and an undulating bending moment curve.

In some cases the information on shear forces and bending moments of calculated loading conditions includes the deflection at MP. This information can be used as a reference for estimating the deflection in other loading conditions. This may be useful for the simplified draught survey.

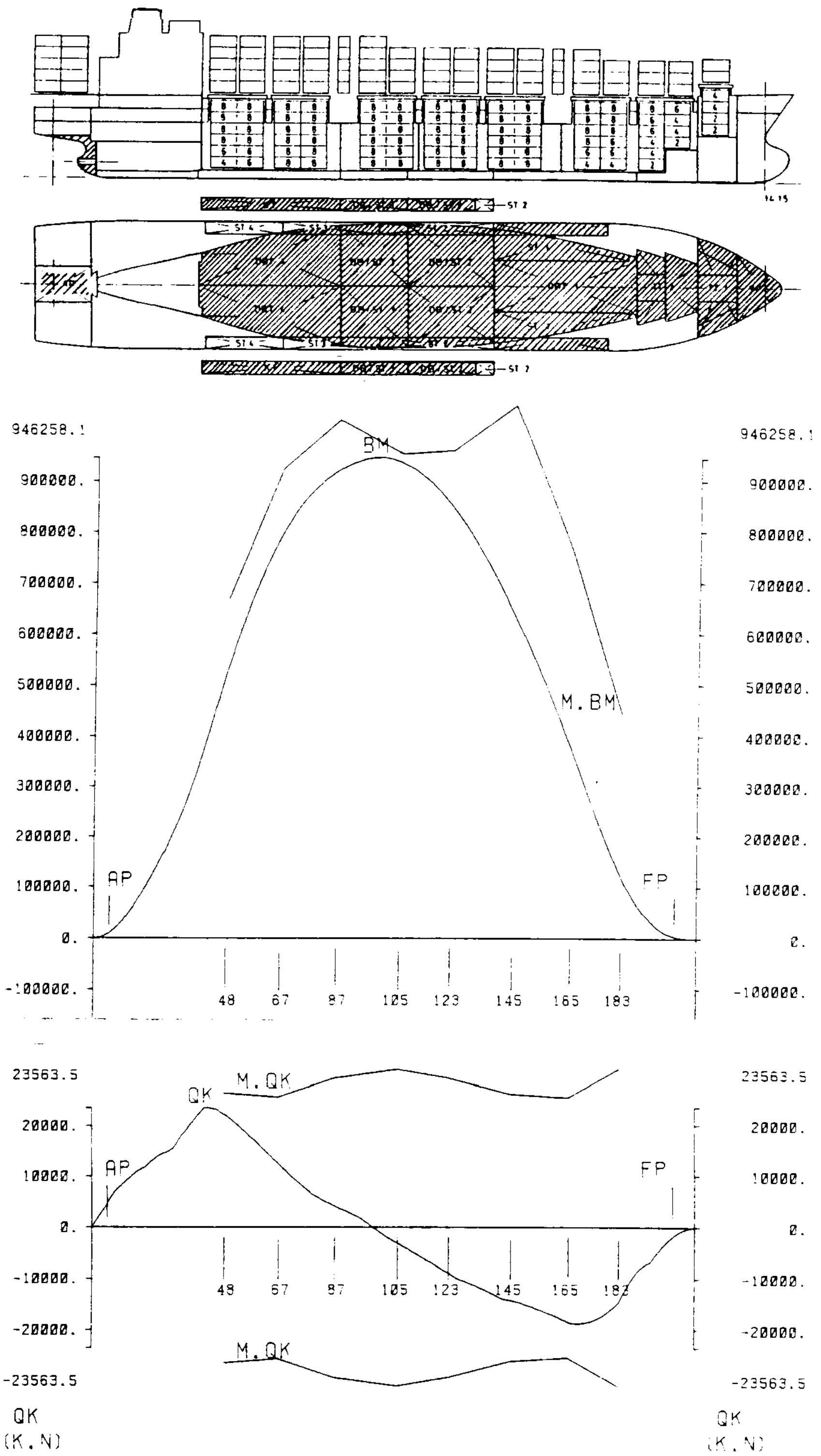


Figure 28: S.F. and B.M. for a container vessel in ballasted condition

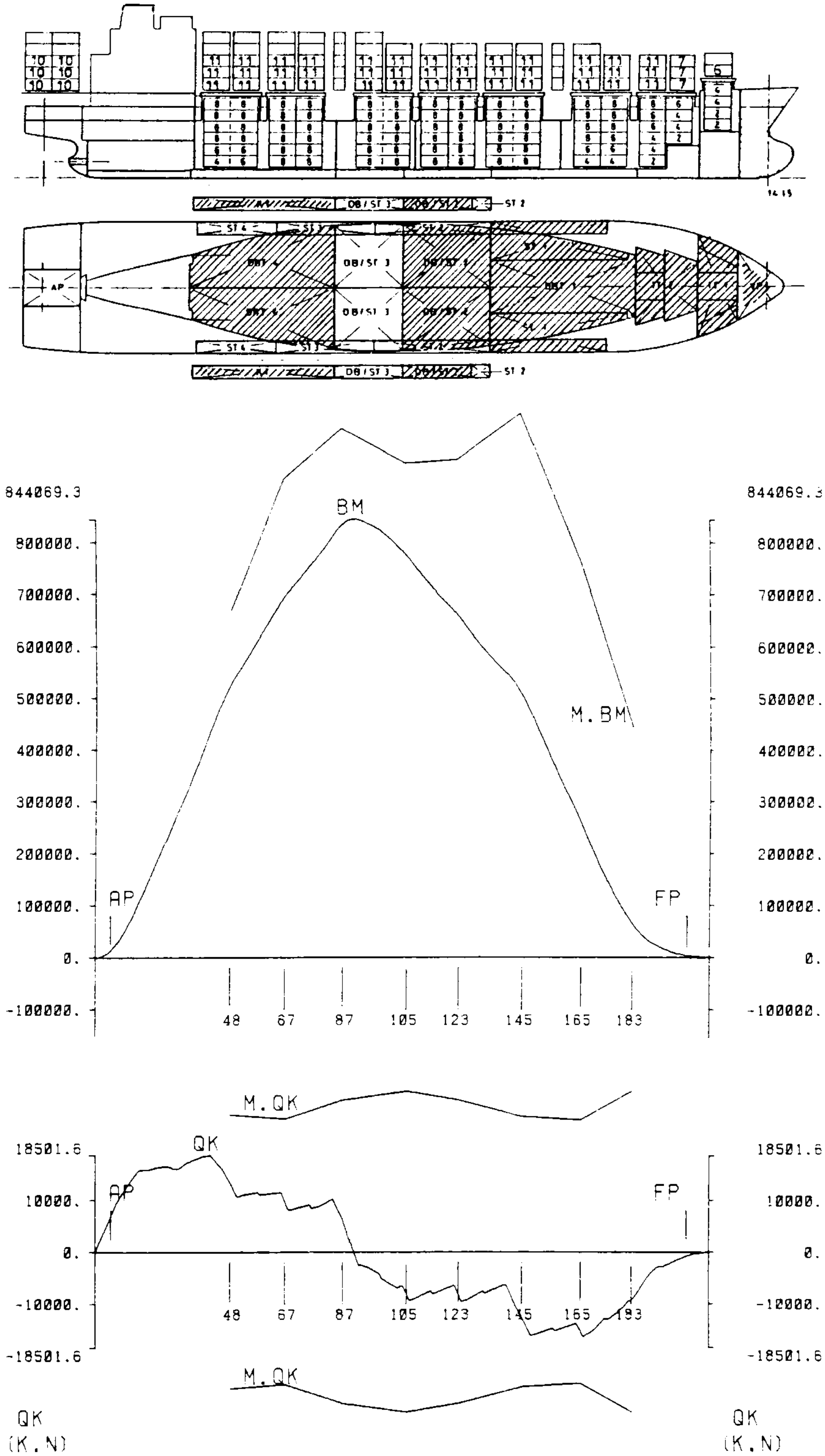


Figure 29: S.F. and B.M. for a loaded container vessel

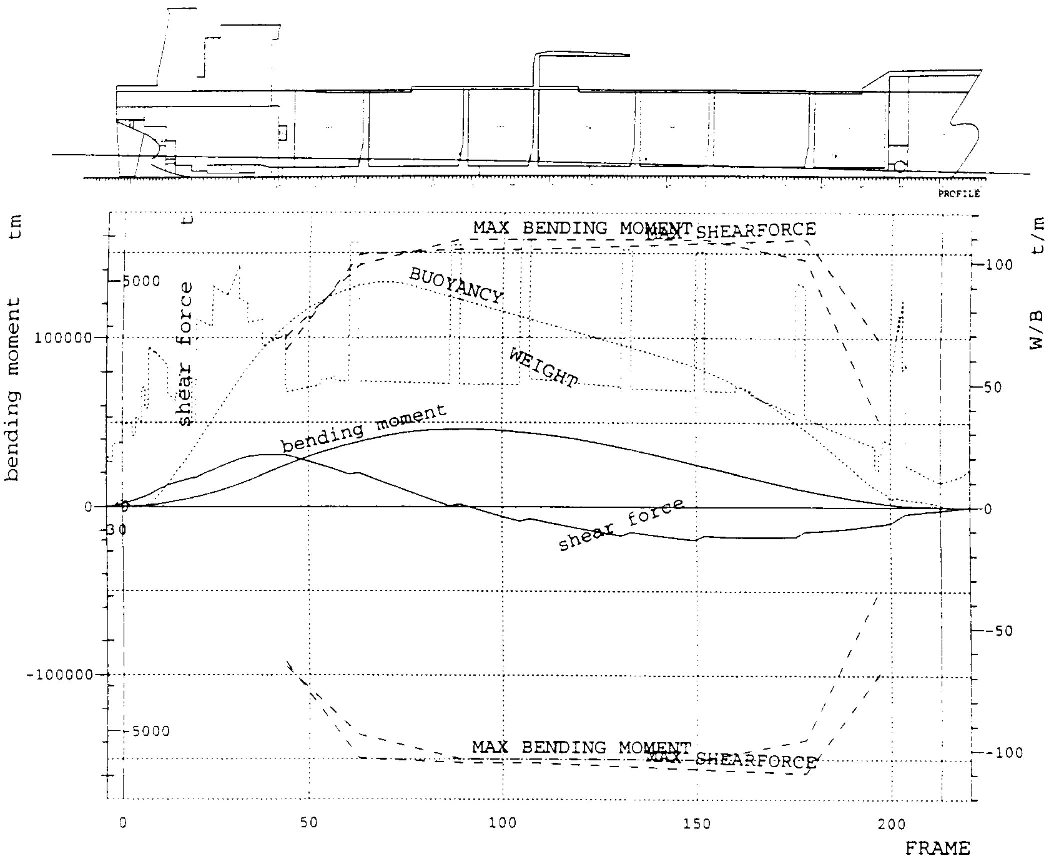


Figure 30: S.F. and B.M. for a tanker in light ship condition

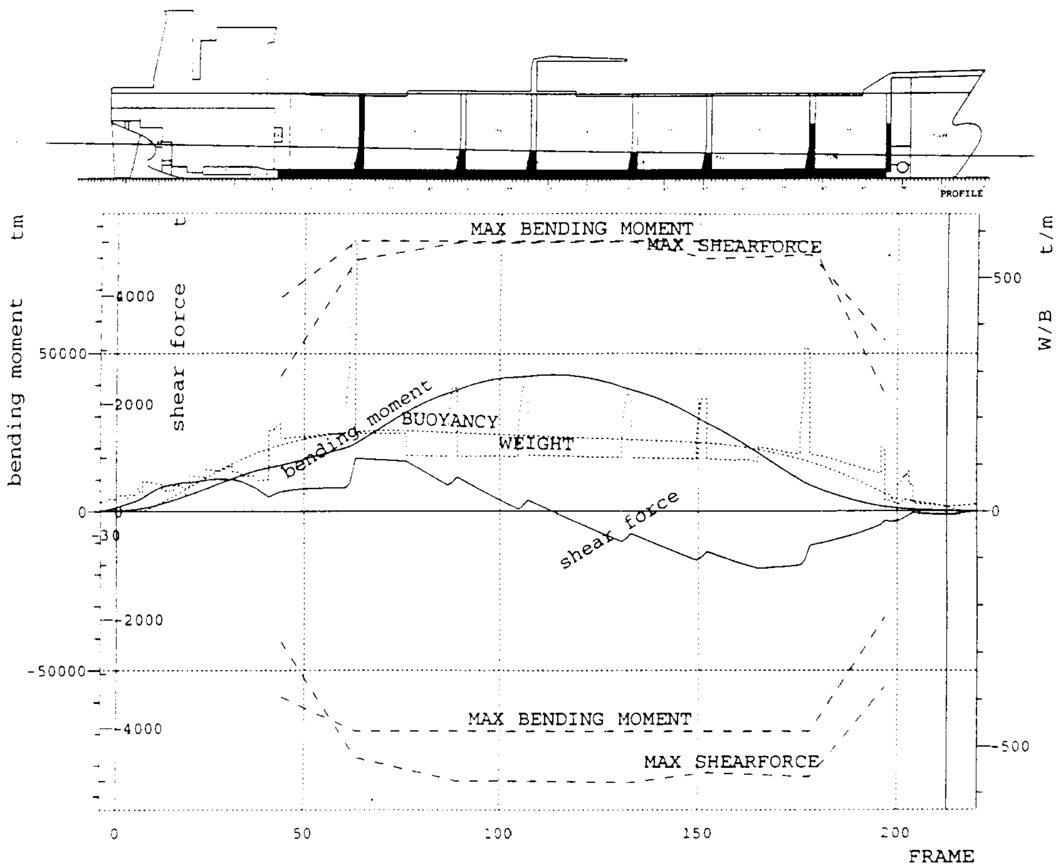


Figure 31: S.F. and B.M. for a tanker in ballasted condition

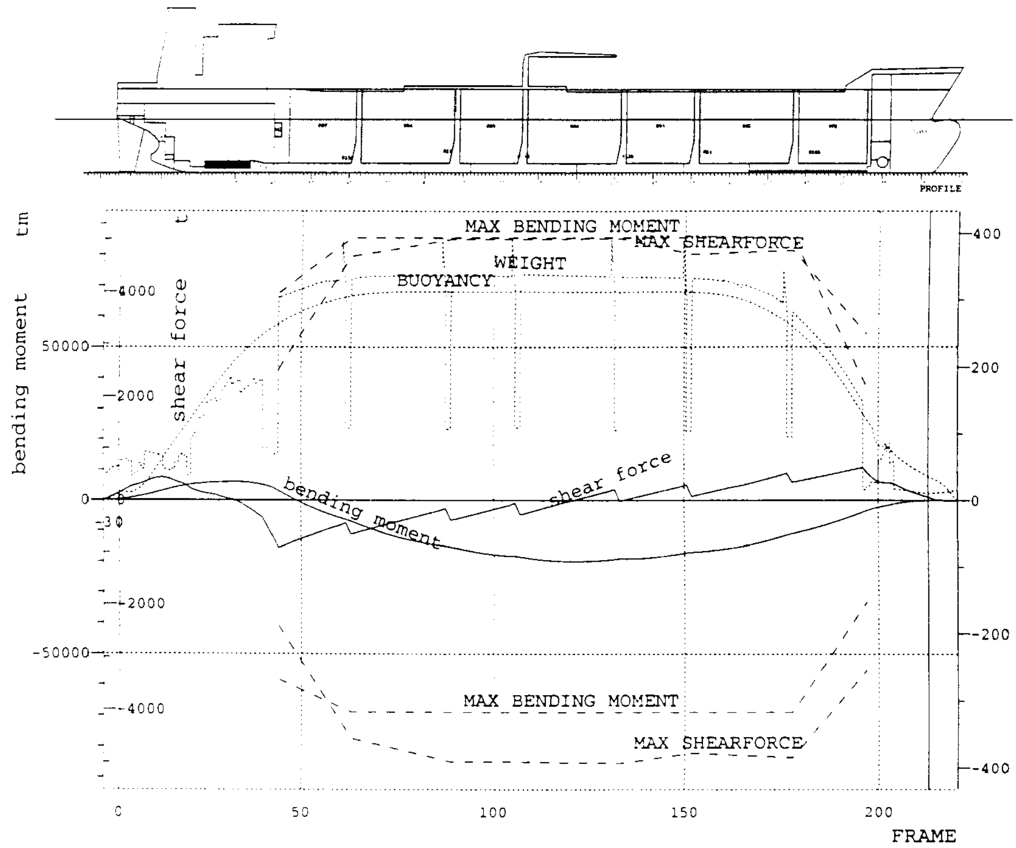


Figure 32: S.F. and B.M. for a homogeneously loaded tanker

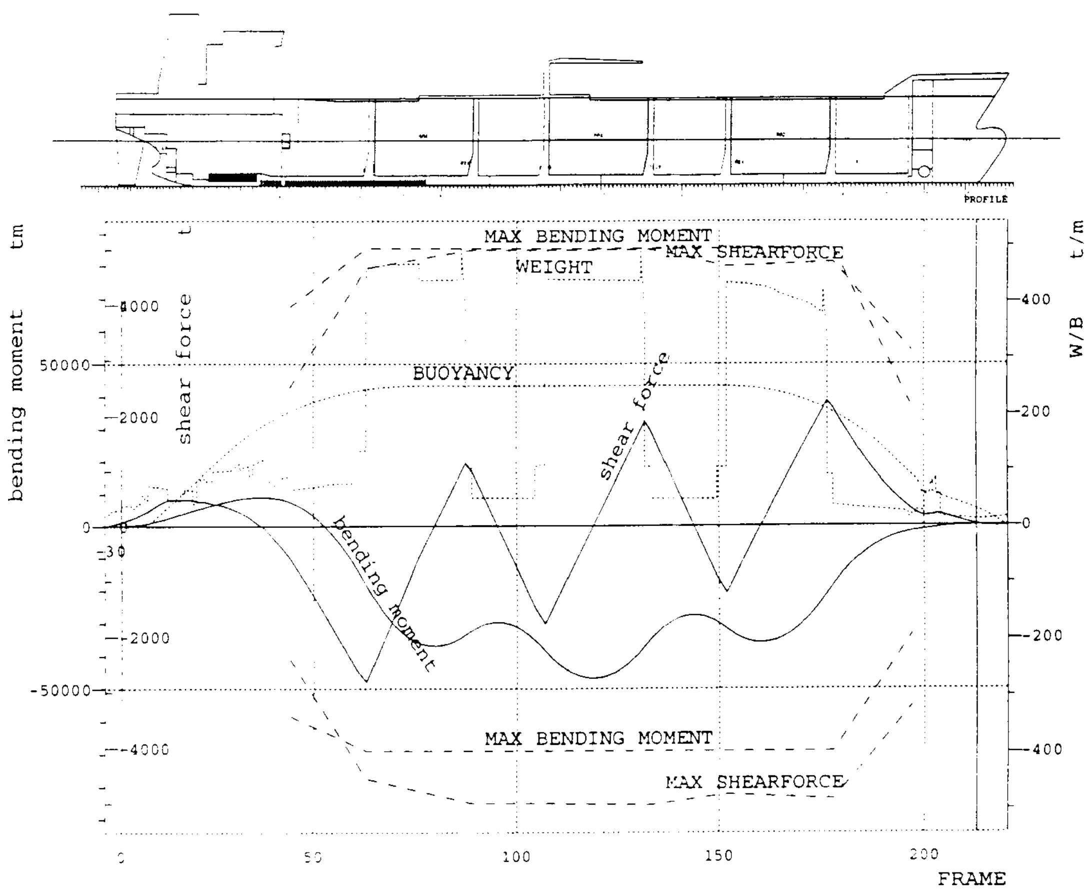


Figure 33: S.F. and B.M. for an alternately loaded tanker

4.2.3 Manual calculation of shear forces and bending moments

The manual calculation of shear forces and bending moments was required on board ships in the 1950s and 1960s when ships had become large and more sensible to stresses, but electronic calculators were not available or too expensive for owners. The preferred method of safely loading and unloading large tankers and bulk carriers in those years however was by strictly observing pre-calculated loading patterns and loading/unloading sequences.

The manual calculation method developed for MV. Bockenheim as presented in the extract of the appropriate loading and stability manual should be considered as a tool for training and comprehension of the background of information only. The results of the manual calculation can be checked by the appropriate DOS-programme bock-a.exe or bock-c.exe.

4.3 Torsional strength

Torsion of the ship's hull can be induced by asymmetrical loading in individual cargo holds or tanks and when running in diagonal heavy seas.

The sensitivity of ships against torsion depends on the size of cargo hatches on deck. Tankers are least sensitive while container vessels and multipurpose vessels with hatches covering up to 80% of the deck area are most sensitive.

Torsion produces shear forces in transverse planes of the hull in bottom, side and deck plating. These shear forces are not at all critical. However they cause secondary deformations of hatchways and other structural components which may result in normal forces (pressure and tension). Most critical are the corners of large cargo hatches which may show buckling or cracks when over-stressed.

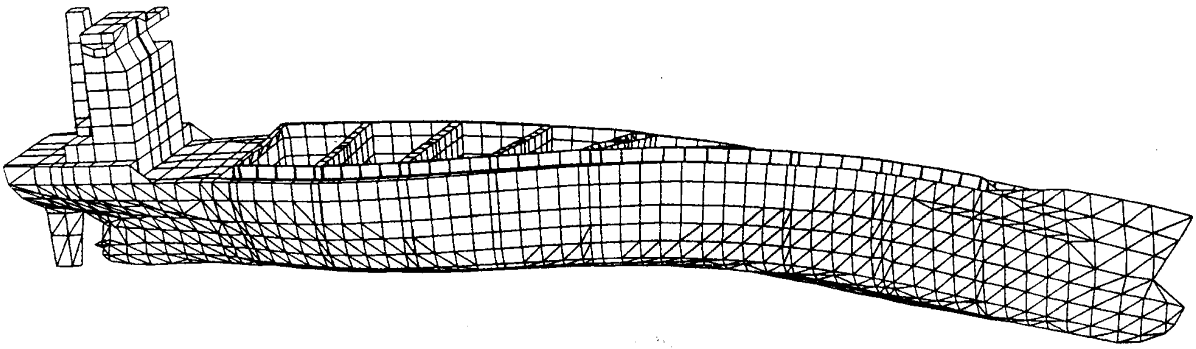


Figure 34: Deformation from combined hogging and torsion

Some loading and stability computer programmes on container ships calculate the net transverse moment from containers plus ballast or bunkers for each bay-section of the ship. By integration of these bay moments the torsional moments are found.

From these torsional moments the normal tensions in critical points (e.g. hatch corners) are calculated and converted into corresponding longitudinal bending moments. These are added to bending moments from the longitudinal strength calculation and displayed against the limiting values. Thus a combined control of longitudinal and torsional stresses is obtained.

The following rules for the avoidance of undue torsion should be observed:

- An unavoidable transverse moment of containers in a bay should be compensated by ballast in the same sectional compartment as far as possible.
- The residual compensation, i.e. the avoidance of a residual list, should be done in a section as close as possible to the section where the imbalance has appeared.

- The accumulation of transverse moments to the same side in successive bays or holds must be avoided by all means.
- Although tankers are much less sensible to deformation by torsion the diagonal loading of wing tanks without due compensation by ballast in the same section is not permissible.

Homework exercises No. 11

.1 Calculate the permissible stowage height of a cargo of cement in paper bags with a stowage factor of 0.9 m^3/t in a tween deck of 2.1 t/m^2 permissible surface load.

.2 Explain the reasons for the "half hatch rule" for loading large bulk carriers with only one or two loading facilities ashore.

.3 Estimate the deflection of the ships in the Figures 28 to 33.

.4 Calculate manually displacement, draught, trim, shear forces and bending moments for MV. Bockenheim for the following conditions:

Condition	A	B	C	D	E
Deeptanks P+S	450 t	860 t	220 t	735 t	520 t
Bunkers P+S	275 t	500 t	480 t	375 t	284 t
Set.tanks P+S	90 t	76 t	84 t	44 t	62 t
DO tanks P+S	125 t	150 t	98 t	135 t	82 t
LO tank 10C	9 t	5 t	4 t	7 t	9 t
LO tank 11C	6 t	5 t	9 t	8 t	9 t
FW ER	66 t	35 t	46 t	57 t	28 t
FW P+S	120 t	142 t	115 t	68 t	140 t
Stores	60 t	55 t	45 t	65 t	70 t
Forepeak	420 t	-	-	-	-
Ballast 1	full	-	-	-	-
Ballast 2	full	-	-	-	-
Ballast 3	full	-	-	-	-
Ballast 4	full	-	-	-	-
Ballast 5	full	-	-	-	-
Ballast 6	full	-	-	-	-
Ballast 7	full	-	-	-	-
Afterpeak	105 t	27 t	27 t	20 t	20 t
Hold 1	-	3743 t	6125 t	7120 t	3655 t
Hold 2	-	3921 t	-	-	2505 t
Hold 3	-	4527 t	7546 t	8330 t	-
Hold 4	-	5288 t	4911 t	-	-
Hold 5	-	5282 t	7546 t	8275 t	4685 t
Hold 6	-	5288 t	-	-	3780 t
Hold 7	-	4487 t	7116 t	8213 t	-

5. Guidelines on the Management of Ship's Stability

The following guidelines have been submitted by Germany to the IMO Sub-Committee on Stability and Load-Lines and on Fishing Vessels Safety (paper SLF 43/9) for consideration and approval at its 43rd session in September 2000. Under the pressure of ship owners interest the SLF Sub-Committee rejected the proposal and decided to delete the appropriate agenda item from its work program.

There were some delegations, however, who expressed support for the material in this submission, considering it useful for ship masters and officers. For this reason the text of the submission is used as study material for nautical students.

Introduction

1 These Guidelines on the Management of Ship's Stability have been prepared by the International Maritime Organization to minimise accidents and losses caused by improper ship operation. The Guidelines are directed to Administrations, to shipping companies and to masters and officers.

2 It is recognised that the general stability characteristics of ships by design should be in accordance with relevant SOLAS-regulations and other IMO-instruments, in particular with provisions lined out in the Intact Stability Code.

3 There is, however, an urgent need for additional care for stability by the ship's master and officers during cargo operations, navigation and emergency procedures.

4 The stability of the ship is a vital element in any shipboard consideration of safety and environment protection. Proper management of ship's stability should therefore be addressed as a key shipboard operation.

5 As the operation of ships and thus the management of stability may differ considerably among ship types and trade patterns, specific guidance should be provided by the company as appropriate.

6 The following aspects are common to all ships and should therefore be addressed in the specific guidance provided by the company:

- .1 Care for and monitoring of the ship's water tight and weather tight integrity;
- .2 Control of KG_c in the course of cargo, ballast or bunker operations;
- .3 Avoidance of transverse shifting of masses, such as cargo or heavy items of equipment;
- .4 Avoidance of large liquid free surfaces;
- .5 Preparedness for corrective measures to mitigate detrimental effects on stability; and
- .6 Keeping of records for control and reference (e.g., light ship characteristics).

7 The Guidelines on the Management of Ship's Stability are intended as an aid to focus on problems of shipboard stability management rather than presenting a comprehensive manual. Specific guidance, however, on certain issues is provided in the Appendices to these Guidelines.

8 When developing or revising the Safety Management System (SMS) Manual for a particular ship or group of ships these Guidelines and Appendices may be used as references.

Section 1 - Definitions, documentation and recording

1.1 Definitions

1.1.1 *Stability parameters* are, as a minimum, the figures of KG_c and the draught of the vessel in the actual condition. The figure of GM_c and the righting levers for the positive range of stability are considered of additional value for assessing the stability.

1.1.2 *Stress condition parameters* are the curves of shear forces and bending moments or figures of shear forces and bending moments for selected frame positions of the vessel in the actual condition. Alternatively percentage figures of shear forces and bending moments with regard to harbour or sea going limits can be used as stress condition parameters.

1.1.3 *Limits of stability* are stability parameters presenting the minimum stability as defined by the IMO Intact Stability Code or by appropriate instruments of the Administration, or presenting the maximum stability as considered tolerable by the master or provided by company instructions.

1.1.4 *Assessment of stability* is any procedure or action taken by the master or cargo officer to identify the stability parameters of the actual or pre-planned condition of a ship.

1.2 Documentation

1.2.1 Each ship should be provided with a Loading and Stability Manual, approved by the Administration, which contains sufficient information to enable the master to operate the ship safely and in compliance with relevant statutory requirements.

1.2.2 The Loading and Stability Manual and associated plans should be in harmony with the IMO Model Loading and Stability Manual (MSC/Circ.920). It should be drawn up in the "working language" of the ship and any other language the Administration may require. If the working language is neither English, French nor Spanish, the text should include a translation into one of these languages.

1.2.3 For certain ships the information provided in the Loading and Stability Manual should include additional details related to specific requirements in those ships.

1.2.4 The arrangements for responsibility, authority and competence on board with regard to cargo operations and tank operations should be clearly laid down by the company.

1.3 Records

1.3.1 Records on ship's stability should be filed and kept in a suitable way and over a period according to the company's requirements.

1.3.2 Departure records should include:

.1 voyage number, port, date and time;
.2 cargo and tank status;
.3 actual stability parameters;
.4 result of ship's draught survey (if applicable);
.5 result of stability measurement (if applicable); and
.6 assessment of stability over the forthcoming voyage and applicable limits of stability.

1.3.3 During the voyage daily and at arrival, an update of tank status and actual stability parameters should be established and recorded.

1.3.4 The records may consist of appropriate printouts of the ship's loading and stability computer or tank monitoring system.

1.3.5 Records on actual longitudinal and torsional stress condition parameters should be included, if deemed appropriate.

Section 2 - Control of stability during loading and unloading

2.1 Minimum stability requirements in port

2.1.1 The stability criteria required by MARPOL I/25A for oil tankers and as lined out in the IMO Intact Stability Code or in similar instruments of the Administration should be observed while the ship is at sea. In port, particularly during loading and unloading operations, a deviation from those criteria is generally acceptable provided the metacentric height GM_c is positive at all times and of sufficient magnitude.

2.1.2 It should be noted however that certain types of cargo operations like loading or unloading containers, ro-ro vehicles and any other heavy units may require a metacentric height exceeding the usual minimum values in order to avoid unsuitable heeling of the ship. The company should provide specific guidance regarding the minimum GM_c during cargo operations on such ships. Heeling restrictions of the ship with regard to the operation of ship's cranes should be observed.

2.2 Risks to stability during loading and unloading

2.2.1 Stability of a ship during cargo operations may suffer from inappropriate planning of the sequence of loading and unloading, particularly with both operations to be undertaken simultaneously. A close review of the operations plan should be carried out before the operation starts.

2.2.2 During cargo operations deviations from the agreed plan may occur due to delays or other unforeseeable circumstances. In order to avoid undue risks to stability the planned procedure should be divided into steps with check points or mile stones which provide for an effective control.

2.2.3 Incorrect figures of cargo unit masses in cargo documents may upset the operations plan and affect the final stability as well as the compliance with load line requirements. It is therefore recommended to take draught readings at suitable time intervals and check the cargo intake appropriately (see Appendix 1).

2.2.4 Lack of co-ordination between tank operations and cargo operations and shortcomings in tank operations may adversely affect the stability of the ship. A proper management of bunker and ballast tanks in co-ordination with cargo operations is therefore of utmost importance.

2.2.5 The loading or unloading of heavy cargo units by lift-on/lift-off or roll-on/roll-off operation may require the movement of large quantities of ballast water for avoiding excessive heel or trim. This can be a threat to stability depending mainly on the vertical location of the ballast tanks. A properly calculated balance of heeling levers and righting levers should be made up for critical situations and evaluated using criteria accepted by the Administration.

2.2.6 A controlled list during heavy lift operations may cause other cargo units to shift if they are not adequately secured. This will increase the list, which may be dangerous. It may also cause accidents to persons. Cargo and any loose equipment should therefore be adequately secured before such heavy lift operations are started.

2.2.7 Free surfaces in ballast and/or cargo tanks reduce the stability margin. During loading or unloading operations, this may cause negative initial stability with unexpected list and loll behaviour of the ship. This may happen particularly to OBO-Carriers loading or unloading oil and to tankers of the "single tank across" design. The approved operations plan for loading or unloading those types of ships should be strictly observed.

2.3 Measures of control

2.3.1 The company should provide general instructions with regard to the control of stability during loading and unloading cargo, appropriate to the type of ship and her cargo, in particular covering:

.1 the proper planning of cargo loading and unloading sequences including ballast and bunker operations;
.2 adequate control of operations including suitable checks of cargo mass intake; and
.3 specific advice as may be necessary for loading or unloading special cargoes like heavy lift units or liquid bulk cargoes.

2.3.2 The company's instructions should require a suitable recording of cargo loading and unloading operations.

2.3.3 Adequate communication should be maintained between the port facility and the master corresponding to the agreed responsibility for the operational control of loading.

Section 3 - Assessment of stability before departure

3.1 Defining stability limits for departure

3.1.1 Minimum stability requirements, as imposed by the Administration, should be well understood and identified with regard to:

.1 relevant information in the Loading and Stability Manual, i.e. limiting curves or tables of maximum KG_c or minimum GM_c; and
.2 additional criteria as may be applicable for certain cargoes or certain modes of operation (see Chapters 4 and 5 of the Intact Stability Code).

3.1.2 Bearing in mind the season of the year, weather forecasts and the area of navigation the master should also appraise and establish specific lower and upper limits of stability by his own experience to improve the behaviour of the ship at sea. Selected lower limits however must be kept within statutory minimum requirements.

3.1.3 The stability criteria contained in Chapter 3 of the Intact Stability Code or appropriate requirements of Administrations generally specify limits of minimum stability but no limits of maximum stability. It is advisable however, to avoid excessive values of metacentric height and righting levers, since these might lead to acceleration forces at sea which may cause undue strain to the securing of cargo and thus endanger the ship's stability by the risk of cargo shifting.

3.1.4 Reduction of stability during the forthcoming voyage should be assessed and taken into account when defining limits of departure stability. This should include, if applicable:

.1 water absorption of deck cargo;
.2 icing;

.3 heaving a haul of fish on deck.;
.4 reduction/redistribution of consumables; and
.5 ballast water exchange.

3.2 Methods of assessment of stability

3.2.1 Stability should be assessed before departure or whenever deemed necessary by one or more of the following methods as appropriate:

.1 comparing the intended loading plan or the existing loading condition with similar conditions of known stability parameters;
.2 individual calculation of masses and moments of allocated or existing cargo distribution and tank fillings;
.3 measurement of stability by in-service inclining test or by evaluation of the observed natural period of roll (see Appendix 2 or Appendix 3).

3.2.2 The method under 3.2.1.1 should only be chosen if an ample margin of stability against minimum requirements is obviously existing.

3.2.3 An approved computer programme will facilitate the method under 3.2.1.2. The results will be accurate, provided that cargo masses, tank fillings and centres of gravity are available with sufficient accuracy and reliability.

3.2.4 The method under 3.2.1.3 generally provides results which take all uncertainties regarding masses and centres of gravity into account. However, it can only be used in a close to final state of loading and needs further adaptations to arrive at the result for departure condition or worst condition during the voyage (see Appendix 4).

3.3 Special considerations

3.3.1 Ships carrying grain cargo shall comply with the requirements of the International Code of the Safe Carriage of Grain in Bulk.

3.3.2 Ships loaded with timber on deck shall comply with the provisions of the Code of Safe Practice for Ships Carrying Timber Deck Cargoes.

3.3.3 Ships carrying certain solid bulk cargoes other than grain may require a defined effort of transverse cargo trimming before commencement of the voyage, according to the IMO Bulk Cargoes Code.

3.3.4 Oil tankers built after 1 Feb 1999 and of 500 tdw or more need to comply with the provisions of MARPOL I/25A.

3.3.5 Before a voyage commences, care should be taken to ensure that the cargo and sizeable pieces of equipment have been properly stowed or lashed so as to minimise the possibility of both longitudinal and transverse shifting, while at sea, under the effect of accelerations caused by pitching and rolling.

Section 4 - Control of stability while at sea

4.1 Fuel consumption

4.1.1 The order by which bunkers from storage tanks are consumed during the voyage should be agreed between the master or cargo officer and the chief engineer with regard to consequential changes of stability.

4.1.2 Reduction of stability by consumed bunkers should be compensated by ballast in dedicated tanks, if necessary. This compensation should be done at pre-defined stages following an appropriate plan.

4.1.3 The number of partially filled or slack tanks should be kept to a minimum because of their adverse effect on stability. If a tank is kept slack deliberately in order to reduce a large metacentric height care should be taken to avoid dangerous sloshing of the tank contents in a seaway. Sloshing effects may be substantially reduced with filling above 90% or below 20% of the tank capacity.

4.2 Ballast exchange at sea

4.2.1 The exchange of ballast at sea may be required in certain trades as an option to avoid the transfer of unwanted aquatic species between geographical regions. For applicable vessels, the company should provide specific guidance in the form of a ballast water management plan on performing at-sea ballast water exchange (BWE).

4.2.2 Stability, strength, manoeuvrability, and bridge visibility are a concern during BWE evolutions. These safety attributes can be manageable through proper evaluation and timing of the BWE sequence. The above aspects are dependant on the tank exchange sequence selected, the amount and distribution of ballast to be exchanged, the margin between actual conditions and allowable limits and, to a lesser extent, the cargo and consumables loading arrangement.

4.2.3 Therefore, the ship's stability and strength may have to be analysed prior to each voyage to ensure that the ship does not violate its stability or strength limits during a BWE procedure. The use of stability and strength computers may facilitate performing these complex calculations.

4.2.4 When developing a ballast water management plan, the company should refer to IMO Resolution A.868(20), Guidelines for the Control and Management of Ship's Ballast Water to Minimise the Transfer of Harmful Aquatic Organisms and Pathogens.

4.3 Water absorption of deck cargo and icing

4.3.1 Certain deck cargoes like timber, open pipes, open barges, cork, coke and others may acquire added mass by heavy rain or overcoming sea water. Care should be taken to provide a good drainage in order to limit the reduction of stability to the anticipated value.

4.3.2 For any ship operating in areas where ice accretion is likely to occur, adversely affecting a ship's stability, icing allowances, as described in Chapter 5 of the Code on Intact Stability, should be included in the analysis of conditions of loading.

4.3.3 The "Recommendations for skippers of fishing vessels on ensuring a vessel's endurance in conditions of ice formation", as lined out in the Annex 2 of the IMO Code on Intact Stability, can be a useful guidance in case of ice accretion also on vessels other than fishing vessels.

4.4 Measures in case of negative GM_c

4.4.1 Although a proper allocation of departure stability would prevent a negative GM_c during the voyage in principle, experience has shown that a negative GM_c can develop due to extreme water soaking or icing or failures in tank management.

4.4.2 Depending on the existing sea conditions the decrease of GM_c may not be detected until a small overturning moment causes the ship to slightly list. This situation is critical in such a way that a first attempt may be to correct this list by re-arranging the transverse distribution of bunkers or ballast. Care must be taken as to the extent of re-distribution as it could exacerbate matters and the ship could loll to the opposite side and resume a list greater than before.

4.4.3 Although the observed list may be a combined result of negative GM_c and an eccentric centre of mass it is strongly recommended that with any corrective action the possible consequences of negative GM_c should be borne in mind. Emptying or filling of slack tanks, flooding of double bottom tanks, reducing weight on deck, or any other measure to increase the metacentric height should be given priority but with due regard for free surface effects at intermediate stages of filling/emptying tanks.

4.4.4 As flooding a double bottom tank will produce another liquid free surface until the tank is full, a narrow centre line tank should be chosen if possible. If a transverse pair of tanks has to be flooded the tank on the low side should be flooded first. This will temporarily increase the ship's list but avoids a possible loll to the opposite side.

Section 5 - Measures before and in heavy weather

5.1 Weather tight and watertight integrity of the ship

5.1.1 Weather tight and watertight hatches, doors, etc., should be kept closed during navigation, except when necessarily opened for the working of the ship, and should always be ready for immediate closure and be clearly marked to indicate that these fittings are to be kept closed except for access.

5.1.2 All doorways and other openings through which water can enter into the hull or deckhouse, forecastle, etc., should be suitably closed in adverse weather conditions and accordingly all appliances for this purpose should be maintained on board and in good condition.

5.1.3 All small equipment and loose gear, such as hoses, electric lines, and dunnage, in spaces accessed by watertight doors, particularly remotely controlled sliding doors, should be secured to prevent blockage of the watertight door.

5.1.4 Any closing devices provided for vent pipes to fuel tanks should be secured in bad weather.

5.2 Stowage and securing of cargo and equipment

5.2.1 Before the ship commences a sea passage, all cargo should be properly stowed and secured in accordance with the Code of Safe Practice for Cargo Stowage and Securing. It is also advisable to re-inspect all cargo in holds and on deck on a regular basis unless the nature of cargo or its stowage excludes any risk of shifting.

5.2.2 In doing such inspection it may be useful to observe the behaviour of critical cargo units or stowage blocks of cargo in the beginning of any major seas in order to detect possible deficiencies of the securing arrangement. This should be done timely however in order to upgrade the securing arrangement, if necessary, without undue risk for crew members.

5.2.3 Although any heavy items of equipment on board should be suitably stowed, locked or secured before the ship commences a sea passage there should be an inspection of this equipment before the ship enters a heavy weather area. This applies to the deck-, engine- and catering department.

5.3 Sailing in heavy weather

5.3.1 In severe weather, the speed of the ship should be reduced if excessive rolling, propeller emergence, shipping of water on deck or heavy slamming occurs. Six heavy slammings or 25 propeller emergences during 100 pitching motions should be considered dangerous (refer to Chapter 2.5 of the IMO Code of Intact Stability).

5.3.2 Water trapping in deck wells should be avoided. If freeing ports are not sufficient for the drainage of the well, the speed of the ship should be reduced or the course changed, or both. Freeing ports with closing appliances should always be capable of functioning, be routinely checked for paint closure, and are not to be locked.

5.3.3 Masters should be aware that steep breaking waves may occur in certain areas, or in certain wind and current combinations (river estuaries, shallow water areas, funnel-shaped bays, etc.). These waves are particularly dangerous, especially for small ships.

5.3.4 Special attention should be paid when a ship is sailing in following or stern quartering seas, because dangerous phenomena such as parametric resonance, broaching to, reduction of stability on the wave crest, and excessive rolling may occur singularly, in sequence or simultaneously in a multiple combination, creating a threat of capsize. Specific advice on how to navigate in such conditions is found in the IMO document "Guidance to the master for avoiding dangerous situations in following and quartering seas" (MSC/Circ.707).

5.3.5 Reliance on automatic steering in heavy weather may be dangerous as this prevents ready changes to course which may be needed in certain occasions.

5.4 Measures of control

5.4.1 The company's instructions should contain general advice on the issue "entering heavy weather" with regard to:

.1 water tight and weather tight integrity of the ship;
.2 re-assuring proper stowage and securing of cargo and equipment; and
.3 ship handling in heavy weather.

5.4.2 Before entering heavy weather the master should instruct crew members with regard to necessary safety measures and personal behaviour.

5.4.3 Fuel day tanks and settling tanks should be topped up appropriately in order to avoid loss of suction during heavy weather.

5.4.4 Dynamically supported craft should not be intentionally operated outside the worst intended conditions and limitations specified in relevant statutory documents.

Section 6 - Control of stability in small fishing vessels

6.1 General operating conditions

6.1.1 Fishing vessels should only be operated within the scope of approved loading conditions as specified under Chapter 4.2.5 of the IMO Intact Stability Code.

6.1.2 On small fishing vessels the master should be supplied with suitable information on minimum GM-values and appropriate maximum periods of roll for loading conditions as specified above.

6.1.3 The general precautions against capsizing as lined out in Chapter 4.2.2 of the IMO Intact Stability Code should be observed.

6.1.4 A concise and comprehensive operating manual covering the applicable relevant aspects should be prepared and carried on board.

6.2 Operating in adverse weather and sea conditions

6.2.1 Hatch covers and flush deck scuttles should be kept properly secured when not in use during fishing operations. All portable deadlights should be maintained in good condition and securely closed in bad weather.

6.2.2 If icing is likely to occur the provisions of Annex 2 to the IMO Intact Stability Code ("Recommendations for skippers of fishing vessels on ensuring a vessel's endurance of ice formation") should be observed. All relevant particulars should be contained in the operating manual addressed to under 6.1.4 above.

6.2.3 The use of an approved automatic warning system which is designed to directly indicate the loss of stability due to fuel consumption, high deck loads of water, fish or ice or any other reason, is recommended, but should not be solely relied upon.

6.2.4 The development and use of simple information on the permissible co-relation of effective GM_c and wave height or any other suitable weather parameter is recommended.

Section 7 - Control of stability in damaged condition

7.1 Damage stability criteria

7.1.1 Certain ship types, in particular passenger ships and oil-, gas- and chemical tankers, have to be operated under the regime of damage stability criteria. Moreover, all cargo ships built after 1 Feb 1992, passenger ships, and ships assigned with reduced freeboard under the 1966 ICLL, need to be operated in accordance with stability limits based on a subdivision standard.

This may include separate information provided to the master in the form of diagrams, tables or suitable computer programmes prescribing the observation of a value of minimum GM_c or maximum KG_c related to the actual condition of loading. This value affords an acceptable level of protection against capsizing under specified conditions of damage while operating in a nominal environmental condition.

7.1.2 Generally damage stability criteria require a higher initial stability than the intact stability criteria. Damage stability criteria on tankers need not be observed by the master when the ship is in a pure ballast condition with cargo residues in normal quantities.

7.1.3 Compliance with damage stability criteria does not ensure immunity against capsizing in any damaged condition. Masters should therefore be aware of the necessity and benefit of proper contingency planning covering damage control.

7.2 Effects of damage on stability

7.2.1 Damages which affect ship's stability may result from collision, grounding, fire and explosion and any leak under or above the waterline through which progressive flooding may occur. Specified damages are found in various IMO instruments for the purpose of damage stability control based on ship design. The specified damages for the appropriate ship type may be taken as reference to judge the consequences of actual damage to an individual ship of that type. Damages are specified:

.1 for oil tankers in MARPOL, Annex I, Regulation 25 and in Regulation 13 F (raking damage);
.2 for chemical tankers in the IBC-Code, Chapter 2.5 and in the BCH-Code, Chapter 2.2;
.3 for gas tankers in the IGC-Code, Chapter 2.5 and in the GC-Code, Chapter 2.3;
.4 for passenger ships in SOLAS, Chapter II-1, Regulation 8;
.5 for cargo ships greater than 80 metres in length, probabilistic damage stability requirements in SOLAS, Chapter II-1, Part B-1; and
.6 for offshore supply vessels in IMO Resolution A.469(XII), Guidelines for the Design and Construction of Offshore Supply Vessels.

7.2.2 Water entering a damaged ship will generally assemble in the lower parts of the hull and thus tends to lower the ship's centre of gravity. The amount of water able to enter the ship depends on the permeability of the flooded space, i.e. the volume percentage not occupied by other items like cargo, equipment, ballast or bunkers.

7.2.3 Water entering a damaged ship causes the draught to increase and thus changes relevant stability parameters like KM and cross-curve values. In fully loaded conditions KM is likely to increase slightly while cross-curve values for inclinations above 10° heel will decrease considerably with the draught. The latter bears the risk of capsizing, even with positive GM_c, in the case of asymmetrical flooding where heeling levers may exceed the reduced righting levers.

7.2.4 Asymmetrical flooding causes the immediate development of a list. This list is a most serious effect as it not only lowers the water inlet and increases the rate of flooding but also reduces the righting levers on the low side of the vessel.

7.2.5 If the flooded space has a large surface area the negative effect of liquid free surface will affect the stability seriously. Most commonly the initial ingress of water will heel the ship which will then fail to upright because of negative GM_c. Subsequently, the ship could capsize for the same reason as mentioned under sub-paragraph 7.2.3 above.

If however, during the process of flooding, the ship's waterplane area increases sufficiently and/or the amount of water taken in is sufficient to restore a positive GM_c, the ship could also potentially return to upright condition if there is no other heeling moment from asymmetrical flooding.

7.2.6 In most damage and flooding situations the effect of asymmetrical flooding combines with the effect of free liquid surfaces and reduces righting levers due to list and reduction of freeboard. The risk of capsizing in such a situation is higher on ships with low freeboard than on ships with ample freeboard.

7.3 Assessment and control of damage

7.3.1 Any actions undertaken to assess and control the damage and secure the stability and integrity of the ship should be made commensurate with preparations for safety and rescue actions for persons on board.

7.3.2 The assessment of damage should be undertaken with the aim to get a reasonably clear picture of the affected parts of the hull and an estimation of progress and final stage of flooding. For this purpose the following issues should be surveyed with due regard to damage control plans:

.1 location and extent of damage;
.2 estimated rate of flooding;
.3 size and permeability of flooded spaces;

.4 possible asymmetry of flooding and expected list; and
.5 neighbouring spaces liable to be affected by breaching of bulkheads or by leaks.

7.3.3 The information obtained should be used to control the flooding procedure in order to avoid capsizing of the ship. The following aspects should be taken into account:

.1 An intolerable list of the ship may be counteracted by deliberate counter-flooding, bearing in mind the additional risk from free liquid surfaces and the reduction of free-board.
.2 Breaching of bulkheads to adjacent spaces may be prevented by shoring with timber or other suitable means. Small holes or cracks may be secured by wooden wedges or plugs.
.3 If the casualty has happened alongside or close to a jetty a good mooring of the damaged vessel may prevent capsizing. The support of tugs pressing the vessel to the jetty may be useful too.
.4 In the case of a collision bow to side with another vessel, it may be useful to secure the bow of the one vessel to the breached side of the other in order to prevent capsizing. This option however would not be feasible if motions from the seaway would cause further damage to the ships in contact or, if the nature of the cargo or the presence of passengers would impose a risk higher than currently exists.
.5 Using the ship's pumps and/or pumps supplied by other vessels may control the flooding, at least to an extent to save time for other useful measures.
.6 Deliberate beaching or stranding, although bearing the threat of reducing the longitudinal strength and/or the structural integrity with serious consequences, may save a damaged vessel from capsizing in the first place.
.7 The damage may have affected the longitudinal strength of the ship by weakening the structure. Additionally, there may be an increase of existing shear forces and bending moments by the effect of the incoming water. These aspects should be borne in mind when taking deliberate actions to secure the stability of the ship. As there is currently no simple comprehensive guidance available for assessing possible strength problems from damage, such decisions will have to be left to the discretion of the master, unless specific guidance is given in damage control plans.

7.3.4 A damaged vessel sitting on the ground should not be towed off or be allowed to re-float until sufficient structural integrity, stability and a close to upright floating condition is confirmed by thorough investigation.

Section 8 - Control of stability in special situations

8.1 Control of stability after a major shift of cargo

8.1.1 A major transverse shift of cargo will cause the ship to heel and reduces the righting levers at the immersed side (refer to the International Code for the Safe Carriage of Grain in Bulk). The stability of the ship is therefore at risk and action by the master may be required.

8.1.2 As the amount of shifted cargo and distance of shifting will be unknown until the cargo space has been inspected it may be useful to estimate the residual stability at the immersed side by the following method:

.1 Take the actual righting lever curve for the upright ship from the last record statement.
.2 Indicate the observed angle of heel after cargo shifting and draw a horizontal line through the intersection of the heeling angle ordinate with the righting lever curve (Figure 1).

.3 The residual stability is presented by the shaded area that is bounded by the righting lever curve, the horizontal line established under 8.1.2.2, and the down-flooding angle (if applicable). The residual stability should be compared against usual minimum stability requirements and prevailing weather conditions in terms of range, area, and value of maximum lever.

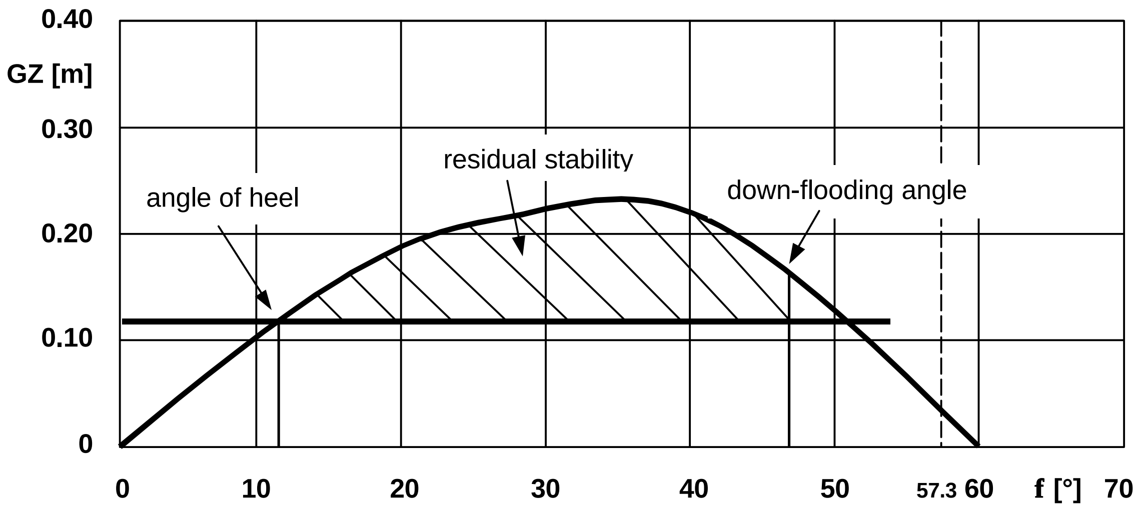


Figure 1: Residual stability after cargo shifting

8.1.3 If remedial actions are deemed necessary to secure the stability of the ship the following aspects should be considered:

.1 Change of course and/or speed to reduce further rolling of the ship may be useful as a quick reaction.
.2 Securing of the shifted cargo to its new position may be advisable before righting the ship up by counter-flooding with ballast or by transfer of bunkers.
.3 As securing a shifted bulk cargo may be impractical any measures to upright the vessel should be restricted to a moderate reduction of the heel in order to avoid a re-shifting of cargo with a possibly larger heel to the other side.

8.1.4 A one-sided loss of deck cargo, e.g., containers, has the same effect to stability as a transverse shift of cargo notwithstanding the slight advantage of lowering the ship's centre of gravity by the loss of top mass. The method of assessing the residual stability and the measures of control are in principle the same as described under 8.1.2 and 8.1.3 above.

8.2 Towing operations

8.2.1 A ship, when engaged in towing operations, should possess an adequate reserve of stability to withstand the anticipated heeling moment arising from the tow line without endangering the towing ship (refer to MSC/Circ. 884, Guidelines for Safe Ocean Towing).

8.2.2 In particular ships shifting berths within the port area may have a stability less than for seagoing condition. If a tugboat is used for this procedure the tug master should be warned accordingly to pull or push at reduced power.

8.3 Fire fighting

8.3.1 Fire fighting on board in port or at sea may involve the use of large quantities of water, in particular if access to the fire is restricted and an action of more or less flooding the space is the only way to control the fire. In such a case care should be taken not to endanger the ship by the risk of capsizing through the effect of liquid free surfaces from the water used for fire fighting.

8.3.2 Another threat to stability may arise if water from fire fighting becomes entrapped on upper decks, especially in unsymmetrical areas.

8.3.3 In particular with fire fighting alongside a jetty any developing list may not be noticed until the mooring ropes give way. Additionally shore fire brigades may not be fully aware of the risk of capsizing of a vessel due to the free surface effect.

8.3.4 In order to control the risk of capsizing the bilge pumps should be run to de-water the area as appropriate or drainage of spaces in upper decks should be effected.

8.4 Dry-docking

8.4.1 Ships being dry-docked have to go through a short period of reduced stability which is the time span between the first touching of the keel timbers and the settling on the full length of the keel whereupon lateral support booms or side propping devices can be put in place. For this reason ships being dry-docked should have ample stability and as little trim as possible.

8.4.2 During the docking period ballast tanks may have to be emptied and bunkers shifted depending on the work programme. Therefore, before the ship is re-floated again, a full survey of all tanks and a subsequent stability and trim calculation should be carried out to make sure that after re-floating

- .1 the ship has sufficient stability;
- .2 the ship will float without list;
- .3 the trim is within reasonable limits; and
- .4 stress condition parameters are within acceptable limits.

Section 9 - Miscellaneous issues

9.1 Equipment for stability management

9.1.1 Equipment and instrumentation for stability management should, with due regard to the operating parameters of the ship, consist of:

- .1 an approved computer and software supporting the documentation of cargo and tank operations, statical calculations with regard to stability, draught, trim and stress, and the evaluation of draught readings (shipboard draught survey);
- .2 an approved system for carrying out a fast and reliable stability measurement;
- .3 an approved remote draught gauging system; and
- .4 an approved remote tank gauging system.

9.1.2 A simple and straightforward instruction manual, written in the working language of the ship and any other language the Administration may require, should be provided with this equipment (see MSC/Circ.891, Guidelines for the On-Board Use and Application of Computers).

9.1.3 If computer based on-line evaluation of stability measurement, draught measurement or tank gauging is to be implemented, suitable means, like intermediate results and specific interrelations, should be provided for the user to check final results for plausibility.

9.1.4 It is desirable that the input/output form in the computer and screen presentation be similar to the one in the loading and stability manual so that operators will easily gain familiarity with the computer and the manual.

9.1.5 In order to validate the proper functioning of the equipment, test conditions should be run periodically at intervals specified in the company's instructions. Test results should be recorded and kept within the appropriate recording system.

9.2 Other considerations

9.2.1 The company should, when issuing instructions on the management of ship's stability, in particular in the context of the distribution of cargo, ballast and bunkers, provide attention also to other aspects of safe ship operation. This may include:

.1 longitudinal strength in terms of permissible bending moments and shear forces or torsional moments;
.2 vertical sequence of masses in container stacks on deck (refer to the ship's Cargo Securing Manual);
.3 observation of deck loading restrictions due to sight line requirements;
.4 suitable trim of the ship with regard to steering and handling in heavy weather; and
.5 load line requirements.

9.2.2 The above mentioned and other considerations related to the management of ship's stability should be appropriately reflected within records (see Section 1).

Section 10 - Training requirements

10.1 General education and training

10.1.1 General education and training of masters and mates with regard to the management of ship's stability is addressed to in the appropriate tables of Sections A-II/1, A-II/2 and A-II/3 of the Seafarers Training, Education and Watchkeeping (STCW) Code.

10.1.2 The instruction and education on the theoretical background of stability related issues and appropriate calculation procedures, generally carried out by Maritime Education and Training (MET) institutes, in complying with STCW-requirements, should reflect the needs and provisions of stability management as lined out in these guidelines.

10.1.3 The practical training of future deck officers, as addressed to in Section B-II/1 of the STCW-Code, should include appropriate familiarization with procedures of stability assessment and recording.

10.2 Specific shipboard training

10.2.1 The company should ensure that a deck officer, designated to assume the duties of a cargo officer, is given proper familiarization with the ship and the documentation and equipment regarding the management of ship's stability and related aspects.

10.2.2 The master should verify the appropriate ability of the particular deck officer and provide supervision if necessary.

10.2.3 Aspects of stability management within the contingency planning scheme should be appropriately addressed to within shipboard drills or paper exercises on damage control issues. This applies to all deck officers and engineers on board.

Appendix 1 - Simplified draught survey

1 Other than a full draught survey as described in detail in the IMO document BC 32/Inf. 9 and preferably used in bulk carriers, a simplified draught survey, as described in this appendix, may be carried out in any short break of cargo operations, even on a container ship. Its accuracy is sufficient to check the cargo intake, preferably by the differences of displacements between particular stages of loading.

2 The definitions and symbols used in this Appendix are consistent with the definitions and symbols presented in the MSC/Circ. 920. These are in particular:

L	length between perpendiculars	m	MTM	moment to change trim one metre	t·m/m
B	breadth moulded	m	TPC	tonnes per centimetre immersion	t/cm
DISV	displacement volume	m^3	KM	transverse metacentre above base	m
DISM	displacement mass	t	KG	centre of mass above base	m
ρ	density	t/m^3	KG_c	KG corrected for free surfaces	m
B.M.	stillwater bending moment at L/2	t·m	GM	metacentric height	m
d	deflection at L/2; $d = T_{KM} – T_K$	m	GM_c	GM corrected for free surfaces	m
t	trim; $t = T_{KF} – T_{KA}$	m	ZG	centre of partial mass above base	m
T_{KF}	keel draught at FP	m	XF	centre of flotation from AP	m
T_K	keel draught at MP	m	X_1	aft mark from AP	m
T_{KA}	keel draught at AP	m	X_2	mid mark from AP	m
T_{KC}	reference keel draught	m	X_3	fore mark from AP	m
T_{KFR}	reading at fore mark	m	FP	fore perpendicular	-
T_{KR}	reading at mid mark	m	MP	mid between perpendiculars	-
T_{KAR}	reading at aft mark	m	AP	aft perpendicular	-
T_{KM}	mean draught; $0.5 \cdot (T_{KF} + T_{KA})$	m	WL	actual waterline	-

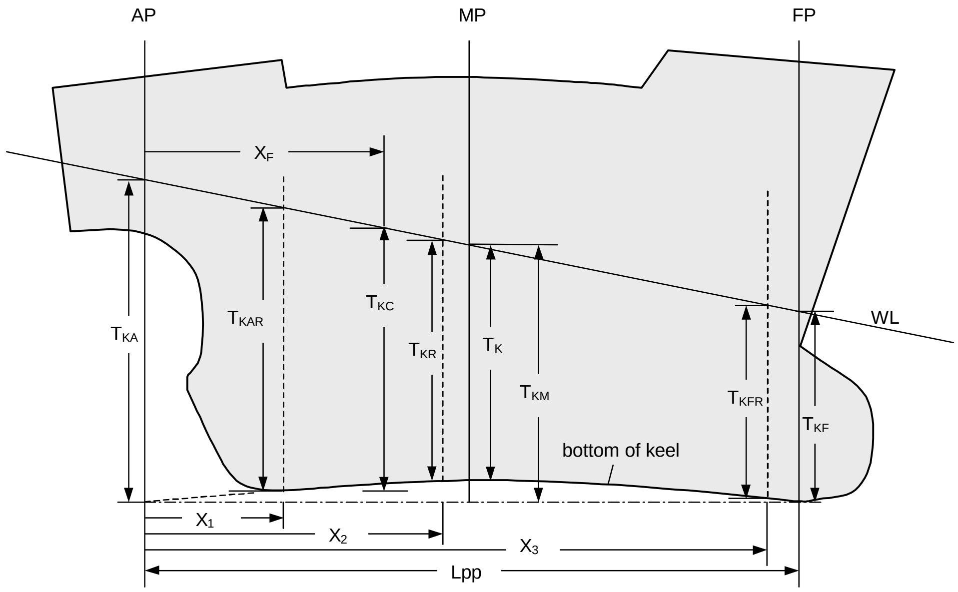


Figure 2: Definition of draughts and mark positions

3 A ship in any given state of loading will be slightly listed, trimmed and longitudinally deflected. Draught readings are taken at marks which are generally close to but not exactly at the perpendiculars. Therefore a number of corrections must be applied to such readings to obtain a reference draught. This reference draught provides the immersed gross volume of the ship which, multiplied by the measured harbour water density, presents the actual mass-displacement (DISM) of the ship.

4 This slightly complex task is described below in a step by step procedure. Calculations should preferably be performed by a suitable routine within the ship's loading and stability computer.

.1 Remove any heel of the ship as far as practicable using the automatic anti-heel system or other suitable tanks.

.2 Take draught readings fore and aft as accurately as possible. Results are T_{KFR} and T_{KAR} .

.3 Measure the harbour water density by means of a hydrometer. Use a water sample from a depth of about half the ship's draught. The result is ρ.

.4 Estimate ship's deflection at L/2 using the formula:

$$d = \frac{L \cdot \text{actual B.M. at MP}}{1000 \cdot \text{B.M.}_{\text{lim}} \text{ at MP}} \quad [\text{m}]$$

(the sign of d equals the sign of actual B.M. at L/2)

.5 Apply corrections to draught readings for obtaining draughts at perpendiculars:

$$T_{KF} = T_{KFR} + (L - X_3) \cdot \left(\frac{T_{KFR} - T_{KAR}}{X_3 - X_1} + \frac{3.4 \cdot d}{L} \right) \quad [\text{m}]$$

$$T_{KA} = T_{KAR} - X_1 \cdot \left(\frac{T_{KFR} - T_{KAR}}{X_3 - X_1} - \frac{3.4 \cdot d}{L} \right) \quad [\text{m}]$$

6 Calculate mean of draughts and the trim using the formulae:

$T_{KM} = 0.5 \cdot (T_{KF} + T_{KA})$ [m]

$t = T_{KF} - T_{KA}$ [m]

.7 Calculate the reference draught using the formula:

$$T_{KC} = T_{KM} - 0.7 \cdot d + t \cdot \frac{XF - L/2}{L} + t^2 \cdot \frac{MTM_2 - MTM_1}{200 \cdot L \cdot TPC} \quad [\text{m}]$$

MTM_2: moment to change trim at (T_{KM} + 0.5 metres)

MTM_1: moment to change trim at (T_{KM} – 0.5 metres)

.8 Enter hydrostatic table using T_{KC} for obtaining gross volume DISV in m^3.

.9 Calculate mass displacement using the formula:

DISM = DISV · ρ [t]

5 An estimation of ship's deflection based on the actual bending moment at L/2 may be impaired by high temperature differences between deck and bottom of the ship or by a permanent deflection of the hull. It is recommended to check the estimated deflection on occasion by additional draught readings at the mid marks of the ship.

6 The accuracy of the result of a draught survey depends largely on the accuracy of draught readings, density measurement and estimation of deflection. For a ship of 100 m length, loaded close to her marks, the true displacement will be with 95% probability within ± 0.7% of the value found by this draught survey, provided the following margins are not exceeded with 95% probability:

draught readings:	± 0.020 m
estimation of deflection:	± 0.025 m
measurement of density:	± 0.004 t/m^3

For larger ships results are even more reliable.

7 The procedure described under paragraph 4 can be simplified and made more reliably by an equipment consisting of remote draught reading devices fore, mid and aft which are processed on-line and converted into a suitable display of the ship's displacement.

Appendix 2 - Measurement of stability by in-service inclining test

1 The purpose of an in-service inclining test is to measure the metacentric height GM_c and consider the result when deciding on further loading of deck cargo or on ballasting. The stability parameters obtained from an in-service inclining test include free surface effects and all masses and their vertical position in a realistic manner and should be preferred to parameters obtained from a mere calculation.

2 The accuracy required in shipboard practice can be sufficiently described by ± 10% with 95% probability. That is ± 5 cm with a GM_C of 0.5 m. This margin is easily met with reasonable effort in a test of less than 10 minutes duration. However care should be taken to observe the performance standards as outlined below.

3 The basic test procedure can be described by the following steps:

.1 Prepare the ship to heel freely.
.2 Eliminate interfering moments.
.3 Measure first angle of heel ϕ_1.
.4 Induce a defined heeling moment $m \cdot e$.
.5 Measure second angle of heel ϕ_2.
.6 Remove the defined heeling moment and measure a third angle of heel ϕ_3 (cross-check).
.7 Carry out a simplified draught survey (see Appendix 1).
.8 Calculate the metacentric height GM_C using the formula:

$$GM_C = \frac{m \cdot e}{DISM \cdot \tan(\phi_2 - \phi_1)} \qquad [m]$$

m = heeling mass [t]
e = heeling lever [m]
$(\phi_2 - \phi_1)$ = test angle of heel [°]

.9 Obtain KGc using the formula:
$KG_c = KM - GM_C$ [m]

Note: If the absolute trim of the ship is greater than 0.01 · L, then KM for trimmed condition should be used. KG_C is already increased for the effect of free surfaces in tanks.

Note: If the absolute difference of ϕ_3 and ϕ_1 (cross-check) exceeds 5% of the test angle of heel it should be considered to repeat the test and re-check any interfering moments.

Preparation of the ship to heel freely

4 The following principles should be observed when preparing the ship for the test with regard to slackening the mooring ropes:

.1 **Wind blowing off-shore:** Slack all mooring ropes until distance from fenders is about 0.5 metres. Steep ropes from fair leads on shore side of the ship should be slack.
.2 **Wind blowing on-shore:** Slack all mooring ropes until sag in the rope is about 10% of the free length. Steep ropes should be slackened a little more. Ship's contact to fenders is no hindrance to the test.
.3 **Wind blowing parallel to quay:** Keep one or two long mooring ropes taut and slacken the rest to 10% sag. Further contact of the ship to fenders is no hindrance to the test.
.4 Shut down automatic mooring winches and tighten breaks. Hoist up the gangway well clear from the quay unless its foot can roll readily and will not get stuck to any obstacle.

Elimination of interfering moments

5 It is important that in the short span of time between the first, second and third measurement of the heeling angle there is no change of heeling moments other than the test moment and free surface moments in slack tanks. For this reason the following task list should be worked through and arrangements made as appropriate:

.1 Stop all cargo loading, unloading or moving of cargo in the ship.
.2 Stop all moving of cargo gear (derricks, cranes, hatches, ramps) or other equipment and stop all tank operations in deck and engine department.
.3 Stop the automatic anti-heel system, if provided.
.4 Stop all tending of mooring ropes (automatic mooring winches disengaged).
.5 Limit the walk-around of persons on board (on ships below 100 m length only).
.6 Check wind conditions: With wind of 6 Bft or above there is an increased risk of squalls lasting several minutes, which may impair the test.
.7 Check current in the water and its effect to changes of heel (observe the heel indicator).
.8 Check swell in the harbour and decide whether movements of the ship are regular enough to use mean values of heel.
.9 Make sure there is no ship passing near by during the test.
.10 Check keel clearance to avoid touching the ground.

If one or more of the above conditions cannot be met or are considered unsuitable the test should be abandoned.

6 Free surfaces in bunkers and other tanks need not be considered. They are automatically accounted for in the test result GM_c. Care should however be taken that flat ballast tanks, which are to be nominally full, are really full and those, which are to be nominally empty, are really empty. Otherwise the tiny ullage of air or the bottom layer of liquid, which would practically not affect the stability, will lead to a reduction of the test-GM_c, pretending less stability than available.

Measuring of heeling angles

7 Preferably an advanced precision instrument should be used which provides a reading sufficiently smoothed and a print or a graphic record over the time.

8 The instrument should keep an accuracy of ± 0.05° with 95% probability. It should be robust against the usual shipboard environment (vibrations, humidity, accelerations). Equipment for easy re-check of calibration should be provided with the instrument. As the test angle of heel is the difference of two measurements a zero-calibration is not required. Classification societies are generally prepared to approve such instruments according to their specifications.

9 The absolute heel of the ship during an in-service inclining test should not be greater than 3.5° in order to keep the influence of additional form stability on the measured metacentric height within tolerable limits. It is therefore recommended to pre-heel the ship to one side before the test and convey the test heel back and beyond zero to the other side. The maximum obtainable test angle of heel would be 7° in that way providing for a higher relative accuracy of that test angle. The cross-check should be applied accordingly.

Providing a defined test moment

10 The test moment should be numerically between 2% and 7% of the ship's displacement, i.e. between 200 and 700 t·m for a ship of 10000 t displacement. The amount of the test moment should be known or determinable with a relative accuracy of ± 2% with 95% prob-

ability. The time for inducing the test moment should be less than 3 minutes, to keep within the desired overall duration of 10 minutes.

11 With these requirements there are three suitable choices available:

.1 One or two cargo units of known mass can be transversely shifted or loaded/unloaded on the side of the vessel. Preferably standard containers should be used. The mass should be determined by running the container over a weigh-bridge. The accuracy of weight control in container loading bridges is generally not sufficient. The lever of transverse shifting should be determined by using a tape-measure.

.2 Liquid of known density can be shifted between side tanks. Ballast tanks - although a preferred choice on large vessels (DISM > 25000 t) - are normally not suitable for this purpose because of low transfer capacity and inaccurate control of filling state. Special stability test tanks however with fast liquid transfer and accurate determination of test moments are available and successfully in use on cargo vessels and ro/ro-ferries with approval by the Administration.

.3 A heavy crane jib or heavy-lift derrick. can be given a defined transverse movement. The preferable method is to turn an empty crane jib or derrick to an extreme transverse position at a defined inclination. After taking the first measurement of heel the jib or derrick is turned to the opposite side at the same inclination. The test moment induced by this procedure should be suitably documented in the ship's Loading and Stability Manual.

12 It is recommended that the amount of the appropriate test moment is determined and approved by the Administration in the course of the ship yard inclining experiment or by a similar suitable test arrangement.

Overall accuracy of the test

13 Taken the required relative accuracy's with 95% probability as proposed above, i.e. average ± 2.5% with the test angle of heel, ± 2% with the test moment and a relative accuracy of the displacement by draught survey (see Appendix 1) of ± 0.7%, the probable relative error in GM_c is:

$$e_{GMc} = \pm \sqrt{(2.5^2 + 2^2 + 0.7^2)} = \pm 3.3\%$$

This error is well below the accepted error margin of ± 10% with 95% probability.

14 In order to achieve a reliable result of KG_c the value of KM should be carefully interpolated from ship's hydrostatic tables or curves using trimmed hydrostatics if the ship is trimmed more than 1% of L_{pp}.

Monitoring and recording the test

15 The in-service inclining test should be appropriately monitored and recorded in accordance with procedures provided by the company's Safety Management System. In particular the preparation of the ship and the task list for elimination of interfering moments should be filed together with measurements taken for the draught survey and the inclining test itself. If the test is carried out by on-line computer management the appropriate printed records should be kept with the documentation.

Abandon test conditions

16 The in-service inclining test should be abandoned if one of the following conditions are met:

.1 swell, ice or other circumstances which prevent a reasonable determination of the ship's displacement,
.2 lack of suitable means to produce a defined test moment of a magnitude sufficient for a test angle of heel of at least 1°,
.3 swell or other circumstances which prevent a precise measurement of heeling angles,
.4 inability to avoid interfering moments (see paragraph 5); this may be revealed by the cross-check heel procedure.

Advanced equipment for inclining tests

17 Such approved equipment may include a remote draught gauging system, a fast and precise inclining tank system and an inclinometer. The performance and evaluation of the test may be controlled by a computer programme. The use of advanced equipment for performing in-service inclining tests is recommended.

Appendix 3 - Measurement of stability by observing natural periods of roll

1 The so-called rolling test may be recommended as a useful means of approximately determining the initial stability of the ship. The advantage of the rolling period test against the in-service inclining test is its quick performance and the independence from a draught survey, although for a complete stability assessment the mass displacement of the ship should be determined as well. Disadvantageous however is its lesser accuracy compared with the in-service inclining test.

2 The result of a rolling test is the metacentric height GM_c which contains the effect of free surfaces in tanks holding liquids with usual viscosity. GM_c is obtained by the formula:

$$GM_C = \left(\frac{C_\phi \cdot B}{T_\phi} \right)^2$$

with
C_ϕ = rolling co-efficient
B = ship's breadth [m]
T_ϕ = natural rolling period [s]

3 The rolling period required is the time for one complete oscillation of the ship. The test should be conducted with the ship in harbour, in smooth water with the minimum interference from other disturbing influences. The effect of free surfaces in the ship is taken into account automatically.

4 The rolling co-efficient is a value ranging between 0.72 and 0.84 in general, although these figures have been exceeded in certain situations. It should be noted that the greater the distance of masses from the rolling axis, the greater the rolling coefficient will be. Therefore it can be expected that:

.1 the rolling coefficient for an unloaded ship, i.e. for a hollow body, will be higher than that for a loaded ship; and
.2 the rolling coefficient for a ship carrying a great amount of bunkers and ballast – both groups are usually located in the double bottom, i.e. far away from the rolling axis – will be higher than that of the same ship having an empty double bottom.

5 Although the preparation of the ship is similar to that for performing an in-service inclining test the sensitivity against interfering moments is much reduced. Thus the checklist given in Appendix 2 paragraph 5 may be restricted to the items 1, 3, 4, 8, 9 and 10 when applied to the rolling test. It is important however that the ship is prepared to roll freely by slackening the mooring ropes in accordance with paragraph 4 of the Appendix 2.

6 For the following reasons, it is not generally recommended that results be obtained from rolling oscillations taken in a seaway with the ship under way:

.1 coefficients for tests in open waters are not available,
.2 the rolling periods observed may not be free oscillations but forced oscillations due to seaway,
.3 frequently, oscillations are either irregular or only regular for too short an interval of time to allow accurate measurements to be observed; and
.4 specialised recording equipment is necessary.

Ships up to 70 m in length

7 For ships up to 70 m in length the IMO Intact Stability Code contains comprehensive guidance on the performance of the rolling test in Chapter 7.6 based on earlier studies on this issue.

Ships above 70 m length

8 A limited number of combined rolling and inclining tests with ships greater than 70 m length has indicated that there is in principle no difference to the behaviour of small ships. Ships over 70 m length should be prepared to roll freely in the same manner as described for small ships. A suitable way to initiate roll motions is to lift a heavy cargo unit, favourably a loaded container, with ship's gear from the quay and set it down again giving sufficient slack to the runner.

9 As the roll amplitude will be only small, i.e. in the range of 2 to 3 degrees in the beginning with a considerable rate of reduction due to damping, it has been found convenient to observe the roll motions on the quay by watching the rise and fall of the ship's side against the edge of fenders or similar reference. The average time of two complete roll motions, taken by a stop watch, will provide a sufficiently accurate period of roll. This procedure may be repeated without undue delay to cargo operations.

10 The rolling coefficient C_ϕ behaves on larger ships in the same manner as found with small ships below 70 metres length. Particularly in a situation where stability may become critical, i.e. a container vessel with full deck cargo and appropriately ballasted, the coefficient C_ϕ is found closing or even exceeding the value of 0.8. It is however recommended to evaluate the coefficient C_ϕ by a number of double tests (in-service inclining test and roll test) for such loading conditions.

Accuracy of rolling test

11 With reasonable assumptions the relative error margins of the rolling test can be found at ± 15% with 95% probability. This unfavourable result follows from the square expression in the rolling formula which indicates an increased sensitivity of GM_c against errors in C_ϕ and T_ϕ. The rolling test is therefore inferior to the in-service inclining test although there may be situations where a rolling test will be suitable to indicate whether a critical situation may be expected or not. The rolling test should however not be used to check the stability of a ship in a critical situation, i.e. close to stability limits.

12 Experiments have shown that the results of the rolling test method get increasingly less reliable the nearer they approach GM_c values of 0.20 m and below.

Monitoring and recording the test

13 The rolling test should be appropriately recorded in accordance with procedures provided by the company's Safety Management System. If the rolling test is carried out using a graphical heel recorder, the printed graphs should be appropriately identified and kept with the record.

Appendix 4 - Adaptation of test results for assessing final conditions

1 Preferably a measurement of stability should be carried out shortly before loading of cargo is completed in order to decide on the final intake without the commercial risk of unloading cargo already accepted for transport. As the condition of the ship at such an earlier test will generally deviate from the final departure condition and even more from the "worst condition" during the voyage, appropriate adaptations have to be made to the test result in order to compare it with limit values as set by the master or by statutory requirements.

2 These adaptations should regard all major changes or shifts of masses as:

.1 loading/unloading or shifting of cargo,
.2 lowering/hoisting of heavy cargo gear from working position into sea condition,
.3 returning hatch covers from the jetty to the ship,
.4 hoisting ramps or lowering bow visor,
.5 filling or emptying/consuming tanks including changes of free surface effects,
.6 increase of mass of deck cargo due to absorption of water,
.7 increase of top mass due to icing.

3 Results of a measurement of ship's stability are DISM and KG_c. The aim of any adaptation is to determine DISM and KG_c for the adapted condition. The two basic types of calculations, i.e. adding/removing a mass or mere vertical shift of a mass can be done within the same scheme. This is shown in the following example:

Calculated example

4 It is assumed the results of an in-service inclining test are DISM = 11425 t and KG_c = 8.24 m.

	mass [t]	ZG [m]	vert. Mom. [t·m]
Condition at time of test	**11425**	**8.24**	**94142**
Adaptations:			
Loading of 4 containers into tier 82	36	19.58	705
Lower crane boom No.2 from 80°	---	---	- 407
Hoist and stow stern ramp	---	---	784
Return hatch cover No.1 from shore	29	12.79	371
Consume fuel from DB tank No. 4	- 140	0.75	- 105
Cancel free surface moment in DB tank No. 4	---	---	- 560
Increase top mass due to icing	100	20.00	2000
Worst condition during the voyage	**11450**	**8.47**	**96930**

These results for the worst condition during the voyage should be compared with limit values of stability.

5 It is recommended that information on the adaptation of test results by moving cranes, ramps, hatch covers and similar heavy equipment into sea condition is contained in the loading and stability booklet in the form of suitable tables or diagrams.

6 Calculations for adapting stability test results to a departure condition or to a worst condition during the voyage should be kept with the record documents on stability management.

Annex 1 Training requirements

STCW-Code

Table A-II/1 contains the following requirements for knowledge, understanding and proficiency (column 2) at the operational level:

Working knowledge and application of stability, trim and stress tables, diagrams and stress-calculation equipment. Understanding of fundamental actions to be taken in the event of partial loss of intact buoyancy. Understanding of the fundamentals of watertight integrity.

Table A-II/2 contains the following requirements for knowledge, understanding and proficiency (column 2) at the management level:

Knowledge of the effect on trim and stability of cargoes and of cargo operations. Use of stability and trim diagrams and stress-calculating equipment, including automatic data-based (ADB) equipment, and knowledge of loading cargo and ballasting in order to keep hull stress within acceptable limits.

Understanding of fundamental principles of ship construction and the theories and factors affecting trim and stability and measures to preserve trim and stability. Knowledge of the effect on trim and stability of a ship in the event of damage to and consequent flooding of a compartment and countermeasures to be taken. Knowledge of IMO recommendations concerning ship stability.

StAK-Ausbildungsanforderungen

The following key-words are listed for the subject "Schiffbau und Schiffstheorie":

Grundkenntnis der Schiffstheorie in Bezug auf Schwimmfähigkeit, Stabilität, Trimm und Festigkeit;

- *Stabilitätsbelastungen durch*
- *Übergehen von Ladung,*
- *Wassereinbruch,*
- *Winddruck,*
- *Seegang,*
- *Schwergutübernahme,*
- *freie Flüssigkeitsoberflächen,*
- *Wasseraufsaugen der Decksladung,*
- *Vereisung,*
- *Hartruderlage.*

Kenntnis der nationalen und der IMO-Stabilitätsempfehlungen

Additional requirements are found under the subject "Ladungstechnik":

Überwachung von Stabilität und Festigkeitsbeanspruchungen unter Anwendung von einschlägigen Verfahren und Methoden (Bordrechner, manuelle Rechnung); Dokumentation im Sinne des ISM-Codes.

Annex 2 Questions and assignments

At the end of the lectures and studies the student shall be able to:

1. Define the metacentre M and the centre of mass G.[1]
2. Illustrate the righting lever GZ in a cross-section of a heeled vessel.
3. Identify in a formulary the approximation function for GZ-values up to 5° heel.
4. Identify in a formulary the approximation function for GZ-values up to 15° heel.
5. Explain the static effect of liquid free surfaces on ship's stability.
6. Calculate the change of GM due to a given liquid free surface.
7. Identify in a formulary the moment of inertia for triangular, trapezoid and circular surfaces.
8. Describe the influence of breadth and draught of a ship on the position of the metacentre.
9. Describe the influence of breadth and freeboard on the character of the GZ-curve.
10. Explain the purpose and contents of the Loading and Stability Manual (LSM) of a ship.
11. Identify and explain the principal dimensions of a ship.
12. Identify in an LSM the reference planes for co-ordinates a ship.
13. State the reference plane for ship board draught readings or calculations.
14. Demonstrate the lifting of form data of the ship from hydrostatic tables.
15. Demonstrate the lifting of cross curve data and the generation of a GZ-curve.
16. Explain the role of GM with regard to the gradient of the GZ-curve at zero heel.
17. Demonstrate the lifting of cargo space and tank space data from the L&S Manual.
18. Demonstrate the calculation of KGc of a ship with given masses and ZG-values.
19. Calculate the change of KGc of a given ship when loading or unloading containers.
20. Calculate the change of KGc of a given ship from a vertical shift of a single mass.
21. Calculate the change of KGc of a given ship when consuming bunkers.
22. Calculate the change of KGc of a given ship by ballast operations including slack tanks.
23. Explain the principle of an in-service inclining test.
24. Calculate GMc from test conditions of an in-service inclining test.
25. Explain the principle of a rolling test in port.
26. Explain the influence of radial mass distribution on the roll co-efficient C_ϕ.
27. Calculate GMc from test conditions of a rolling test.
28. Outline the purpose and limitations of intact stability criteria (IMO and national).
29. Demonstrate the checking of a given GZ-curve against intact stability criteria.
30. Demonstrate the determination of maximum KGc-values from an LSM.

[1] Abbreviations and symbols used in this Annex are in conformity with the IMO MSC/Circ. 920.

31. Demonstrate the determination of minimum GMc-values for trimmed condition.
32. Explain the terms "stiff", "normal", "sea-kindly", "tender" related to a ship.
33. Describe the effect of a transverse shift of cargo on the GZ-curve.
34. Determine the angle of heel from a transverse shift of cargo.
35. Determine the angle of heel from transverse wind pressure to a ship.
36. Determine the angle of heel from of hard rudder at a given speed.
37. Determine the angle of heel from a towing tug for given stability conditions.
38. Describe the effect of following high waves on the stability.
39. Describe the effect of resonance with encountered waves.
40. Describe the effect of ingress of water on the stability.
41. Determine a GZ-curve for negative GM.
42. Calculate the angle of loll using a formulary.
43. Demonstrate the calculation of XG of a ship with given masses and XG-values.
44. Determine the trim of a ship from the difference between XG and XB.
45. Determine the draughts at perpendiculars following the determination of XG.
46. Define the tabulated "moment to change trim one metre" (MTM).
47. Calculate the change of trim by loading, unloading or shifting a single mass.
48. Calculate the change of trim of a ship by entering from seawater into freshwater.
49. Determine the approximate XG from draught readings.
50. List the ship types to which the International Load Line Convention applies.
51. Calculate the freshwater allowance, the dock-water allowance using a formulary.
52. Define the difference between summer draught and tropical draught.
53. Define the difference between summer draught and winter draught.
54. List all conditions under which a vessel is allowed to be loaded to the seasonal mark.
55. Identify ships which are given a Winter North Atlantic mark.
56. Define the deflection of a ship (hog or sag).
57. Calculate the loss of dead weight caused by sagging.
58. Explain the change of draught at the Plimsoll mark when the vessel is trimmed.
59. Explain the use of the chart of load line zones.
60. Determine the maximum departure draught with regard to area or season.
61. Compare the maximum stack load and permissible surface load on a hatch cover.
62. Define shear forces in a ship's hull in the context of longitudinal strength.
63. Define bending moments in a ship's hull in the context of longitudinal strength.
64. Explain the meaning of a positive gradient of a section of the shear force curve.
65. Explain the meaning of a bending moment curve section in the positive range.

66. Explain the limiting values for shear forces and bending moments at sea and in harbour.
67. State the maximum static deflection of hull from hogging or sagging at sea and in harbour by rule of thumb.
68. State a rule of thumb for the relation of hull deflection and midship bending moment.
69. Explain the bulkhead correction for a ship with longitudinal bottom girders.
70. Explain stresses from undue torsion of hull in an "open" ship.
71. Interpret and check a container stowage proposal prepared in a planning centre ashore.
72. Determine the gain in stability for an estimated average reduction of c.o.g of containers.
73. Optimise the consumption of fuel and intake of ballast for controlling stability.
74. Evaluate the free surface effect of bunker tanks during transfer of bunkers.
75. Prepare a ship for the performance of an in-service inclining test.
76. Perform and supervise an in-service inclining test.
77. Analyse the influence of disturbing moments to an in-service inclining test.
78. Determine the ship's displacement by a simplified draught survey.
79. Determine the ship's displacement by a comprehensive draught survey.
80. Perform a rolling test for the determination of GMc.
81. Calculate the departure stability from a stability measurement before end of loading.
82. Calculate the stability for the worst condition during a voyage, considering fuel consumption, water soaking of deck cargo and icing.
83. Organise stability management in a case of loading towards stability limits.
84. Maintain records on stability and stresses of a vessel within the SMS of the company.
85. Organise the control of stability and strength considerations before leaving a dry-dock.
86. Control the stability and strength in case of fire fighting with huge masses of water.
87. Determine and judge the residual stability after an apparent shift of cargo at sea.
88. Decide on correct remedial measures for a ship showing lolling behaviour.
89. Decide on correct measures for improving stability after damage to the ship.
90. Organise the watertight integrity at commencing a voyage and at entry into bad weather.
91. Pre-calculate the risk to stability by resonance with encountered waves.
92. Determine the required trim of a vessel at departure for achieving a desired trim at arrival.
93. Determine the required distribution of residual cargo for a desired trim at departure.
94. Determine the approximate displacement from draught reading amidships considering trim and deflection.
95. Determine the permissible draught amidships at departure for complying with load-line regulations if another zone is entered after departure by date or by sailed distance.
96. Discuss the display of shear forces and bending moments of a vessel with regard to alternatives of distribution of cargo, ballast or bunkers.

97. Interpret instructions in an LSM with regard to strength limits under certain conditions as part loading, alternate loading and others.
98. Prepare a concept of diminishing the influence of torsion in a container vessel by appropriate ballasting.
99. Decide on correct measures for reducing stresses after damage to the ship.
100. Interpret advice to the control of stability and strength during ballast water exchange at sea.