1991

A scenario for the avoidance of dangerous stability situations

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A SCENARIO FOR THE AVOIDANCE OF DANGEROUS STABILITY SITUATIONS

by

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Togo

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the

Degree of Master of Science

in

Maritime Education and Training (Nautical)

Year of Graduation

1991

I certify that all material in this dissertation which is not my own work has been identified and that no material is included for which a degree has been previously conferred upon me.

The contents of this dissertation reflect my personal views and are not necessarily endorsed by the University.

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A SCENARIO FOR THE AVOIDANCE OF DANGEROUS STABILITY CONDITIONS

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MET(N)-1991

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DEDICATION

TO

MY WIFE AND CHILDREN

ACKNOWLEDGMENTS

The achievement of this project is not a work of one person. It is the result of various contributions which finally bring me to this stage. The Stability had been and will inevitably always be a topic into which many experts will put more and more attention. This project represents my modest contribution in this matter.

I would like to thank first of all Capt. **Stephen CROSS** and Professor Capt. **Hermann KAPS**, who have accepted to supervise this paper, without whom it would have been impossible. They have employed their efforts to bring me from nothing to this stage, therefore this end, I sincerely thank them for their assistance.

My special thanks goes to my course Professor Prof. **Jef. H. MULDERS** for his encouragement and advice.

I am grateful to Prof. Dr.-Ing. **Sigismund KASTNER** who advised me to choose this subject and supplied me with useful information.

I would like also to thank all the resident and visiting Professors, Faculty Staff, the English Language and Library Staff for their assistance during the two-year study.

I am indebted to the United Nations Development Program (UNDP) for its generosity in sponsoring me for this two-year study at the World Maritime University.

My sincere and profound gratitude goes to the "Ministère du Commerce et du Transport; Direction des Affaires Maritimes" of TOGO and the "Academie Régionale des Sciences et Techniques de la Mer d'Abidjan" for nominating me for this course.

I owe a special debt of gratitude to my parents and friends: M. **Koffi ADONSOU, ANKOU, SOUDI, AZAMETY, AKOUMANY, PAUL, BENEDITE** who have always provided me with necessary moral assistance and motivation.

My thanks goes also to my family in law, my sisters and brothers and particularly **Hélène** who helped me in one way or another by their contribution to the successful completion of my study.

Finally I owe all my gratitude to my friends and class mates which I could have mentioned by name.

Koffi FACHAO
November 91
Malmo

ABSTRACT

Ship Stability is one of the maritime subjects which raises lot of enthusiasm and controversy. As long as ships continue to be lost at sea, the need will exist for a constant reviewing of stability standards and increasing exigency to provide more effective regulations.

The present study will be focussed on three main modules. These modules are: technology, regulations and training. Whenever an accident happened at sea people are called to find probable persons or authorities responsible. They concentrated their research on: the ship Master and crew, the national and international regulations and the ship. As far as navigation is concerned, the master will be responsible, from a legal point of view, for any accident or damage caused by his ship to any other things. The problem highlighted here is to know if the ship master get the necessary technical background to confront all kinds of situation he might encounter at sea.

This study will be divided into five chapters.

The first chapter deals with what we can call the naval architecture heritage. The characteristic conditions of a vessel are the doing of the naval architect. As far as the building is finished the Master will just have to cope with it.

The second chapter concerns the factors affecting the ship stability and mostly the marine environment. The marine environment in which the ship will sail for all its life is not always friendly.

Chapter three is about how ship Masters use the information given by the shipbuilder in order to find the best conditions in which they can navigate safely and in accordance with the regulations.

The case study is only one of various incident that can happen if something goes wrong or somebody makes a mistake. The case of the HERALD OF FREE ENTERPRISE is interesting in the way that it raises many problems and questions involving all the parties concerned.

Finally it is time to try to understand what training can and must do in order to improve the navigation conditions. On other hand we will look at the International Maritime Organization for assistance in upgrading trainers.

INTRODUCTION

Navigation and Ship Stability and Dynamic calculations are important elements in the curriculum of maritime academies regardless the philosophy of the maritime education and training system. This importance comes from the extent of ship officers involvement in these fields aboard ships. With the introduction of computers, the work and performance of the student or the ship officer has been facilitated. Moreover the database management and the accuracy of the results have been improved. The development and improvement of such tools resolved partly the need for high accuracy for safer navigation as far as position fixing and stability calculations are concerned. These artificial tools have also their deficiencies characterized by errorneous outputs when the inputs have not been done properly.

There are other factors which influence the way in which maritime transport is done as well as its impact on the training philosophy. These factors can be summed up as follows: "bigger and technically advanced ships for reduced crew". Ships are becoming bigger and greater for economical reason. The shipping world call it the economy of scale which is the need to maximize the benefit of size. New ships have been developed during the last twenty years in order to satisfy this need. The last decade has been marked by the building of many Freight RORO ships and large container ships able to carry more than 4400 containers at once.

Ship operations do not depend only on the degree of sophistication of the ship. It depends mainly on the interaction between human performance and the level of technology. It is generally admitted that a ship must be stable in order to perform its function effectively, but an accurate definition of this concept has great importance. Furthermore, once a criterion for the stability judgement has been developed, the next question is how far it is valid for all loading conditions and seaways; whether its application will restrain a vessel's performance, and so on.

The real crest of the problem is the need to quantify the "stability" of a ship in a way that it represents reality acceptable and is at the same time, in form that designers and operators can use. A number of basic requirements must be met when designing a ship for operation in various seaways, but the most fundamental of these is undoubtedly satisfactory stability. During last ten years many attempts have been made to find an acceptable stability criterion able to satisfy the users. Specially IMO (the International Maritime Organization) is currently involved in developing stability criteria which take full account of vessel dynamics in a realistic environment.

Nevertheless after a ship has been built, the ship operators have the whole responsibility to handle it with its qualities and deficiencies. The training philosophy needs to follow both the new technology and the economical constraints. This paper will outline problems encountered by ship officers in handling their ships and give some advice to overcome some difficulties they might encounter during their duty.

CHAPTER I

CHARACTERISTIC STABILITY CONDITIONS OF A VESSEL

1.1. LIGHT SHIP PARTICULARS

1.1.1. Principal Dimensions

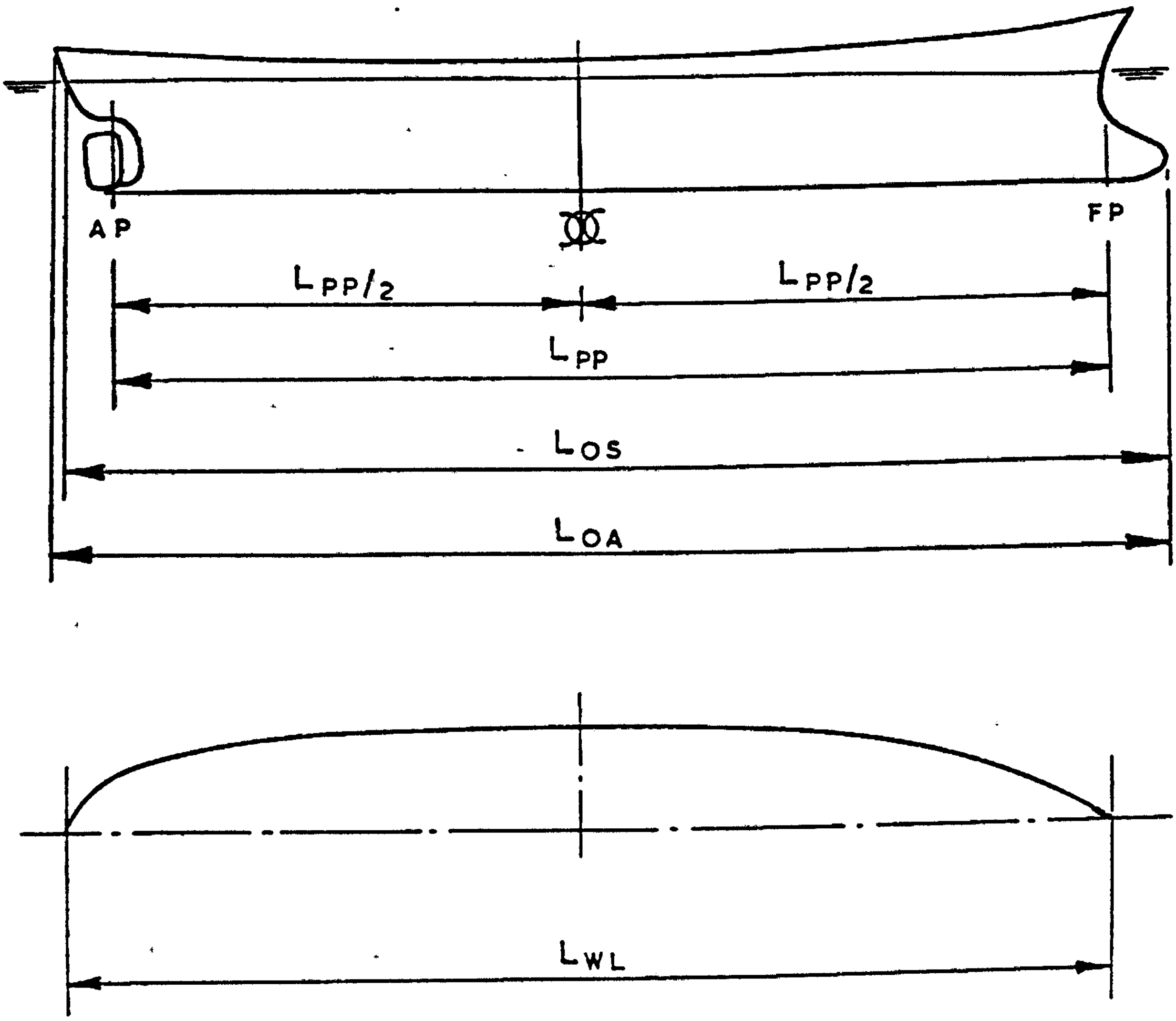
The principal dimensions of a vessel can be divided into three categories: Longitudinal, Transverse and Vertical dimensions.

- Longitudinal Dimensions.

Length-Over-All (LOA) is the linear distance from the most forward point of the forwardbow to the aftermost point of the stern, measured parallel to the base line.
Length Between Perpendiculars (LBP) is the linear distance between the forward and after perpendiculars measured parallel to the base line.
Length on Load Waterline (LLW) is the linear distance from the most forward point to the aftermost point of the waterline. Each different length has its own purpose:

LOA is useful for manoeuvering information.

LBP is used by ship designers as an average effective length. It is also used for ships calculations.
In assigning Registered Tonnage, the Regulations may specify a Registered Length which may be regarded as the official or governmental length.



Characteristic ship lengths

-Transverse Dimensions.

The only transverse dimension used in naval architecture and ship calculations is the moulded breadth.
The Moulded Breadth (B) is the linear distance from the molded surface on one side to the moulded surface the other side. The Moulded Breadth is the widest portion of a vessel's hull (excluding the shell plating) parallel to the waterlines. This dimension is used in ship calculations and dock entries.

- **Vertical Dimensions:**

The vertical dimensions more used in naval architecture are depth, draft, freeboard, camber and sheer.
The depth is the vertical distance from the lowest point of the hull to the side of the to witch it is referred. Depth varies amidships to the ends. The most used depth in ship operations and naval architecture is the moulded depth.

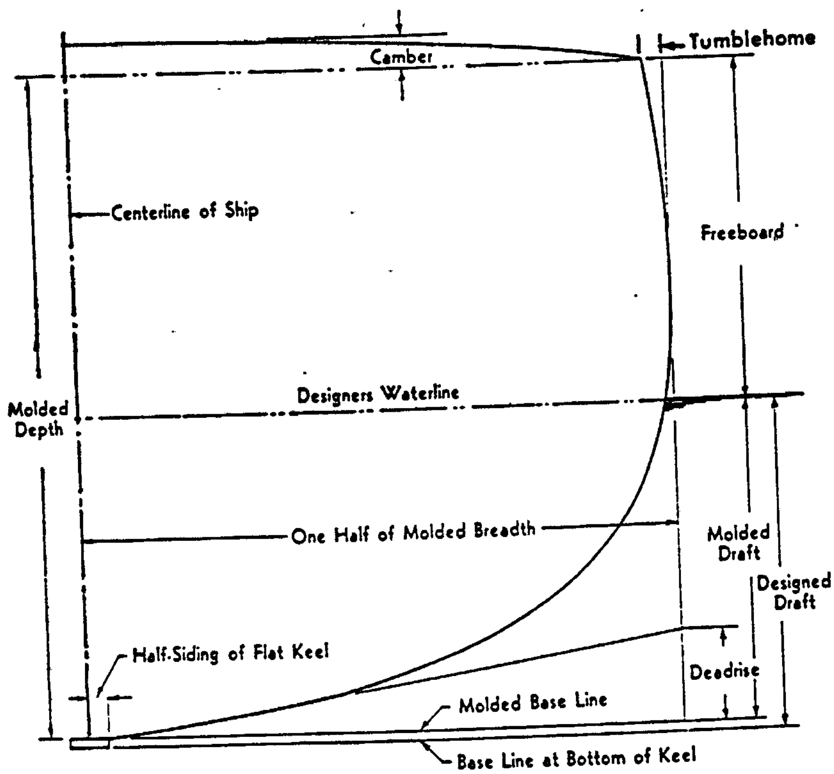
The Moulded Depth is the vertical distance from the lowest point of the base (excluding the bottom plating) line to the moulded line of the upper deck at the side. It is measured amidships.

The draft is the vertical distance from the lowest point of the hull to the waterline. This dimension is indicated on the sides of the vessel forward, midships and aft by draft marks.

The freeboard at any point along the ship's side is the vertical distance from the waterline to the upper deck at that point. Officially, freeboard is measured amidships. a freeboard can be considered at any point to be the difference between draft and depth at that point.

Camber : the height of difference at the center and the side.

Sheer: at any point is the vertical distance between the ship's side amidships and the ship's side at that point. It is the longitudinal curvature of a vessel's deck.



Midship-section molded-form definitions

Fig. 1.2

1.1.2. Tonnages

A ship is more than a three-dimensional body. It is a floating body which must be designed to transport cargo, crew and passengers as rapidly, safely and economically as possible. A definition of a ship is necessary than mere lengths and breadths. It includes the various types of ship's tonnages. A study of ship's tonnages not only helps to express the size or weight of a vessel but answers many questions of importance to the ship's officer.

Displacement Tonnage.

The weight of a vessel is obtained by calculating the volume of water displaced in cubic meter and multiplying that volume by the density of the water in which the vessel is floating. The mass of a vessel is known as Displacement Tonnage (Δ). When the vessel is completely empty, her mass is called Light Displacement. It is calculated in ship's yard by experiment.

Deadweight Tonnage.

The mass of cargo, fuel, water and stores necessary to submerge a vessel from her light draft to her load draft is called Deadweight Tonnage. It is the difference between the load displacement and the light displacement.

Gross and Net Register Tonnage.

Register Tonnage is used to assess fees on the vessel when she berth at a pier, enters a drydock or goes through a canal. Gross Register Tonnage is the internal volume of a vessel less certain exempted spaces. These exempted spaces are of importance to the shipowner as he naturally wishes to keep his Gross Tonnage as low as possible in order to reduce the fees.

Net Register Tonnage.

Net Register Tonnage is determined by deducting from Gross Tonnage most spaces which are not used for the carriage of goods or passengers. Tonnage laws affect design, and, in general, the larger the machinery space in relation to the vessel, the larger the deduction allowed for the space and the lower the Net Tonnage.

The Net Tonnage and the Gross Tonnage are determined by the rules described in the Tonnage Convention of the International Maritime Organization (IMO). To clarify the relationship between the tonnage and the load line at which a ship is designed to float and the ship's draft, the Plimsoll marks and tonnage marks are drawn on the ship's sides.

1.1.3. Coefficients of Form

In the definition of hull geometry, there are certain coefficients which are of great value for the prove of the fatness or slimness of the hull. These coefficients are:

- Block coefficient
- Midships coefficient
- Prismatic coefficient
- Waterline coefficient

1.1.3.1. Block Coefficient C_B.

The Block Coefficient C_B is the ratio of the volume of the displacement (V) up to a given waterline to the volume of a rectangular solid. The length L, breadth B and depth D are equal respectively to the waterline length, the moulded breadth at the waterline and the moulded draft of the vessel up to that waterline.

$$C_B = \frac{V}{L \times B \times T}$$

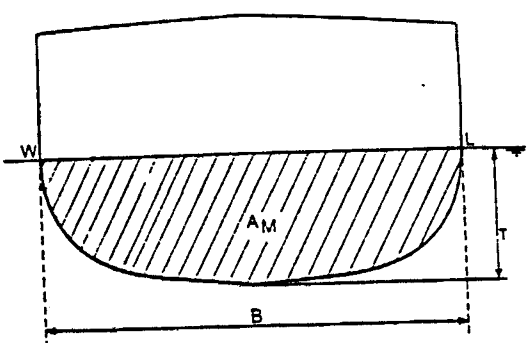
Generally in calculating the Block Coefficient of the merchant ships, the length used is Length Between Perpendiculars (L_{BP}). Values of the Block Coefficient at load displacement vary from about 0.38 for high-powered yachts to 0.80 for slow speed sea going cargo vessels and 0.90 for tankers.

1.1.3.2. Midships Section Coefficient C_M

The Midships Section coefficient is the ratio of the immersed area of the midships section to the area of the circumscribing rectangle.

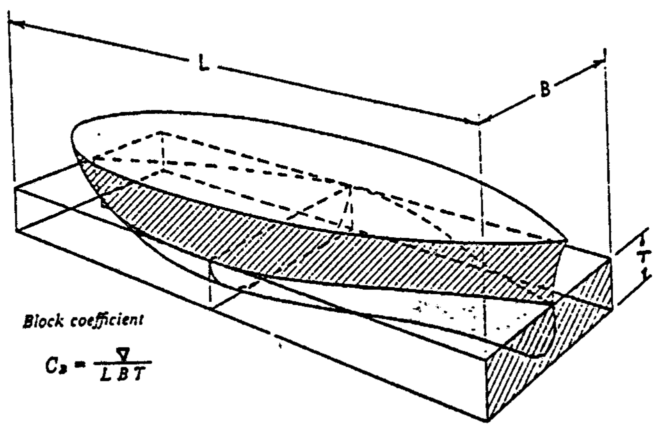
$$C_M = \frac{\text{Immersed Area of Midships section}}{B \times T}$$

This coefficient varies from about 0.75 to 0.98 but vessels of extreme forms, the values might be as low as 0.67.



Midship-section coefficient

Fig. 1.3



Block coefficient relationship

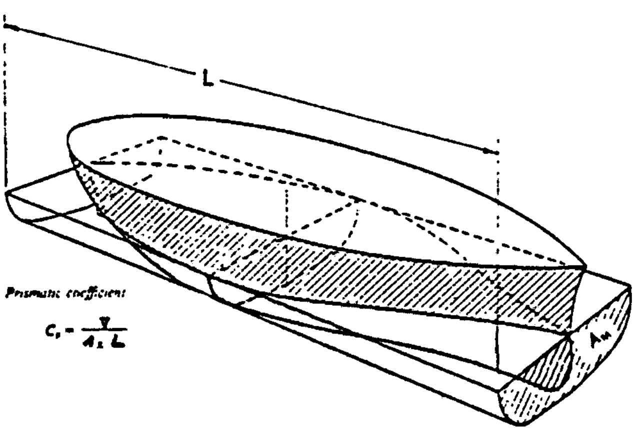
Fig. 1.4

1.1.3.3. Prismatic Coefficient Cp

The prismatic coefficient or longitudinal coefficient Cp is the ratio of the volume of displacement to the volume of a prism having a length equal to the length between perpendiculars and a cross-sectional area equal to midships sectional area. The values generally exceed 0.55.

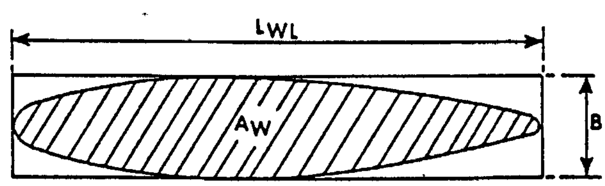
$$C_p = \frac{V}{A_M \times LBP}$$

The principal use of the prismatic coefficient is in connection with estimates of the speed and power for a vessel since the vessel's displacement greatly influences the amount of residuary resistance at a given speed.



Prismatic coefficient relationships

Fig. 1.5



Waterplane coefficient

Fig. 1.6

1.1.3.4. Waterplane Coefficient C_{WP}

The Waterplane Coefficient is the ratio of the area of the waterplane to the circumscribing rectangle. It is given by:

$$C_{WP} = \frac{\text{Area of Waterplane}}{L \times B}$$

Unless otherwise stated, the Waterplane Coefficient refers to the load waterline of the ship.

1.1.4. Purpose and Conduct of the Inclining Experiment.

1.1.4.1. Purpose of the Inclining Experiment

The assessment of the stability of a ship in any particular condition of loading can be done only if the initial conditions are known. That is, if the center of gravity and the weight of the light ship are correctly known.An Inclining Experiment is conducted to establish, experimentally, the weight and the center of gravity of light ship. The International Convention on the Safety of Life at Sea (SOLAS) requires that "every cargo or passenger vessel shall be inclined on completion".

An Inclining Experiment is also conducted after a ship has been converted if the conversion is extensive enough to prelude a reliable estimate of the weight and the center of gravity.
Inclining Experiments are carried out while the ship is in service, if it is felt that the weight and the center

of gravity may have been affected significantly by the accumulation of many minor changes.
Finally the Inclining Experiment, also called "In-service Inclining Test" can be done, if used properly, to find the weight and the center of gravity in any loading condition.

1.1.4.2. Precautions

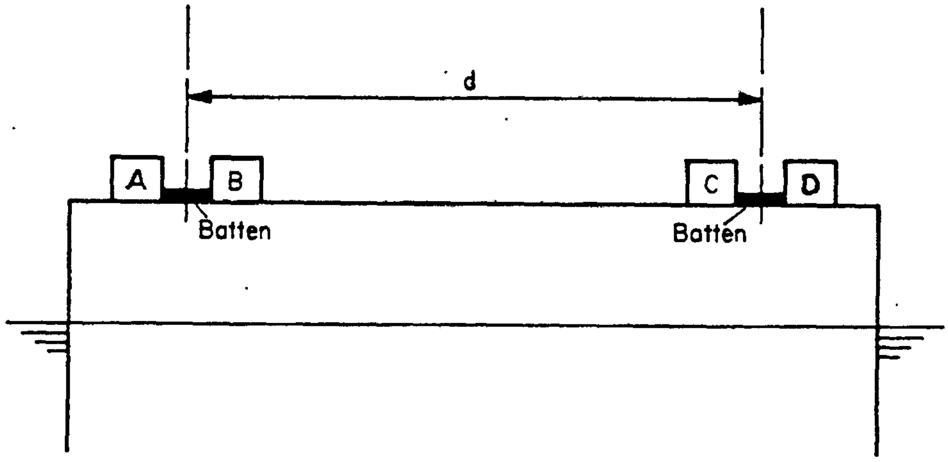
The following conditions are necessary to ensure that the KG obtained is as accurate as possible.

1- There should be little or no wind, as this may influences the inclination of the ship. If there is any wind she should be head or stern on of it.
2- Mooring lines must be slack and the ship clear to the dock, so that she may heel freely. This means that nothing outside the ship should prevent her from listing freely. There should be enough water under the ship to ensure that at any time during the experiment she will not touch the bottom.
3- Tanks should be empty or pressed full. If neither of these conditions is possible, the level of liquid in tanks should be such that the free surface effect is readily calculable and will remain sensibly constant throughout the experiment.
4- The number of persons on board should be kept to a minimum and they should go to specified positions for each reading of the pendulums.
5- All loose weights should be fastened.
6- Any mobile equipment used to move the weights across the deck must return to a known position

for each set of readings.

7- The ship must be upright at the beginning of the experiment.

1.1.4.3. The Inclining Experiment



Movement of weights during an inclining experiment

Fig. 1.7a

When all is ready and the ship is upright, a weight is shifted across the deck transversely, causing the ship to list. The principal steps in carrying out an inclining test are:

- the ship is surveyed to determine weights to be removed, to come on board or be moved for final completion.
- The state of all tanks should be noted carefully.
- The drafts are accurately read at each set of draft marks including amidships, on both sides of the ship.
- The density of the water in which the vessel is floating is measured at a number of positions

and depths around the ship.

- Weights are arranged on the deck in four groups as indicated on the figure 1.7 and moved in the following sequence:

Weight A to a position in line with weight C
Weight B to a position in line with weight D
Weights A and B returned to their original positions
Weight C to a position in line with weight A
Weight D to a position in line with weight B
Weights C and D returned to their original positions

- The angle of heel is recorded by noting the pendulum positions before the first movement of weights and after each step given above.

1.1.4.4. Analysis of results

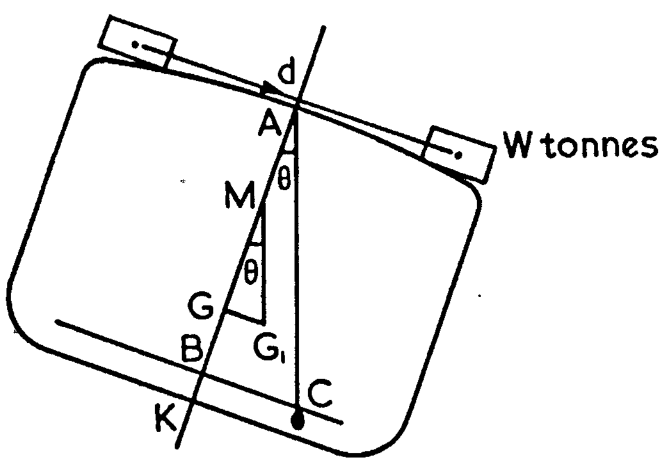


Fig. 1.7b

Due to the shift of a weight w through a distance d, G will move parallel to the movement of G_1 where

$$GG_1 = \frac{w \times d}{\Delta}$$

Since GG_1 is normal to the centerline plane of the ship,

$$GM = \frac{GG_1}{\tan \theta}$$

$$GM = \frac{w \times d}{\Delta \times \tan \theta}$$

$$\tan \theta = \frac{BC}{AB}$$

Then $$GM = \frac{w \times d}{\Delta} \times \frac{AB}{BC}$$

In this formula:

AB is the length of the plumb line
BC the deflection along the batten
w the weight shifted
d the distance through which the weight w is moved
Δ the ship's displacement

The KM for this draft is already calculated by naval architects hence KG is found by using the formula

$$KG = KM - GM$$

The displacement has to be determined from measurements of drafts and water density.

1.2. SHIPBOARD INFORMATION ON STABILITY

1.2.1. Information to be supplied to ships

The assessment of ship stability can be carried out by the Chief Officer in any loading condition. This can be done if the ship is supplied with necessary information about the stability of the ship in accordance to the Regulations. Full details of this information may be found in the Load Lines Rules. Here is a summary of the requirements:

- A plan of the ship to show the capacity and KG of each space; weight and KG of passengers and crew, weight disposition and KG of any anticipated homogeneous cargo.
- The light ship displacement and KG; the weight and KG of any permanent ballast.
- Curves and scales to show displacement, deadweight, KM and TPC, as a function of the draft.
- A statement of the free surface effect in each tank.
- Cross curves stating the assuming KG.
- Statement and diagrams to show displacement, disposition and weights of cargo, drafts, trim

information, KG, KM, GM, free surface, and statical stability when the ship is:

* Light,
* In ballast condition,
* Loaded with homogeneous cargo and
* In service loaded conditions.

- A written instruction concerning any special procedure necessary to maintain adequate stability throughout the voyage.

1.2.2. The stability Information Booklet

There is no statutory requirement as how the stability information booklet is to be set out and this may vary from ship to ship. It would be advantageous to ship's Masters and Officers if a standardized method were used in all ships. The following is a summary of the main contents of the booklet.

a) General particulars of the ship (ship's name, official number, dimensions, tonnage, etc.).
b) Plans of the ship showing cargo, tanks, store spaces, etc
c) Special notes regarding the stability and loading of the ship both in general and as specified to that particular ship.
d) Hydrostatic particulars for the ship in salt water.
e) Capacities and centers of gravity of cargo spaces, storerooms, crew spaces.
f) Capacities, centers of gravity and free surface moments of oil and water tanks.
g) Notes on the use of free surface moments.

h) Special information required if the ship is designed to carry containers: including a container stowage plan and statement indicating the position of the center of gravity of each container.
i) Cross curves of stability (KN curves) and an example of their use.
j) A deadweight scale.
k) Condition sheets, giving a plan and details of weights on board, information on stability on departure and/or arrival, and a curve of statical stability; all for at least each of the following conditions:

- The light ship
- Ballast conditions on departure or arrival
- The ship loaded to the Summer load line with homogeneous cargo on arrival and departure.
- The ship loaded to the Summer loaded line in at least one service loaded conditions on departure and arrival.

For each " Arrival Condition", all fuel, fresh water and consumable stores have been reduced to 10 % of their original amounts. In the "Departure Condition", fuel tanks which are full of oil are taken as 98 % full.

1.3. LOADING CONDITIONS

Stability can be assessed in any particular condition when light ship conditions are known already. As said before information on the light ship conditions is given in the Stability Information Booklet. This means that light displacement, draft, center of gravity, center of buoyancy and the metacenter come with the ship. The problem in calculating the present conditions are sustained on the assumption that the volume and center of gravity of various weight are known. Finding the loaded stability conditions is determination of:

- The deadweight
- The displacement
- The draft
- The trim
- The KG
- The initial stability
- The righting arm curve

1.3.1. Deadweight and displacement

The deadweight is obtained by adding the weights of all items loaded on board including cargo, bunker, stores, crew, passengers, etc. Deadweight together with the light ship displacement give the actual loading displacement. In other words the deadweight is the difference between the displacement at any particular draft and the light displacement. The latter can be calculated knowing the mean draft or the draft at the center of flotation and the trim. Inside the Stability Information Booklet there is a table and/or graph giving the relation between the draft and the displacement. The loaded displacement is that of a ship when she is floating at her summer draft. This displacement is known as the maximum displacement permitted in summer.

1.3.2. Draft, Trim and Center of flotation

The draft, trim and center of flotation are three concepts very important in stability calculations. Trim defines the longitudinal inclination of the ship. It may be expressed as the angle between the baseline of the ship and the waterplane, but it is usually presented as the difference in drafts at the bow and at the stern. The center of flotation is the point in the ship's waterplane through which the axis of rotation passes when she is inclined. The center of flotation is helpful in the computation of drafts and displacement. When a weight is moved forward or aftward there is no change in draft at the center of flotation if the change in trim is moderate. Furthermore, if a small weight is added or removed at the center of flotation there is no change in trim because the increase of weight is added at the same distance from the initial position of the centers of gravity and buoyancy. On the other hand the displacement and the longitudinal location of the ship's center of gravity can be determined if the drafts are known.

1.3.3. Initial Stability

1.3.3.1. Principle

Stability is the tendency of a ship to return to an upright position when inclined from the vertical by an outside force. For a study of initial stability we constantly refer to a diagram of ship's midships section and the relationship between three points on it. These points are known as the center of gravity G, center of buoyancy B, and the metacenter M.

On a ship, the total of the upward forces of buoyancy is considered to be concentrated at point B. When a body is floating, the forces acting through B and G are opposed and equal in magnitude. They are acting along the same vertical line. The forces acting through G is the sum of weights of all elements making up the ship's structure. For convenience, they are considered as acting through this point G.

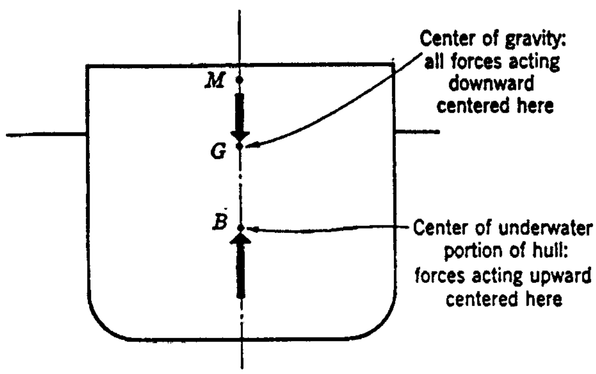


fig. 1.8

1.3.3.2. Curve of statical Stability

For practical applications, it is necessary to present Stability in the form of righting moments or levers about the center of gravity as the ship is heeled at constant displacement. Such a plot is known as statical curve of righting levers.

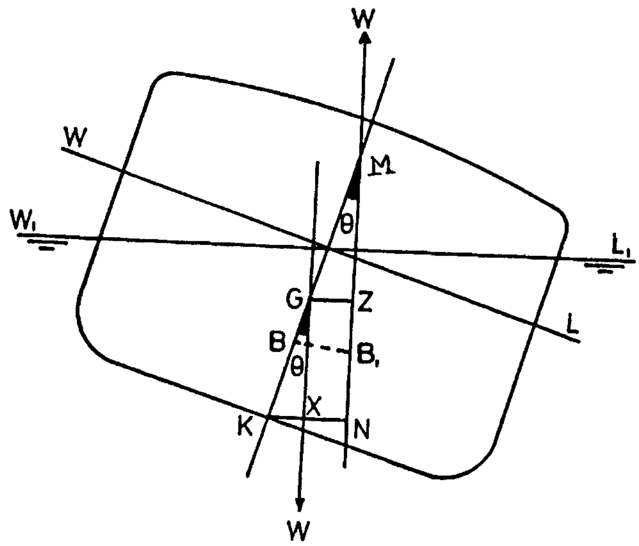


fig. 1.9 Heeled ship

Consider a ship floating freely in still water and slightly inclined by some external force from the upright. Due to the change in shape of the underwater body, the center of buoyancy B will move outward from the centerline to a new position B1. The position of the center of gravity will change from its centerline position. The two equal forces of weight and buoyancy, acting vertically and in opposite directions will now be displaced horizontally by a distance GZ. A couple Δ x GZ is thus formed which tends to rotate the vessel back to her original position.

Now $GZ = XN$

$GZ = KN - KX$

$GZ = KN - KG \times \sin \theta$

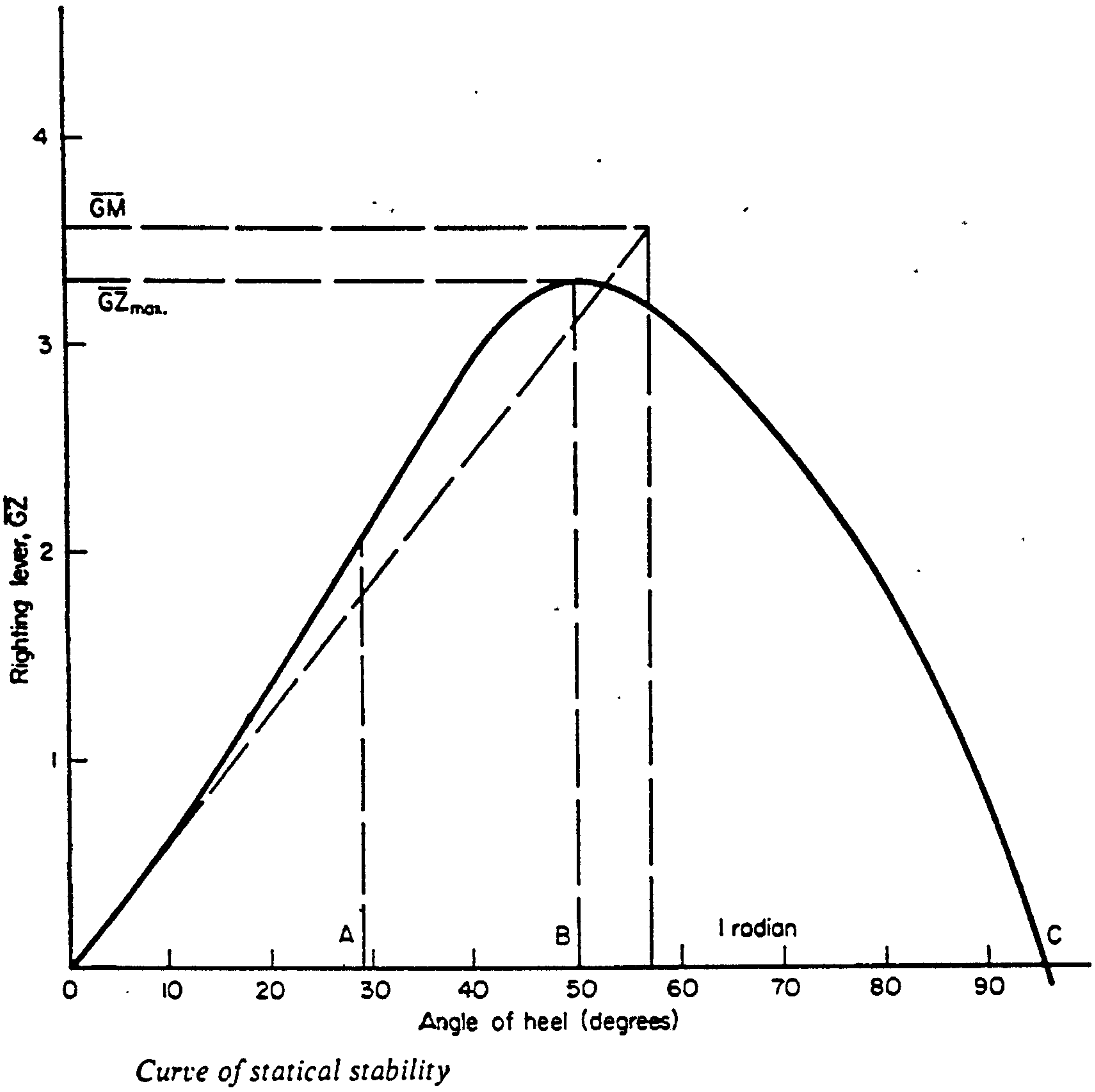


fig. 1.10 Curve of statical stability

1.3.3.3. The main features of the GZ curve

Certain features of the GZ curve are of particular importance and are useful parameters with which to define the stability possessed by a given ship.

- Slope at the origin:

For small angles of heel, the righting lever is proportional to the angle of inclination, the metacenter being effectively a fixed point. It follows, that the tangent to the GZ curve at the origin represents the metacenter height

- Maximum GZ:

this is proportional to the largest steady heeling moment that the ship can sustain without capsizing. Its value and the angle at which it occur are both important.

- Range of stability:

the range over which the ship has positive righting levers. For angles less than this, the ship will return to the upright state when the heeling moment is removed.

- Angle of deck edge immersion:

For most ship forms, there is a point of inflexion in the curve corresponding roughly to the angle at which the deck edge becomes immersed.

- Area under the curve:

The area under the curve represents the capability of the ship to absorb energy communicated to it by any external forces (wind, waves, etc.).

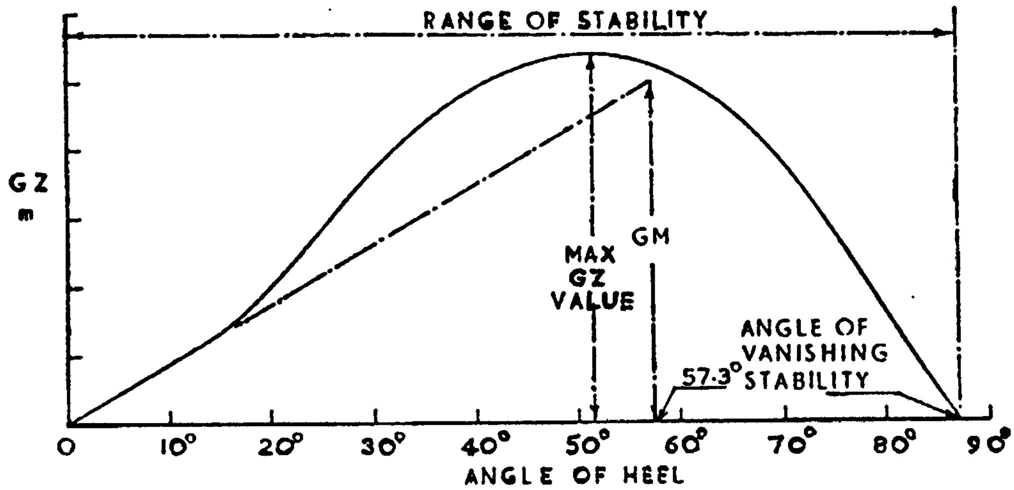


Fig. 1.11 Main features of statical stability

1.3.3.4. Dynamical Stability

The dynamical stability of a ship at a given heel of angle is the work done in heeling the ship very slowly to that angle and at constant displacement.
Considering a ship with a righting moment curve, let the righting moment at an angle of heel θ be M . Then the work done in heeling the ship through an additional small angle $d\theta$ is given approximately by $M_\theta * d\theta$.
The total work done in heeling to angle θ is:

$$\text{Work done} = \int_0^\theta M_\theta * d\theta$$

$$\text{Work done} = \int_0^\theta \Delta * GZ_\theta * d\theta$$

The dynamical stability at any angle therefore is proportional to the area under the statical curve up to that angle.

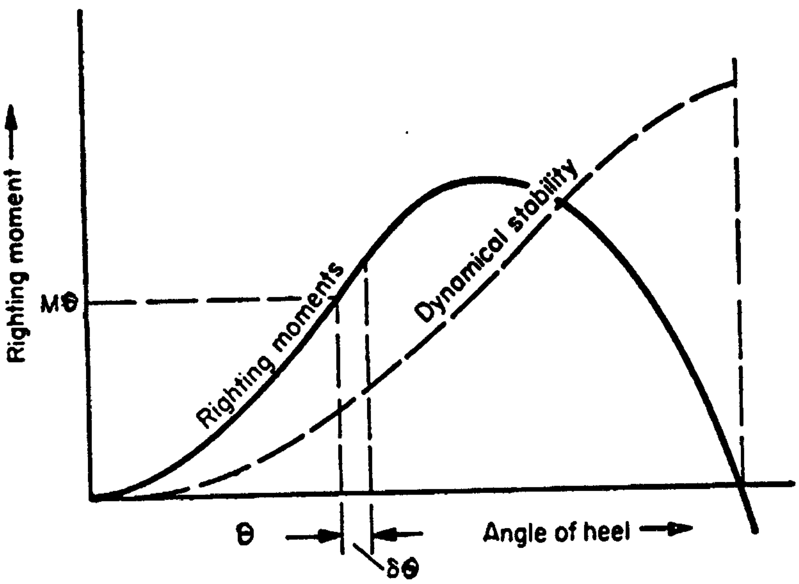


fig. 1.12 Curve of dynamical stability

The measure of dynamical stability may also be found by using the MOSELY's Formula. Consider a ship shown in fig.1.9. When the ship is upright the weight and the buoyancy forces are in the same vertical as B and G. When the ship is inclined, the centers of gravity and buoyancy separate vertically. G moves slightly upwards with the ship, whilst B moves outward and downward, because its shift is parallel to the shift of the centers of gravity of the immersed and emerged wedges. The weight of the ship has therefore been moved upwards by the distance the center of gravity has been raised and downward by the distance the center of buoyancy has been lowered. The work done or dynamical stability is thus equal to the displacement, multiplied by the vertical separation of the centers of gravity and buoyancy.

$$\text{Work done} = \Delta \times (BZ - BG)$$

$$= \Delta \times (BR + RZ - BG)$$

$$= \Delta \times \left(\frac{v(gh + g_1h_1)}{V} + PG - BG \right)$$

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

$$\text{Dynamical Stability} = \Delta \times \left(\frac{v(gh + g_1h_1)}{V} - BG(1 - \cos\theta) \right)$$

In practical stability an officer is more concerned with the power of his vessel to return to a condition of rest than with the forces which incline it. He will probably have noted on occasion that his vessel tends to stay for a moment or two at the extremity of a roll and then, with a rapid or slow movement according to ship's stiff or tender qualities, commences to return to the upright position. This is an illustration of the Statical Forces overcoming the Dynamical forces, thereby enabling the ship to return.

CHAPTER II

FACTORS AFFECTING THE STABILITY OF A SHIP

2.1. STATICAL EFFECT TO THE STABILITY

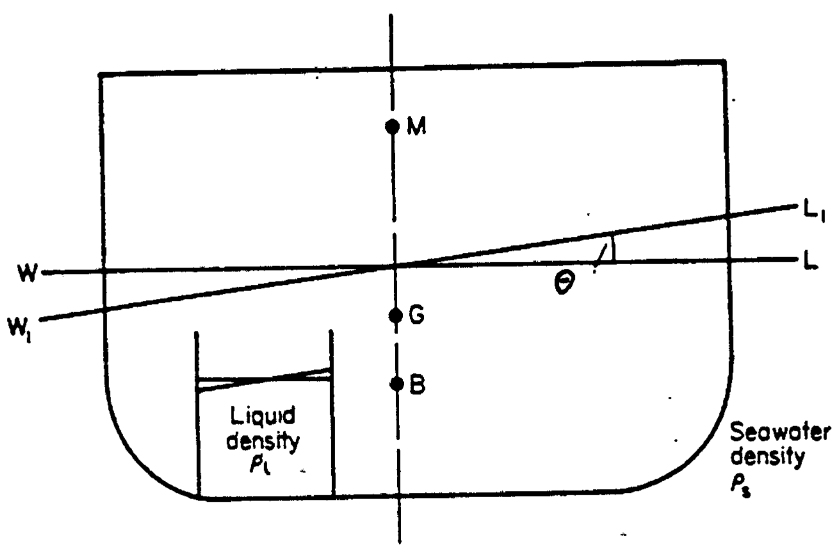
2.1.1. Free Surface Effect

If a tank is full of water or liquid, the effect upon the stability of a ship is the same as that of a solid. Its influence on the center of gravity of the ship depends on its position relative to that point. That is, its weight can be regarded as being concentrated at its actual center of gravity.

In a compartment which is only partly filled, the surface of the liquid is free to move. It has entirely different effects when the ship is inclined from the upright. The moment of inertia of this free surface about its own center line causes a virtual center of gravity to appear at some height above it.

In practice, a ship has tanks with several different liquids: fresh water for drinking or for boilers, salt water for ballast, fuels of various types and lubricating oils. So the problem must be examined in the assumption of the fact that the density of liquid may not be the same in which the ship is floating.

Let the ship floating initially at a waterline WL and let it be heeled through a small angle θ to a new waterline W_1L_1. Since the surface of the liquid in the tank is free, it will also change its surface inclination relative to the tank by the same angle θ (See fig. 2.1). For a ship when I is the moment of inertia of the waterplane and V the volume of displacement:



Liquid free surface

Fig. 2.1

$$BM = \frac{I}{V}$$

If we consider Fig. 2.2 it is apparent that WOL and W_1OL_1 are equivalent to the immersed and the emerged wedges respectively of a ship: that the shift of g, out to g_1, is parallel to the shift of the center of gravity of these wedges. If i is the moment of inertia of the free surface and v the volume of water in the tank:

$$GG_1 = \frac{i}{v} \qquad (1)$$

The effect of the virtual center of gravity is the same as would be that of a solid weight placed at g_1; that is, if the weight of the water in tank were shifted from g to g_1. So if Δ is the displacement of the ship and w the weight of the water in the tank,

$$GG_1 = \frac{w \times gg_1}{\Delta} \qquad (2)$$

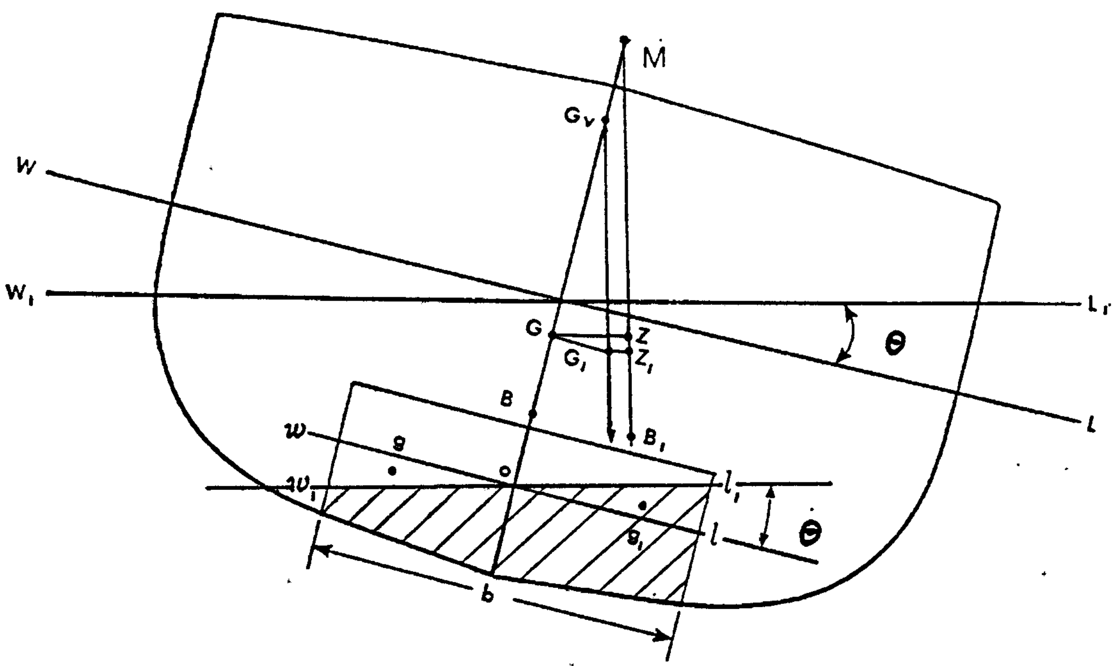


Fig. 2.2 Free surface effect

If d_1 is the density of the liquid in the tank and d the density of the water in which the ship is floating, then

$$w = v \times d_1 \qquad (3)$$

$$\Delta = V \times d$$

$$GG_1 = \frac{v \times d_1 \times gg_1}{V \times d} \qquad (4)$$

Substituting for gm from formula (1)

$$GG_1 = \frac{v \times d_1 \times i}{\Delta \times d \times v} \qquad (5)$$

$$GG_1 = \frac{i}{V} \times \frac{d_1}{d} \qquad (6)$$

It should be noted that the effect of the free surface is independent of the position of the tank in the ship; the tank can be at any height in the ship and at any position along its length. The effect is also independent of the amount of liquid provided that the second moment of area of the free surface is substantially unchanged when inclined.

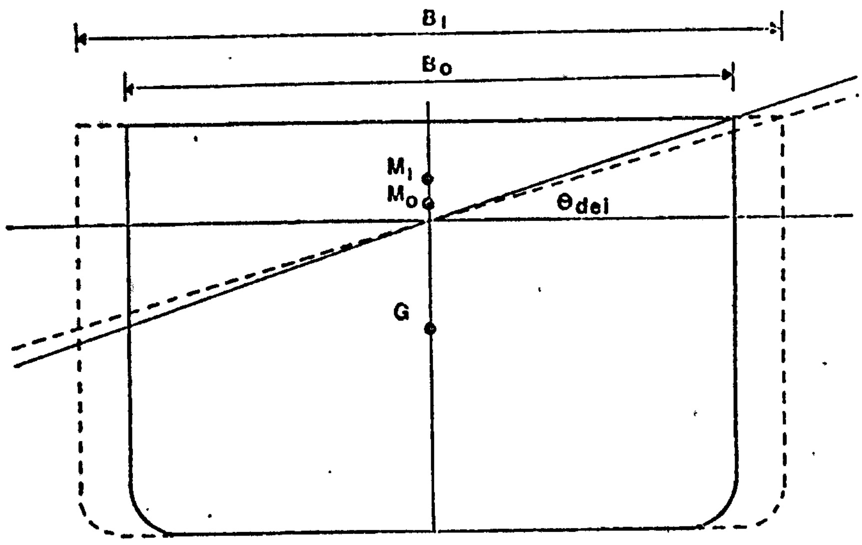
2.1.2. Ship Form Effect on Statical Stability

2.1.2.1. The effect of beam

To investigate the effect of beam on stability, it will be necessary to assume the stability of two vessels, each floating at the same draft but one has a larger beam than the other. B is in the same position, relative to the keel, for both vessels but when they are inclined through a small angle it is to note how the position of M differs. The distance B moves when a vessel is inclined is given by the formula:

$$\frac{BB_1}{GG_1} = \frac{\text{Volume of wedge}}{\text{Displacement}}$$

i.e. the ratio of the movement of B to the distance between the center of gravity of the wedges is equal to the ratio of the volume of the one wedge to the displacement of the vessel.



Effect on stability of increasing beam

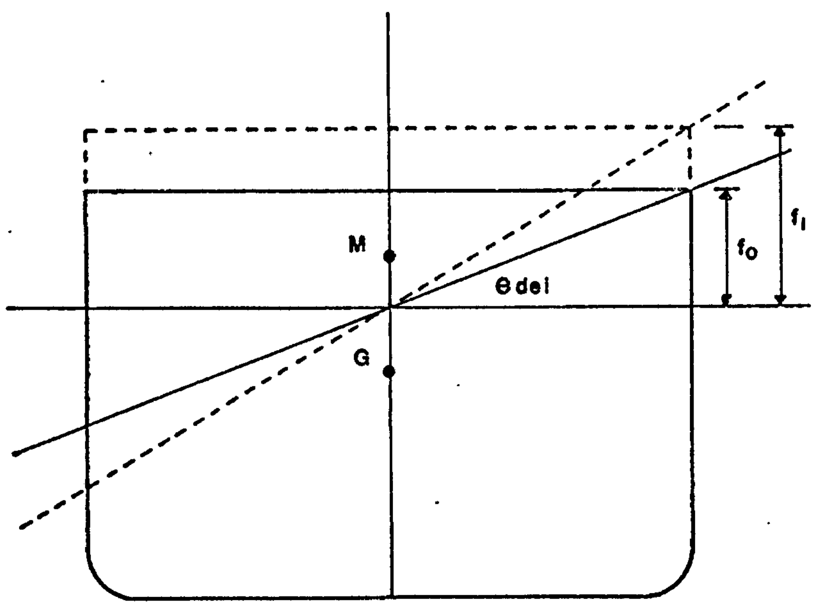
For the two vessels the ratio of the volume of wedge to the volume of displacement is similar but the distance between the centers of gravity of the wedges is greater in the vessel with the larger beam. Consequently, in that vessel, B will move to a greater distance than in the vessel of smaller beam.

The vertical line through the new position of the center of buoyancy will intersect the original vertical line at a much higher position in the vessel of larger beam than in the vessel of smaller beam. As a result, a greater range of movement of G is permissible for the former vessel. The higher position of M is due entirely to the increased beam and it must follow that a vessel so designed is less likely to become unstable than a narrow ship.It is reasonable to suggest that an officer would have less worry loading a vessel of large beam than one of small beam, knowing that M is reasonably high and that the vertical distribution will not result in an unstable condition.

2.1.2.2. The effect of freeboard

It would, of course, be a little value to the seaworthy condition of a vessel to concentrate upon beam in the design and neglect other features which also influence the stability of a vessel. Of these, freeboard plays a big part, particulary in its influence upon the range of stability available. In designing a ship, a judicious combination of beam and freeboard generally results in an ideal ship. When a vessel with a small freeboard is inclined to a larger angle, the deck line becomes immersed. This destroys, to a certain extent the effectiveness of the wedge of immersion and its center, in consequence, moves in towards the midpoint. As B moves in proportion to the distance between the center of the wedges, it follows that its movement to take up the new position of the new center of the underwater form, will be restricted.

From the above it can be said that an increase in freeboard has no effect on the stability of the vessel up to an angle of heel at which the deck edge became immersed. But beyond this angle of heel, all of the righting levers will be increased in length. The maximum GZ and the angle at which it occurs as well as the range of stability.



Effect of stability of increasing freeboard

Fig 2.4

2.1.3. The effects of weight and center of gravity

The center of gravity is dependent upon the weight of material in the body and its distribution. When there is change in the distribution of the weights, the center of gravity changes. The initial stability is governed by the position of the center of gravity in relation to the metacenter height and the displacement. It leads that any change in the vertical distribution of the loading will affect the initial stability.

Practical stability is more associated with the performance of the vessel under different conditions of weight distribution. In this respect it is most necessary that the ship's officer should know the initial position of the point over which his action will have considerable influence namely the center of gravity. It is clear that perfect stability may be conceived, all will be of no benefit if the vessel is loaded without giving due consideration to the position of the Center of Gravity.

2.2. THE SEAWAY

2.2.1. The Sea surface

The sea presents an ever changing face to the observer. In long term, the sea surface may be in any condition from a flat to extreme roughness. Any observer is aware that a stream of air passing over a water surface causes ripples or waves to form but the precise mechanism by which the transfer of energy takes place is not known. The surface is disturbed by the wind and the extent of the disturbance depends upon the strength of the wind, the time for which it acts and the length of the water surface. The disturbance also depends on tide, depth of water and local land contours.

Once a wave has been generated it will move away from the position at which it was generated until all its energy is spent. The sea surface presents a very confused picture which is difficult to assess with mathematical models. Attempted theories are to consider irregular wave systems as a compound of a number of regular systems of various periods. Before proceeding to consider the irregular wave patterns, it is first of all necessary to discuss a regular wave system as this is the basic building brick from which the picture of any irregular system is built up. Considering irregular wave systems, two cases are of particular significance. They are the trochoidal wave and the sinusoidal wave.

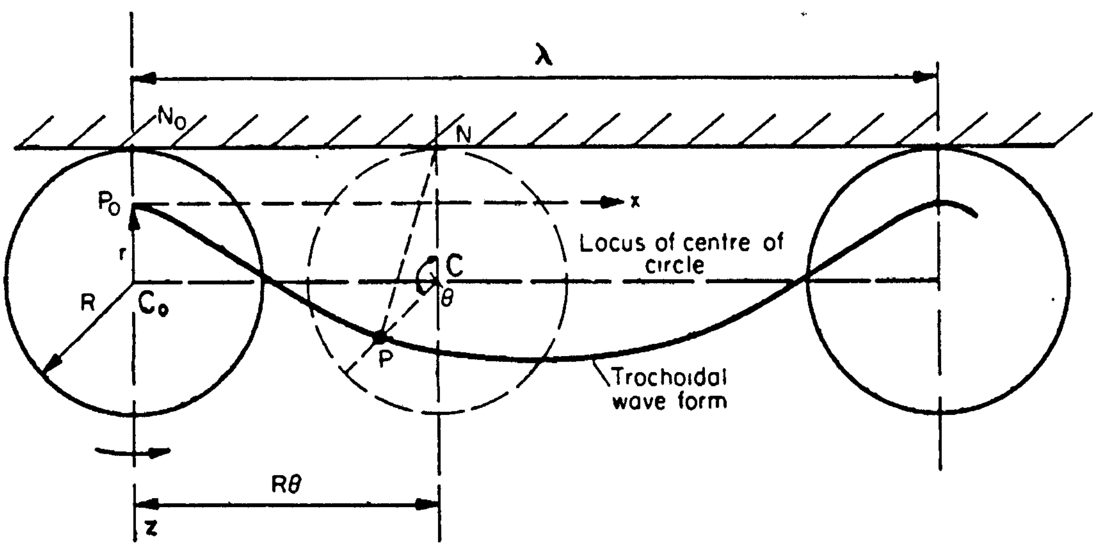
2.2.2. Trochoidal waves.

The surface of the trochoidal wave surface is defined mathematically as the path traced by a point fixed within a circle when that circle is rolled along and below a straight line. The principle is based on the following assumptions:

- In deep water all particles within trochoidal waves follow circular orbits about fixed centers at a constant angular velocity.
- In any horizontal line of orbit centers, the radii are equal but the phase of adjacent particles varies successively.
- In any vertical line, all the particles have the

same phase but the radii of their orbits decrease exponentially as the depth increases.

To draw a trochoidal wave surface, the selected length is divided by a convenient number of equal spaced points, and, with each as a center, a circle of diameter equal to the selected wave height is described. In these circles, radii at successive angles which increase by the same fraction of 360 degrees as the spacing of the circles in relation to wave length are drawn. The curve connecting the ends of these radii is the desired trochoid (see fig.2.5). Properties of the trochoidal wave have been used as wave pressure correction in the longitudinal strength calculations.

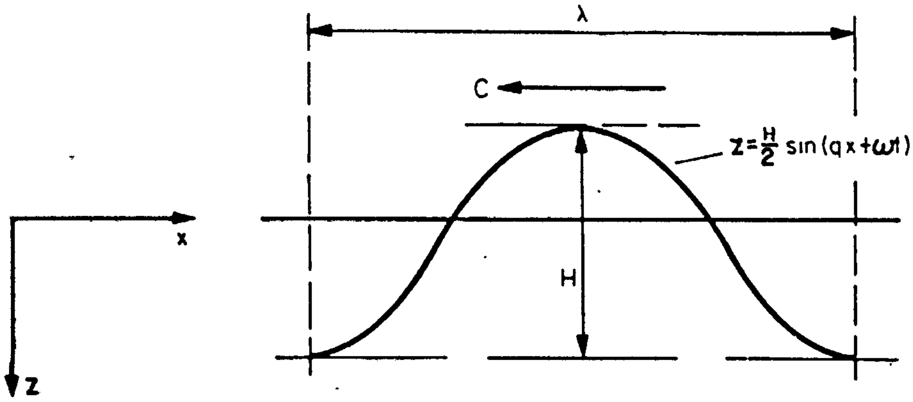


Generation of trochoidal wave form

fig. 2.5

2.2.3. Sinusoidal Waves

When waves at sea arrive at a beach, we notice the up and down motion of water that did not come from the sea along with the wave, that is, the wave particles were there before the waves arrived. Therefore the wave is not the water itself; it is the disturbance of the sea surface that travels. The process is known as wave propagation. A water wave is a disturbance, since the motion of particles is apparently in one direction. The disturbance of propagation of the disturbance is at a right angle to the direction of motion.



Profile of sinusoidal wave

fig. 2.6

A sinusoidal is an idealized water wave, that is, either a sine curve or a cosine curve, that travels outward. The wave crest is defined as the point at which the surface has the highest elevation. The vertical distance between the maximum disturbance and the undisturbance levels is known as the amplitude. Such an elevation can be defined as simple harmonic motion and described analytically as:

$$z = \frac{H}{2} \sin(qx + wt)$$

In this expression, $q = 2\pi/Lw$ is known as the wave number and $w = 2\pi/Tw$ the wave frequency. The wave velocity C is given by:

$$C = \frac{Lw}{Tw} = \frac{w}{q}$$

Other significant features of the wave are:

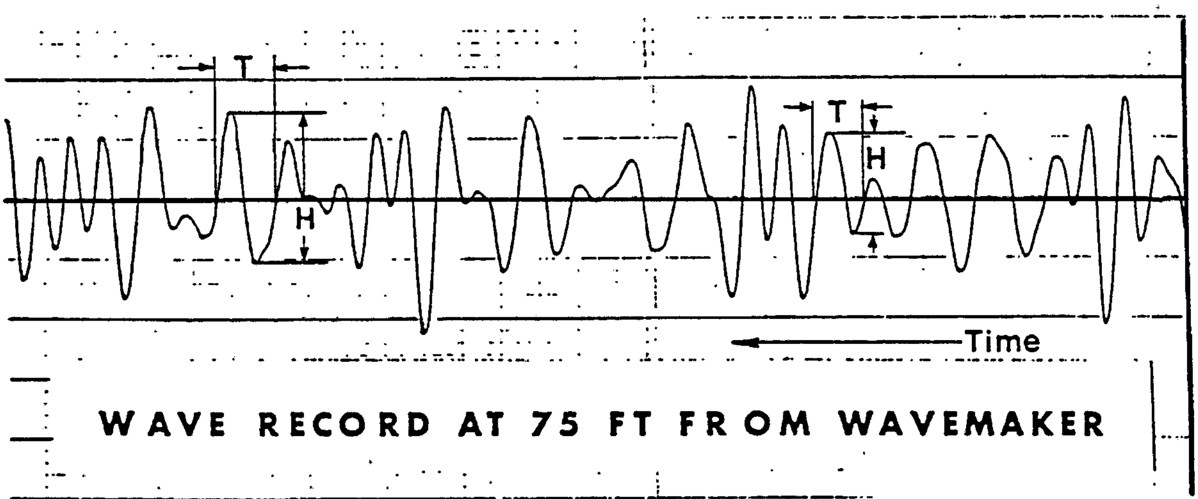
$$Tw^2 = \frac{2\pi Lw}{g}$$

$$w^2 = \frac{2\pi g}{L}$$

$$C^2 = \frac{gL}{2\pi}$$

2.2.4. Irregular sea wave patterns

Behind the apparent confused state of the sea, there is a statical order and the sea surface can be regarded as the result of the superposition of a great number of sinusoidal waves of different height and various lengths. If all these wave components travel in the direction, the irregular pattern will show a series of straight crests extending to infinity in a direction normal to the direction of wave travel. In the more general case, the individual wave components travel in different directions and the resultant wave pattern does not show long crests but a series of bulges and cavities.



Typical record of irregular sea and definitions of apparent wave heights and periods

fig. 2.7

It is possible to measure the time interval between successive crests passing a fixed point and the heights between successive troughs and crests. These vary continuously and can be misleading in representing a particular sea. For instance, a part of the system in which many component waves cancelled each other out because of their particular phase relationships would appear to be less severe than was in fact the case.

Provided the record of surface elevation against time is plotted carefully, it can yield some very useful information. If Lw is the average distance between crests and T the average time interval in seconds, it can be shown that, approximately

$$Lw = \frac{2gT^2}{3 * 2\pi} = 3.41T^2, \text{ ft}$$

$$= 1.04T^2, \text{ m}$$

A complete record would be too difficult to analyze and a sample length is usually taken from time to time, the duration of each being such as to ensure reasonable statistical representation of the sea surface. The values of wave height in a sample can be arranged in descending order of magnitude and the mean height of the first third of the values obtained. This mean highest one-third of the waves is called the significant wave height. If a large number of wave records is so analyzed for a given ocean area, it is possible to plot the probability of exceeding a given significant wave height. Results for the North Atlantic, Northern North Atlantic and world wide is presented in fig. 2.8. It can be noted that the Northern North Atlantic is the most severe area as would be expected from general experience.

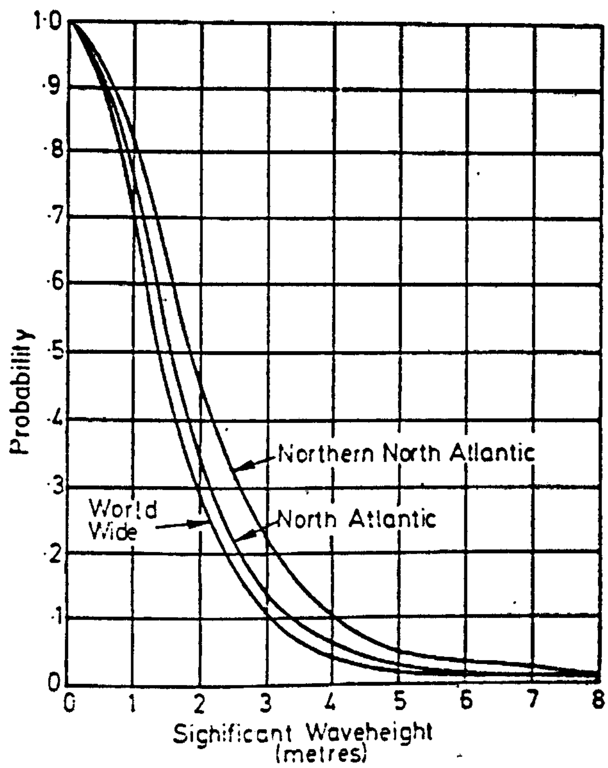


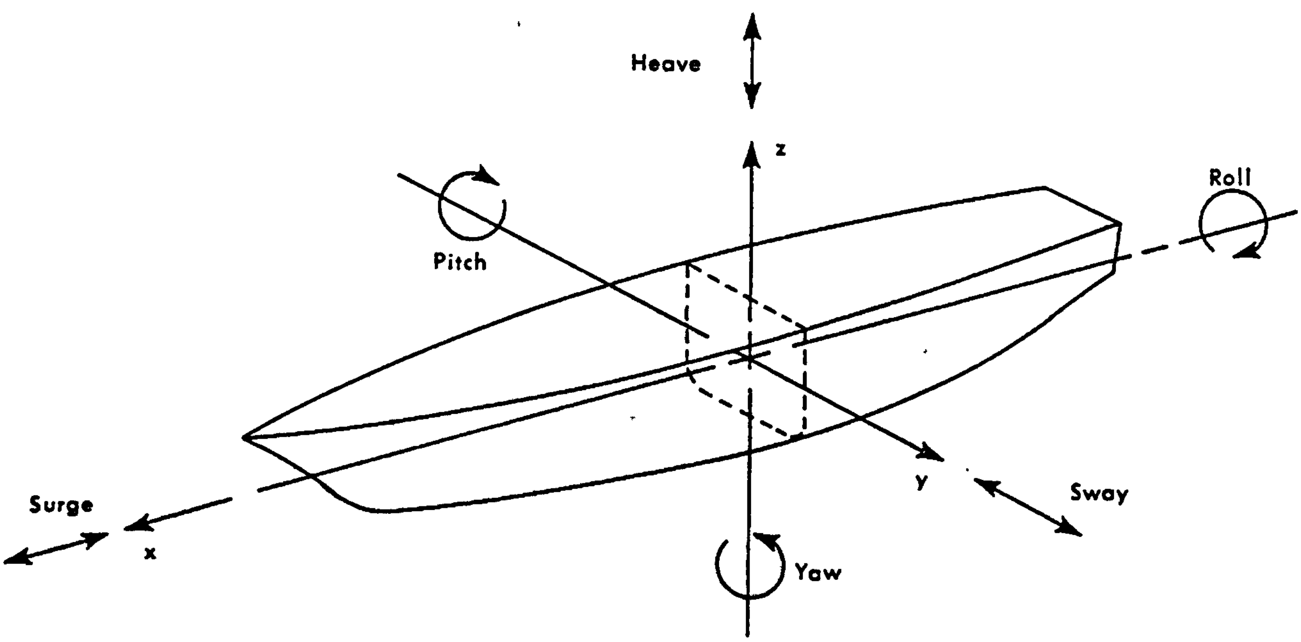
Figure 2.8

2.3 SHIP MOTIONS IN A SEAWAY

2.3.1 Ship Responses to wave fields

Normally ship do not experience regular waves at sea. So the study of ship motions in regular waves appears not to have practical significance. However, it is an essential first step in the calculation of ship motions in a realistic irregular seaway. Moreover the appreciation of regular wave motions can give a valuable understanding of the general nature of the motion of ship in rough a weather.

The motion of ship can be represented by a combination of three linear displacements and three angular or rotational displacements. These motions are known as the six degrees of freedom. It follows that, at any instant, the position of the ship's center of gravity G relative to the moving origin G_o is defined by these six displacements:



Ship motions

fig. 2.9

- **Linear displacements along three axis:**

SURGE: X along x axis positive forward

SWAY: Y along y axis positive to starboard

HEAVE: Z along z axis positive down

- **Angular rotations about three axis:**

ROLL: Θ about xb3 positive to starboard down

PITCH: Φ about yb2 positive to bow up

YAW: Ψ about zb1 positive bow to port

All or any of these motions may coexist in a given short time period resulting in a complex motion that is difficult to describe. The equations of the ship motion result from a summation of all forces and moments acting on the ship body. These movements lead to six basic equations of motions:

$$A_1\ddot{X} + B_1\dot{X} + C_1X + (\text{Coupling Moment}) = D_1$$

$$A_2\ddot{Y} + B_2\dot{Y} + C_2Y + (\text{Coupling Moment}) = D_2$$

$$A_3\ddot{Z} + B_3\dot{Z} + C_3Z + (\text{Coupling Moment}) = D_3$$

$$A_4\ddot{\Theta} + B_4\dot{\Theta} + C_4\Theta + (\text{Coupling Moment}) = D_4$$

$$A_5\ddot{\Phi} + B_5\dot{\Phi} + C_5\Phi + (\text{Coupling Moment}) = D_5$$

$$A_6\ddot{\Psi} + B_6\dot{\Psi} + C_6\Psi + (\text{Coupling Moment}) = D_6$$

It is possible to solve these six second order differential equations but it is not the purpose of this work. These are given only to show the complexity of the ship motion in a seaway which is the combination of the six movements. In practice a ship will never perform one only movement, at the time she is constrained to perform one of these motions by some external means, forces are immediately brought into play which induce the vessel to respond with the other five motions.

2.3.2 The wave and ship's natural periods

When talking about waves, there are basic Parameters to describe regular waves which are:

Wave height	:	Hw
Wave length	:	Lw
Wave period	:	Tw
Circular wave frequency	:	ω
Wave velocity	:	C

Rolling about a longitudinal axis is usually considered to be the most important periodic motion of a ship at sea. It is related to the stability of the ship and therefore her safety at sea. Resistance to rolling and the vessel's rolling period are aspects of primary importance. A ship does not behave like a pendulum with its point of suspension, she has no fixed axis of oscillation but what is called the instantaneous axis is located some where near the CG. Certainly, the CG itself describes a path in space as the vessel rolls even though it remains fixed relative to the ship. A complete period of roll is the time taken to roll from port to port or starboard to starboard. For unresisted rolling in still water, this is called the ship's natural period of roll. The formula for this is:

$$T_o = 2\pi \frac{f}{\sqrt{g \times GM}}$$

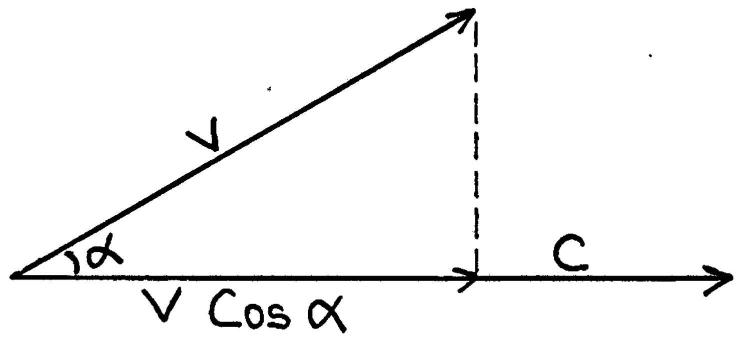
where T_o is the natural period in seconds; g the acceleration due to gravity. The parameter f is called the transverse radius of gyration, which depends on the distribution of all weight in the ship. From the inspection of the formula it will be seen that the bigger the GM the shorter will be the rolling period. The shorter the period the more tendency to roll and the quicker it will be and the greater the discomfort. Because the period is inversely proportional to the square root of the metacenter height.

Although a ship's still water natural period of roll is no practical utility in itself, it is of great importance in predicting the probable behaviour of the vessel at sea. An another important factor is the wave period.

The wave period is the time interval between successive crests passing a fixed point. The apparent period will depend on the ship's speed through the water and her course relative to the direction of the waves.

2.3.3 Encounter Period

The motion excitation of a ship from waves is governed by the wave encounter period which is the time elapsing from crest to the next wave crest passing the ship. From the following diagram, the encounter period can be derived by a simple transformation.



where

C wave celerity (velocity of wave crest)

V ship speed

α Heading of the ship relative to the wave

Vrel is the speed of the vessel relative to the wave, we can easily derive T_E the encounter period

$$T_E = \frac{Lw}{Vrel} = \frac{Lw}{C - V \cos \alpha} \qquad (1)$$

$$C = \frac{Lw}{Tw} \qquad (2)$$

From the basic formula (seen before)

$$C = \frac{g}{2\pi} Tw = \frac{Lw}{Tw} \qquad (3)$$

From (2) and (3),

$$Lw = \frac{g}{2\pi} Tw^2 \qquad (4)$$

With (3) and (4) put into (1), we calculate T as function of Tw , V and α :

$$T_E = \frac{Tw^2}{Tw - 2\pi/g * V \cos \alpha}$$

$$\text{Or} \quad C = gLw / 2w$$

$$\text{then} \quad T_E = \frac{Lw}{g/2\pi * Lw - V \cos \alpha}$$

2.3.4 Roll Resonance

It has been shown that the ship's encounter period depends on the wave length and therefore the wave period. Ocean waves cause a ship to roll and if these waves are regular they will impose their own periodicity on the ship instead of the ship's own natural period. This is called forced rolling. If the wave period is not constant, the rolling period will not be constant as the ship is always tending to revert to its own natural period.

There are problems when the natural rolling period of the ship Tw equals to the wave period. The passage of each wave adds to the inclination of the ship which builds up in magnitude until, in theory the ship capsizes. This is known as synchronism and it occurs whenever in beam sea the ratio of wave period to the ship's natural period equals or is close to one. The effect is bad enough when the synchronism occurs at interval in passing of a series of waves, but when it happens at every oscillation the effect is more pronounced. The ship's motion becomes rapid and discontinuous and dangerous results may occur.

Tw = To condition for resonance in beam sea

Resonance from time variations of hydromechanic properties of a ship in a seaway is called MATHIEU resonance. It appears mainly for roll motions in following and quartering seas from variations of the uprighting moment and from nonlinear coupling with heave and pitch motions. It occurs when the wave period of encounter T_E is either

- half to the natural roll period To (or close to it)
- equal to the hatural roll period To (or close to it)

Therefore to avoid roll resonance, the value of encounter period in following and aft quartering sea must not be equal or half the natural frequency.

2.4 SHIP HANDLING IN ROUGH SEA

2.4.1 Rolling

Rolling is one of the most important displacements of the vessel. The ship will always roll in any particular sea. But the problem arises when she is helped by external forces such as waves. Several similar consecutive waves must pass the ship before she rolls in the encounter period (T_E) with the waves; and such uniform waves are extremely rare at sea. The ship usually completes a roll in a time not very different from her own resisted period T_E. The amplitude of roll will be large if T_E approaches T_R , and to reduce the possibility of the vessel in meeting weather conditions which might produce synchronism between T_E and T_R , it is advisable to make her natural roll period as long as possible.

The heaviest rolling takes place when the waves meet the ship between angles approximately 15° each side of the broadside on. Increase in the wave length tends to shift the critical direction of the weather towards the ship's bow and increase in ship's natural roll period will shift it to aft. In this situation, change in ship direction is more effective in reducing the roll than any change in speed.

2.4.2 Pitching

A ship's natural pitching period T_P is usually less than her natural rolling period. Synchronism between her natural pitching period and her period of encounter with the waves cannot be avoided by any practicable increase in TE. Fortunately the water damping to pitching is much greater than to rolling, and prevents abnormally large angles of pitch developing in synchronous period conditions. The natural pitching period is reduced if the hull and the cargo weights are concentrated towards amidships. This suggests that the heaviest cargo weights should always be carried in the amidships holds.

2.4.3 Heaving

The heave amplitude of a vessel depends upon the volume of the change in static buoyancy with each passing wave. The change in static buoyancy depends upon the area of load water plane which is settled by capacity and stability considerations. And vessels which have little area forward and a large amount of area aft, will experience large differences in static buoyancy for small changes in wave lengths at certain ratio of Lw/L, and a small alteration in course can then produce a large change in the heaving motion.

2.4.4 Other Operational factors

The problem when ship is in rough sea is not only that the ship will roll, pitch or heave. There are numerous danger in which she may be engaged in. The different effects to the ship behaviour and the master needed to be overcome by the master are:

- Variation GZ in longitudinal waves
- High motions acceleration acting on the cargo

a) - GZ variation in Longitudinal Waves.

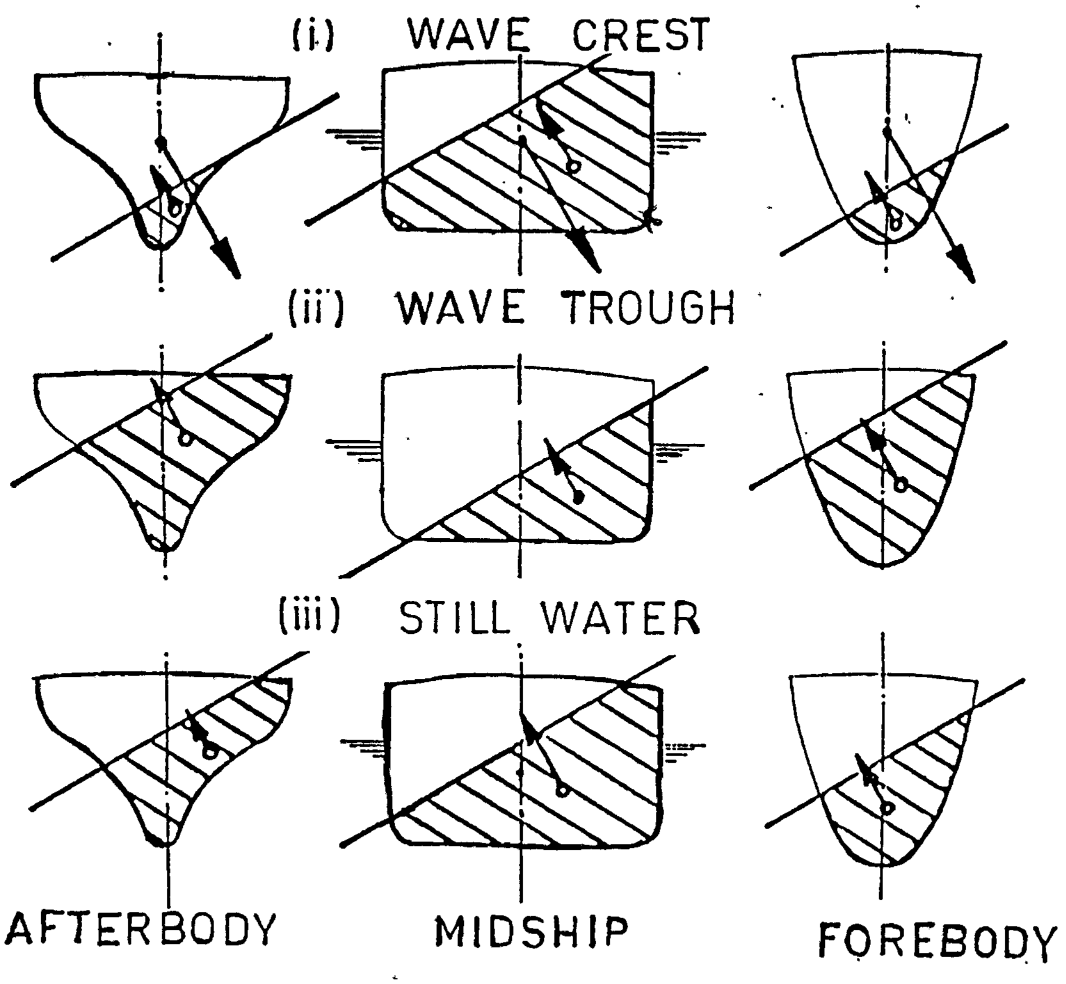


Figure 2.10

Fig. 2.10 shows the variation pattern of GZ in wave crest and wave trough position of the ship compared with still water condition. The change of GZ results only from the change in the location of the center of buoyancy of the heeled ship hull. Extremely steep waves in following seas at small ship stability may capsize a ship by reducing stability in a wave crest. Although this might be a very rare situation, a vessel seems to have no motion at all while staying in the upright position in the following sea.

In the wave crest, the freeboard amidships is considerably reduced and even becomes negative. Due to the lack of buoyancy above the deck side at large heel in the wave crest, Bo (center of buoyancy in heeled condition) will shift towards the gravity center G, thus reducing the righting lever GZ considerably.

On the contrary, when the wave trough is amidships, it will result in an increase of the righting arm curve GZ. In general, the increase is smaller than the reduction. It follows that the mean of GZ at crest and trough is below the still water GZ-curve.

b) - High acceleration acting on the cargo

At sea there are a lot of forces acting on the cargo mainly on the deck cargoes because she never will be at rest. Forces acting on the cargo can be summarized in three groups:

- Static forces;
- Wind forces and
- Dynamic forces.

The static forces include the gravity force acting always vertically, thus producing a compressive force plus components parallel to the deck when the ship is rolling and /or pitching.

The wind forces affect only deck cargoes or deck containers and are acting on the side perpendicular to it. This force increases the transversal tracking of the container.

Dynamic forces are a result of the ship motions mainly rolling, pitching and heaving produced by the action of the waves. As synchronism on rolling, pitching and heaving may lead to larger and larger accelerations these will affect seriously the forces acting on the cargo. In practice it is used to take into account in the wave loads in the lashing process the least severe weather that the ship may meet at sea. Anyway there are limits on the forces that the lashing can withstand. Accelerations produced by rolling, pitching or heaving in synchronism condition can generate transverse and longitudinal forces capable of breaking the lashings and bringing about the lost of some deck cargo. That is why it is necessary to avoid these situations whenever it is possible.

2.4.5 Wind effects on the ship operation

Wind is one of the main factors responsible for the development of waves at sea. The wind exercises also a force in her direction of motion. Its impact on the speed depends on the surface of the ship above the water line. A head wind having a velocity in the range of one or two times the ship's speed will result in wind resistance of about 10 to 20 percent of the ship's water resistance. If the wind strikes at an angle requiring a permanent rudder angle to maintain the ship on the desired course, it may cause a further increase in resistance. If the wind is on the beam, the pressure on the superstructure of a ship and particulary a passenger ship may cause transverse inclination. The action of the wind causes a force which makes the ship to move sideways through the water until resistance is created equal to the wind force.

Because of the difficulties of direct measurement of wind resistance on ship structures at sea during storms, model experiments have been used to secure such data. The result of a most complete set of wind resistance experiments on ship models have been given by D. G. Hughes.

2.4.6 Loss of Speed in Rough Seas

At sea a vessel will always venture in bad weather and of course will have lost speed involuntary or voluntary to avoid to much over work to the ship. In bad weather, modern vessels, in spite of their high engine power, must reduce speed. Slamming, excessive shipping of green water, high accelerations and propeller racing are some of the main considerations. In light load operations, speed will be reduced when in bad sea at Beaufort 4 or 5 because of slamming or propeller racing. However in full load conditions, these phenomena occur under more severe weather; in Beaufort 6 or 8. Because of a large freeboard, water will not be shipped in seas up to 7 for a medium load conditions.

Another effect is the existence of a bulbous bow; in a large tanker it is ordinarily advantageous, but some vessels fitted with bulbous bows may slam and lose speed. Very rough estimates of the percentages of speed loss in head seas is given in the table below for different weather conditions:

Percentage of speed loss.

$$\text{Beaufort 5 :} \quad \frac{900}{L} + 2 \quad \%$$

$$\text{Beaufort 6 :} \quad \frac{1300}{L} + 6 \quad \%$$

$$\text{Beaufort 7 :} \quad \frac{2100}{L} + 11 \quad \%$$

$$\text{Beaufort 8 :} \quad \frac{3600}{L} + 18 \quad \%$$

where L is the length of the ship in meters. It has to be noted that these formulas are functions of only one variable (i.e., length) and are considered as first approximations and therefore do not include the effect of hull form.

CHAPTER III

SHIPBOARD CONTROL OF STABILITY

3.1 REGULATIONS AND RECOMMENDATIONS ON STABILITY

3.1.1 Historical background

The development of the stability concept is not new. Since the end of the last century a lot of work has been done in this field. The concept of metacentric height has been apparently originated with Bougher in 1746. Derivation and calculation procedures for the righting lever curves was published by Atwood in 1796. The dynamic stability development and the concept of energy balance was advanced by Mosley in 1850. Several proposals for the use of GM based stability criteria were offered in the late 1800's and proposals for criteria based on righting energy balance have existed since the early 1900's. The major historical work on the stability was by Rahola in 1939, involved a detailed analysis of Baltic ship capsizing and a proposal for a GZ based criteria. Wind heel GM requirements have been applied in the United States since the 1040's and became a U.S. requirement for cargo ship in 1952.

Wave adjusted stability criteria, which require the calculation of righting arm curves with the ship on a longitudinal wave, were proposed to IMO by the East German and Polish delegations in 1981. Based on a series of model tests in waves, the West German delegation also proposed a form factor correction to Resolution A.167 to account for following waves, beam/draft ratio, and radius of gyration effects. Both proposal are currently under evaluation by IMO.

3.1.2 Types of criteria

The types of criteria can be divided into the following groups: GM or initial stability, wind heel, GZ or dynamic stability, energy balance, wave adjusted stability, and dynamic motion stability methods.

- GM or Initial Stability criteria

GM is based on the geometrical relationship between G the center of gravity and B the center of buoyancy of a ship. M (the initial metacentric height or metacenter) is calculated based on the center of buoyancy and the moment of initial stability of the ship's waterplane. GM is the most basic stability criterion and one of the earliest method used to quantify a ship's stability. Today, many national and international regulations have a minimum GM as one component of their requirement. It is a valid method to measure the static resistance to heel. However, since the position of the metacenter varies when the ship heels, GM is a valid measure within small angles of the initial unheeled position.

- Wind heel criteria

Wind heel criteria are based on the principle of a heeling moment created by a pressure on the lateral profile of a ship coupled with a drag force on the underwater hull. This heeling moment is evaluated against the righting moment to limit heel to a specified angle.

- GZ or quasi-dynamic stability

A ship's GZ, also called righting arm or righting lever, is the lever arm between the displacement (acting down through G) and the buoyancy (acting upward through B). GZ is related to GM by the formula $GZ = GM \sin(\theta)$. Stability criteria based on GZ curves generally specify minimum values of GZ at a specific angle of heel, a minimum positive range, or various area requirements.

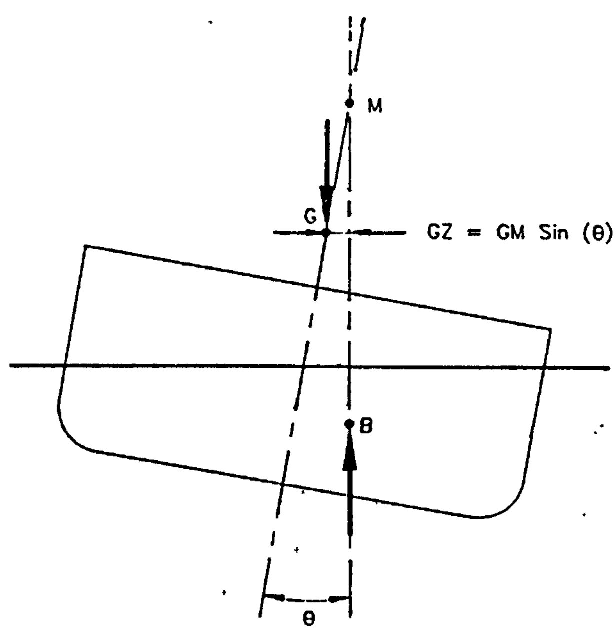


figure 3.1

- Energy balance criteria

The concept of the energy balance criteria method is that the restoring energy or area must be equal or greater than the capsizing energy. Integration of the righting arm curve is interpreted to represent heeling energy. The static heel angle is based on a wind moment and the capsizing energy based on an assumed roll angle opposite to this static heel angle.

- Wave adjusted stability

Several modes of ship capsize are related to the reduction of stability in following or quartering seas. Criteria for account for these effects involve corrections or adjustments to the righting arm curves. This is accomplished either by calculation of the righting arm curves or by form factor adjustments to the righting arm data.

- Dynamic motion and probability stability methods

Researches have indicated that the static or quasi-dynamic models may not be accurate enough to provide safety against complex dynamic modes of capsize. Various new methods are being developed to account for the dynamic behaviour of ships in a seaway.

3.1.3 IMO Resolution A.167

The Resolution A.167 was the first international criterion. Largely based on Rahola's GZ criteria, Resolution A.167 was adopted by IMO in 1968 for ships under 100 m. Resolution A.167 is a set of righting arm and GM criteria extensively used internationally for ships of all sizes by several national authorities. The resolution is currently being extended to apply to ships of unrestricted length. The minimum righting energy requirements are as follows:

- Area under the righting arm curve up to a 30-deg angle θ of heel to be not less than 0.055 m-rad.
- Area under the righting arm curve up to an angle of heel, θ, to be not less than 0.09 m-rad. θ usually equals 40 deg.
- Area under the righting arm curve between 30 deg and θ to be not less than 0.03 m-rad.
- Righting lever GZ to be at least 0.20 m at an angle of heel preferably exceeding 30 deg but not less than 25 deg.
- Initial metacentric height to be not less than 0.15 m

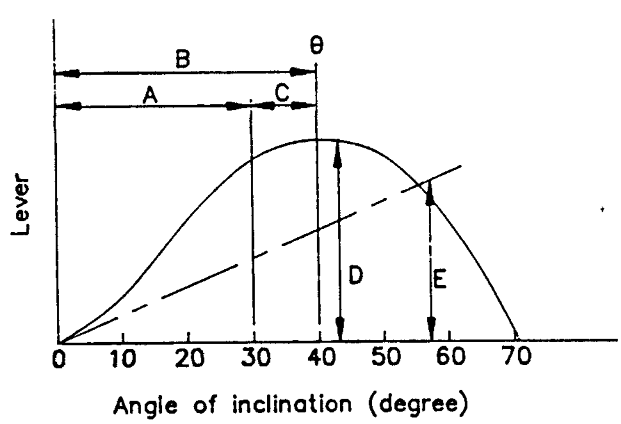


figure 3.2

3.1.4 IMO Resolution A.562

Resolution A.562 is an energy balance criterion designed to account for wind and rolling effects. The criterion is recommended for all ships over 75 m and was approved by IMO in 1985.

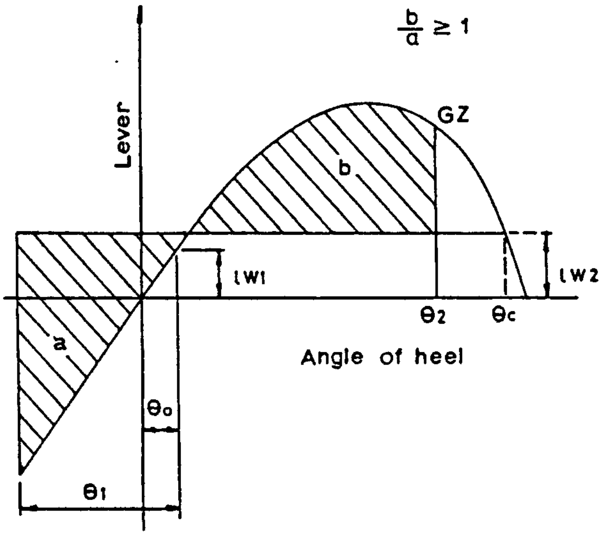
The vessel is assumed to heel to a static heel angle, θ_o, under the action of a steady heeling lever, L_{w1}. Resonant rolling of the vessel is assumed with an amplitude θ_1 about the equilibrium position θ_o. A gust wind heeling lever L_{w2} is then applied. If the righting energy **b** exceeds the capsizing energy **a**, the vessel meets the criterion. The criterion also recommends that under the action of the steady wind heeling lever L_{w2}, the angle of heel shall not exceed 16 deg or 80 percent of the level of deck edge immersion, whichever is less:

$$L_{w1} = (P)*(A)*(Z)/\Delta \quad (m)$$

$$L_{w2} = (1.5)*(L_{w1}) \quad (m)$$

where

- **P** = 0.0514 (m.tons/m^2)
- **A** = projected lateral area of portion of ship and cargo above waterline (m^2)
- **Z** = vertical arm from center of A to center of underwater lateral area (m)
- Δ = displacement (m.tons)
- θ_1 = roll angle
- θ_2 = angle of down flooding (θ_f) or 50 deg or θ_c, whichever is less. θ_c is the angle of second intercept between wind heeling lever L_{w2} and GZ curve.



The IMO Weather Criterion

figure 3.3

3.1.5 New development on the international stability criteria

The IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety is currently developing an Intact Stability Code for all ships covered by IMO instruments, Subdivision and damage stability of dry cargo ships including ro-ro ships as well as flooding protection for passenger ships. Following the thirty-fourth session held from 19 to 23 February 1990, an ad hoc working group on Intact Stability was formed and proposals are under way. The target completion date has been fixed to 1992. Many proposals submitted by various governments are under discussion in order to collate all relevant provisions in one single document.

Following the loss of the Herald of Free Enterprise consideration is given to the use of computer facilities for the determination of intact stability for certain types of ships. There is a need to improve damaged residual stability standards and to have more fast and high degree of accuracy for stability conditions to ensure that such tragedy will not occur. A mathematical exercise carried out by the UK to compare the residual stability standards of existing UK ro-ro passenger ferries was being proposed at the time (1988) by IMO. A slightly modified version of these proposals was successfully adopted by IMO and enters into force internationally for all new passenger ships including ro-ro ferries in April 1990.

3.2 PRACTICAL USE OF STABILITY INFORMATION

No one can doubt that sufficiency of stability is one of the essential qualities for seaworthness. And there is no reason why officers responsible for the safety of ships should lack the information necessary for them to take all reasonable precautions in respect of stability in the preparation of their ships for sea. It is in the stowage planning rather than an emergency arises at sea that the information which the naval architect can give is the most valuable.

On board, the stability information booklet is the basis of the ship's stability assessments. All information is contained in the stability booklet. As said before, there is no mandatory regulations on the manner in which the booklet has to be set up, but IMO Delegations are currently working in order to lay down information to be enclosed in and the requirements of the booklet. This will help to improve the computerization not only of the stability calculation but also all information in connection to the ship's behaviour at sea.

There are many procedures for the computation of the ship's stability, but there is only one set of results they are focussed on. The information presented in the stability calculation can be grouped into five categories:

1- Loading data,
2- Stability calculation,
3- Draft and Trim,
4- Lever Arms, and
5- Longitudinal Bending Moment.

3.2.1. Example of ship stability presentation

SHIP PARTICULARS

SHIP'S NAME: MV ALCOR

LENGTH OVER ALL	129.50 M
LENGTH BETWEEN P.P.	122.00 M
BREADTH MOULDED	21.000 M
DEPTH MOULDED	10.500 M
DRAUGHT SUMMERFREEBOARD	8.074 M
DISPLACEMENT (SFB-DRAUGHT)	14830 MT
DEADWEIGHT (SFB-DRAUGHT)	10460 MT
LIGHT SHIP WEIGHT	4351 MT
PROPELLER IMMERSED AT	5300 M

1) Loading data

CONDITION No 1: SHIP HOMOGENEOUSLY LOADED

COMPARTMENT	WEIGHT TONS	V.C.G. METER	V.C.G. MOMENT	L.C.G. METER	L.C.G. MOMENT	FREE SURF.
HOLD No 1						
ABOVE 2 DECK	832.4	9.70	8074.3	105.29	87643	
BELOW 2 DECK	454.4	4.90	2226.6	101.07	45925	
HOLD No 2						
ABOVE 2 DECK	1715.8	9.41	16145.7	77.72	133352	
BELOW 2 DECK	2150.5	4.40	9462.2	79.72	170083	
HOLD No 3						
ABOVE 2 DECK	17390	9.41	16364.0	41.29	71803	
BELOW 2 DECK	2167.9	4.41	9560.4	40.41	86738	
TOTAL CARGO	9060.0	6.82	61833.2	65.73	5955.45	
AFT PEAK	6.0	2.52	15.1	6.51	39	
TOTAL BALLAST	6.0	2.52	15.1	6.51	39	
F.O. TK MS	428.2	3.94	1687.1	59.64	25538	812
F.O. TK P&S	470.0	4.17	1959.9	59.64	28031	

F.O. TK 1P&S	79.4	6.11	485.1	20.42	1621	76
F.O. T K 2S	7.9	8.30	65.6	9.23	73	1
F.O DT						
TOTAL FUEL O.	985.5	4.26	4197.7	56.08	56263	889
D.B. 4P&S	169.2	0.72	121.8	32.76	55263	
D.O. SERV.TK.	5.8	12.50	72.5	6.04	35	468
TOTAL D. O.	175.0	1.11	194.3	31.87	5578	468
L.O. TK F.A.D	5.0	9.45	47.3	8.54	43	
L.O. TK F.M.D	15.0	9.61	144.2	10.15	152	9
USED LUB.OIL						
TOTAL LUB.OIL	20.0	9.58	191.5	9.75	195	9
SLUDGE TK P						
FRESH W. P&S	203.5	9.50	1933.3	2.59	527	308
PROV/STORE	30.0	18.00	540.0	14.00	420	
DEADWEIGHT	10480.0	6.57	68905.1	62.74	657567	1674
LIGHT SHIP	4350.0	8.90	38715.0	54.42	236727	
DISPLACEMENT	14830.0	7.26	107620.1	60.30	894294	1674

2) TRIM AND DRAFT CALCULATION

DISPLACEMENT	14830 T
LONGITUDINAL CENTER OF BUOYANCY	61.65 M
LONGITUDINAL CENTER OF GRAVITY	60.30 M
TRIMMING LEVER:	1.35 M
FACTOR FOR CHANGING TRIM	0.863 M
TRIM = 1.35 x 0.863	1.165 M
D AFT (TRIM x WL/LPP)	0.572 M
D FWD (TRIM - DRAFT AFT)	0.593 M

DRAUGHT MEAN	8.074 M
DRAUGHT AFT	8.646 M
DRAUGHT FWD	7.481 M

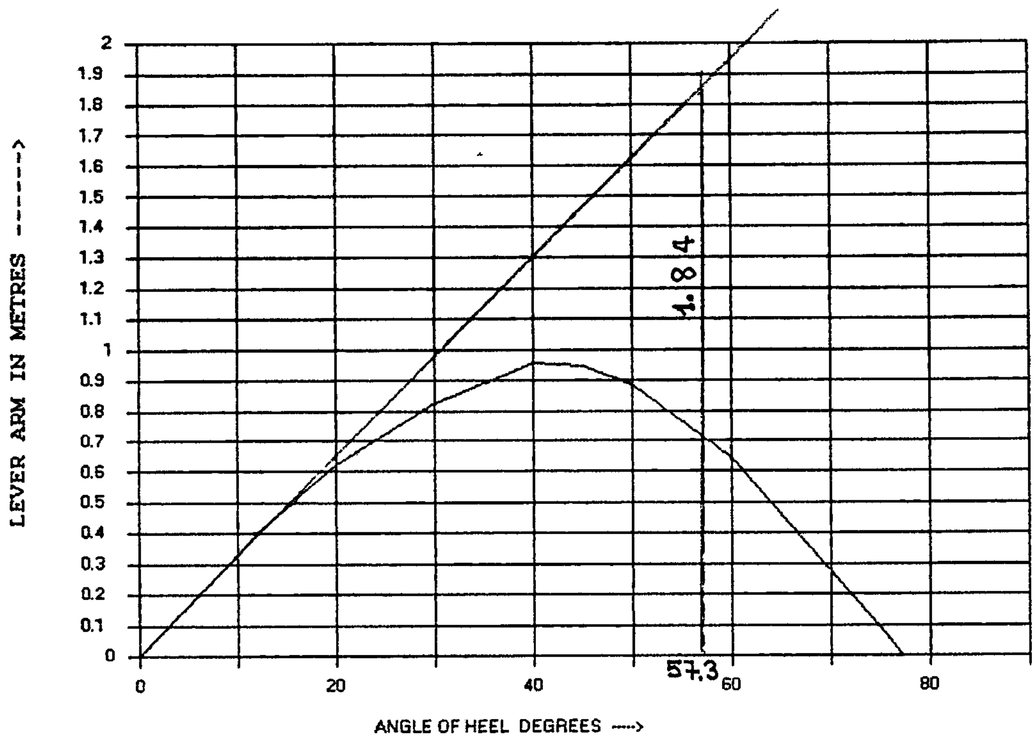
3) TRANSVERSE STABILITY

VERTICAL CENTER OF GRAVITY :	KG	7.26 M
FREE SURFACE	CG'	0.11 M
KG CORRECTED FOR FLUID	KG'	7.37 M
TRANSVERSE METACENTER	KM	9.10 M
TRANSVERSE METACENTRIC HEIGHT	GM	1,84 M
GM CORRECTED FOR FLUID	GM'	1.73 M

4) LEVER ARMS

Angle($\theta°$)	10	20	30	40	50	60	75	90
Sin(θ)	0.174	0.342	0.5	0.643	0.766	0.866	0.966	1.00
KN	1.593	3.106	4.452	5.622	6.447	6.932	7.102	6.743
KG*Sinθ	1.261	2.483	3.630	4.667	5.561	6.287	7.013	7.260
Lever Arm KN-KG*Sin$\theta°$	0.332	0.623	0.822	0.955	0.886	0.645	0.089	-0.517

STABILITY CURVE



3.2.2 LOADING COMPUTERS AS AN AID TO STABILITY CALCULATION

Computer plays and will continue to play an important role in our life. Its impact on the way we live is tremendous. The area of its implications vary from secretary work to a huge company management. Computer finds its application in the field of shipping. In naval architecture every stage of ship building process is set up or controlled by computers. Overall ship design may not be as yet as reality but systematic procedures utilizing computer techniques to determine optimum ship dimensions and form to satisfy prescribed cost requirements have been developed.

An other aspect of computer utilization is in relation to ship operating. The computer on board ship affects design criteria and allows for safer and more economical operation through automatic decision making in regard to loading, engine operation, navigation and other considerations. It is important to mention here, as far loading is concerned, the advantages and the limitations of computer.

a) Advantages of computers.

There are five mayor advantages of computerized data processing compared to manual processing. They are:

- Speed,
- Reliability,
- Precision,
- Flexibility, and
- Economy.

b) The Limitations of computers.

Although have many advantages, they have some limitations as well. A computer will do only what people tell it to do. In ship calculation, it is useful to know the mathematical models in the computer. It is also a great importance to enter at any stage the right value. Here are a few of limitations of computers.

- Needs to be programmed,
- Performs limited Tasks,
- Cannot Evaluate Intangibles, and
- Not always the best solution.

3.3 PROCEDURES AND TECHNIQUES OF STABILITY MEASUREMENT

The main parameter in the stability measurement people are looking for is the metacentric height GM. Although the metacenter M is known relative to the various displacement, the calculation of the center of gravity seems to be the aim of the overall operation. A failure to have accurate or right result of this parameter will have some impacts on the stability measurement.

The reason why the metacentric height has gained so much importance over the time is that all national and international regulations on the stability are based on GM. The point M is dependent on the geometric properties of the ship at each draught. Its positions are found by calculation, generally recorded by means of table and/or curves, in shipyards by the naval architects. This means that the ship operator, the master or the officer has nothing to do, to alter this quantity. It follows that all work done to measure the stability is only to find the real position of the center of gravity. The veritable task whenever it is done by hand or loading calculator can be summarized in calculating at first the center of gravity. The main purpose of cargo planning is to optimize the position of this center of gravity relative to the metacentric height.

Before, when there are no advanced calculators, the calculations are done manually and using tables with many approximations and carry waste of time. Nowadays, digital computers will perform these operations in minutes. There are two ways to perform a stability measurement: the In-Service Inclining Test and

Utilization of the natural roll period.

3.4 IN-SERVICE INCLINING TEST

An In-Service Inclining Test is carried out on existing ships when large alterations are made to the original design affecting the original stability condition. This experiment must be done in the shipyard and will have the same features of the original Inclining Experiment. The results of the experiment enable to calculate accurately the value of GM for ships in service to improve accuracy of stability estimates. A particular loading condition is performed by loading and/or discharging various weights which are not accurately known and their exact positions of the center of gravity are always estimated.

During or after the completion of loading procedures the vertical position of the center of gravity can be calculated by an inclining experiment. The In-Service Inclining experiment also called Operational Ship Inclining experiment (OSI) can be carried out to measure the metacentric height of the vessel during the loading and unloading before leaving the port. The development of new ships types and ways of loading have increased the need for an experimental check of the transverse stability. Some ships such as container ships and RO-RO ferries have the tendency to operate close to the stability limits set by authorities.

In order to analyze the practical aspects of OSI, a large number of operational experiments with container vessels in port have been carried out by Professors Kaps and Kastner in 1989. The work was done in collaboration between the departments of Nautics and of Naval Architecture and Ocean Engineering at Bremen Polytechnic in 1987 and 1988. Results of the two year research programme show some disparities between cargo documents and real weights in terms of stability (KG) and displacement. To overcome these problems, OSI seems to be a very powerful tool to estimate the actual ship stability.

3.5 UTILIZATION OF PERIOD OF ROLL

The stability of a ship may be determined by means of rolling period test. Studies on this matter show that the rolling period test may be recommended as a useful means of roughly determining the initial stability of small ships when it is not practicable to give approved loading conditions. It can also be done to supplement or control the stability given by other means. The performing of the test is based on the equation of the natural roll of period which is :

$$GM_o = \left(\frac{fB}{T_o} \right)^2$$

where:

- B = breadth of the ship in meters
- T_o = time of full rolling oscillation period from port to port or vice versa.
- **f** = factor for the rolling period given in the table below.

The factor **f** depends on the loading condition, the weight distribution and the ship's types. It has to be determined by administration and the table below gives average values for coasters of normal size (excluding tankers) and fishing vessels. Resolution A.167 gives for coasters of normal size the following values for metric unit.

	f-values
Empty ship or ship carrying ballast	0.88
Ship fully loaded and with liquids in tanks comprising the following percentage of the total load on board (i.e. cargo, liquids, stores, etc.)	
20% of total load	0.78
10% of total load	0.75
5% of total load	0.73
Deep sea fishing boats	0.80

However, it must be stressed that for any vessel the f-value should better be determined directly. By carrying out both inclining experiment and rolling test, the value can be established for particular conditions of the vessel.

CHAPTER IV

CASE STUDY: THE CAPSIZE OF THE HERALD OF FREE ENTERPRISE

4.1 INTRODUCTION

In the night of 6th March 1987, the world was petrified by a tragic maritime incident. The news had been relayed by radios and televisions all over the world. The Roll on/Roll off passenger and freight ferry HERALD OF FREE ENTERPRISE capsized a few minutes after leaving the port of Zeebrugge. She turned rapidly to starboard and was prevented from sinking totally only because her port side took the ground in shallow water. Water rapidly filled the ship below surface level with the result that more than 150 passengers and 38 members of crew loss their lives. Many others were injured. This kind of maritime casualty involving such losses of lives was rare in the European community. Before trying to understand the causes of the accident and how this tragedy happened, it is good to take a look of the description of the HERALD OF FREE ENTERPRISE.

4.2 DESCRIPTION OF THE HERALD OF FREE ENTERPRISE

4.2.1 Principal Dimensions

The **HERALD OF FREE ENTERPRISE** was a triple screw Ro/Ro passenger/vehicle ferry built in 1980 by Schichau Unterweser AG, Bremenhaven. Registered at Dover, her official number was 379260. The principal dimensions are as follow:

Different particulars

LENGTH OVERALL	131.9 M
LENGTH BPP..	121.1 M
MOULDED BREADTH	22.7 M
PROPULSION 3x12ZV 40/48 each	9,000 BHP
CONTROLLABLE PITCH PROPELLER	
3 ELECTRICAL POWER PLANT 1063 kVA each	
SERVICE SPEED	12 knots
CLASS +100A2 "Ferry"	

The HERALD was all welded steel construction with a double bottom extending from frame 25 to frame 149. She was 8 decked above the tank tops, the upmost being A deck and the lowest H deck was below the main deck. The H deck was subdivided by 13 watertight bulkheads and had 9 watertight doors for access to between compartments. Access between deck A to G was by staircases at port and starboard sides at aft end, midships and fore end. The staircases at the fore end continued down to H deck.

The vessel was built to comply with the Merchant Shipping Rules 1980 and SOLAS 1974. The day of the accident, she was in possession of a Class II Passenger Certificate. This Passenger ship Safety Certificate for a short international voyage (not more than 600 miles from first to final port) was issued as a temporary extension from 11 February 1987 for a period of one months. In the C1 condition, with a freeboard of 1110 mm, the ship was entitled to carry a total of 630 persons including crew. In the C2 condition the ship was required to have a freeboard of 1310 mm and permitted to carry a total of 1400 persons. The draught of the ship was not permitted to exceed 5.5 m moulded and if not carrying more than 630 persons the draught could exceed 5.5 m but not more than 5.7 m. Therefore the number of passengers and the draught of the ship should be known before the commencement of each voyage.

4.2.2. LIFE - SAVING APPARATUS

8 Lifeboats (4 motor)	for 630 persons
16 Inflatable liferafts associated with M.E.S.	for 672 persons
7 Throwover liferafts	for 175 persons
5 Buoyant apparatus	for 70 persons
20 Lifebuoys	
1525 Lifejackets (including 139 for persons weighing less than 32 kg)	

4.2.3 MANNING

The HERALD, as her two sister-ships (the SPIRIT and the PRIDE) were built for Dover-Calais run. On the Dover-Calais run they are manned by a complement of a Master, two Chief Officers and a Second Officer. They are required to work 12 hours on and not less than 24 hours off. On the other hand, each crew member was on board for 24 hours and then had 48 hours ashore.

The Dover-Zeebrugge run takes 4.5 hours, which is substantially longer than the passage between Dover and Calais. Therefore the Officers have more time to relax. For this reason the Company employed a Master and two deck Officers on this run.

4.2.4 The bow and stern doors

Before proceeding, it is useful to talk about the bow and stern doors. The HERALD, like other modern ferries, had an enclosed superstructure above the bulkhead. At the bow there were inner and outer doors. At the stern only outer doors were fitted. The bow and stern doors were required to be weathertight. Weathertight applies to doors and openings which are only required to prevent the entrance of water from the side exposed to the weather. The construction of the doors was such that they were able to resist the normal expected forces in the bow and the stern areas of the vessel. They are structurally designed to be at least as strong as a fully plated bow and stern. There was an alarm bell which rang whenever the doors were in motion. The bell was a safety device designed to prevent people from mal utilisation of the doors and should not have been switched off. The investigation has shown demonstrated that there is no reason to think that there were any fault which would have prevented the doors from being closed hydraulically.

4.3 CONDITIONS ON DEPARTURE

On departure the HERALD was to make the voyage in the C1 condition. In that condition the ship was of one compartment standard, that means she was capable of accepting damage to any one compartment without either losing stability or submerging the margin line at any time during the flooding. (The margin line is an imaginary line 76 mm below the bulkhead deck.) The ship's displacement calculation consisted of the sum of her light weight with all consumable on board (fuel oil, diesel oil, fresh water and stores etc) the weight of her crew and their effects and the weight of the passengers, cars, luggage, commercial vehicles and coaches. The condition upon the departure of the HERALD was calculated as follow:

Crew	80
Cars	81
Freight Vehicles	47
Passengers .... Approx.	459

Displacement	8874 tonnes
Mean draught (USK)	5.68 m
Trim	0.75 m (by bow)
Draught forward	6.06 m
Draught aft	5.31 m
Vertical centre of gravity (fluid) ...	9.73 m
GMf	2.09 m

After the accident of the HERALD OF FREE ENTERPRISE, a full-scale experiment had been taken in June at Zeebrugge. It was found that the ship could not accommodate the weights calculated from the builder's lightship and the declared weights. To find the reason for this, 105 vehicles incoming to the United Kingdom were weighed at Dover. The average excess of actual to compared way-bill weights has been found approximately 13% per vehicle. The checking of the lightship weight of the PRIDE and the SPIRIT indicated that they were heavier than the Builder's lightship by about 270 tonnes. Another investigation of the history of each vessel had shown that modifications had increased the weight of both vessels by about 115 tonnes. The balance of the weight increase known to be present in the PRIDE and the SPIRIT (about 148 tonnes) must be attributed to the accumulation of dunnage, stores, paint and growth items. the modifications to the HERALD are known to be 102 tonnes. From this it follows that the HERALD lightship was probably increased by about 250 - 270 tonnes above the Builder's lightship weight.

Departure and casualty conditions, using an increased lightship and also an additional weight per vehicle as revealed by the test weighing, had been computed. For this calculation, the additional weight for the vehicles was assumed moderately to be only 10% in excess. On the basis of the upper limit, the departure condition of the HERALD as calculated was as follows:

Displacement	9250 tonnes
Mean draught (USK)	5.85 m
Trim	0.83 m (by bow)
Draught forward	6.26 m
Draught aft	5.43 m
Vertical centre of gravity (fluid) ...	9.75 m
GMf	2.04 m

It can be seen that this condition will be overloaded by some 0.13 m. The probability is that the draught and the trim approached the upper limit condition and that the vessel was in fact significantly overloaded at departure. This overload, however, was not any way causative of the casualty. The real significance are the lessons to be learned from it. The lessons are the need for more information about the weight of cargo to be loaded and the desirability of fitting draught indicators.

4.4 THE INCIDENT

It was difficult to say exactly what happened this day. The accident had so surprised every body that neither the crew nor the passengers could not or did not have the time to understand what was happening. There was a light easterly breeze and very little sea or swell. She left the quai with bow doors open. The HERALD passed the outer mole at 18.24. Water filled the deck and she capsized about four minutes later. The HERALD turned rapidly to starboard and was prevented from sinking totally by reason only that her port side took the ground in shallow water. Water rapidly filled the ship below the surface level. More than 150 passengers and 38 crew lost their lives and many others were injured.

4.5 PROBABLE CAUSES AND LESSONS FROM THE DISASTER.

The main objective of tattling this case of capsizing, is the amount of lessons we can learn from it. No matter how big the error was and who is responsible. Before moving on, less look at some facts which might lead to comments.

- There is an evidence that passenger ferries run on an schedule that they are always on the time pressure whenever it seems that they will be late.
- On the 6th March they were running late. The HERALD sailed 5 minutes late.
- The bow doors could be closed at the berth.
- The doors closing is the responsibility of the bosun assistant. He was sleeping and was not awakened by the call "Harbour Station". He remained asleep on his bunk until he was thrown out of it when the HERALD began to

capsize.

- Nobody checked whether the bow door was closed or not before leaving (it was the duty of the officer in charge of the loading to supervise the doors closing before going to the harbour station").
- The absence of the assistant bosun had not been noticed by the people at the station.
- Nobody knows exactly the number of passengers on board.
- It was frequently necessary to trim the ship by the bow to allow the raised ramp to reach E deck.

This casualty focuses our attention on three kinds of problems which may be the basis of the accident. These problems concern the safety of the ship, the loading and stability and the stability in damaged condition.

4.5.1 Safety of the ship

The safety of a ferry depends on the condition of her doors and the lashing conditions. The main problem is to find the way of showing or notifying to the crew the conditions of the doors and the lashings. The purpose will be to:

- monitor the condition of the doors and convey that information to the bridge.
- check the vehicle decks for intruders, whether innocent or otherwise and to check whether there is any movement of vehicles in a seaway.
- check all superstructure doors, such as passenger access, bunkering and storing doors.
- keep the bridge aware of conditions in the engine.

The solution is to install checking devices and alarm panels.

a) Indicator lights: the lights should not only indicate door positions in a suitable position on the bridge. In addition the entire circuit should be designed on a fail-safe basis so that if there is an electrical failure in any switch circuit the system should indicate danger.

b) Closed circuit television: Freight vehicles should always be secured. If they are unsecured, they may shift with a dramatic effect on the stability. Closed circuit television can give warning of a such movement. The most important use of closed circuit television in the vehicle decks is to monitor the condition of bow doors, stern doors and any side doors.

4.5.2 Loading and stability

The problem of ferries stability during the loading operations and at sea is an important matter. Because not only the tracks and coaches come onboard fully loaded but also nobody knows exactly their weights. In addition it is difficult, if not impossible, to read the aft draught on many ferries. This is due to the extreme flare of the ship's sides as a result of the wide sterns of such vessels. The result is that the total weight and draughts are not reliable and these ships tend to sail very close to their limit of stability. The way to overcome this difficulty is the use of draught gauges, weight bridge and the necessity to evaluate regularly the lightship condition.

a) Draught gauges: The difficulty if not impossibility of reading the aft draught of many ferries has been already mentioned. The draught gauges or indicators can be fitted to give readout at the aft and forward loading position on the bridge. They are of several types: mechanical, electrical, pneumatic or hydrostatic, they should be designed to give a true draught at the loadline mark. Draught gauges or indicators should be a requirement for Ro/Ro passenger ferries.

b) Freight weighing: The weight of cargo of Ro/Ro ferries is predicted on the basis of declared weights for freight and of nominal weights for smaller vehicles such as cars and coaches. The checking at Dover on over 100 vehicles coming to the United Kingdom which showed that on average the actual weight exceeded the declared weight by 13% was very significant. Especially on the ferries, this excess of weight is enough to put the ship a in danger situation. The question of automated weight bridges and loadicators must be considered. The problem on this subject is in term of finance because weighing all cargo loaded will require time and money. If there are any National or International regulations to constrain shipping companies, it will be difficult to conform with.

c) Growth of lightship: during the life of a ship, some minor or mayor changes may increase significantly the lightship weight. The increase of weight can also be attributed to the accumulation of dunnage, stores, paint and other items. The solution is to check regularly the lightship conditions by means of inclining tests.

CHAPTER V

STABILITY IN MARITIME EDUCATION AND TRAINING

5.1 IMPORTANCE OF STABILITY CONTROL IN MARITIME EDUCATION AND TRAINING

Naval architecture is a rapidly developing subject. Development of new design techniques and omnipresent computers enable the ship designer to carry out his work with greater precision and confidence. The ever changing technology will then affect the shipbuilding and the types of ship built. Some twenty to thirty years ago. the shipping industry did have only a few types of ships. Today, there are many varieties of ship types. They vary according to the mission types and the types of cargo. The way in which ships are operated and managed are changing despite the decline of the industry. The ships are becoming bigger and bigger and more sophisticated. The problem is to know if the training, today will follow the trend or not.. Since many years, training approach to the ship stability has not been changed.

5.1.1. The need for skilled personnel

The aim of navigation is to bring a ship safely from one port to another. This includes Loading, discharging, ship handling and navigating. The ship stability is important at least in the same order as other subjects in the ship officer training. Shore industries and managing maritime services seems to be more interested in the matters pertaining to the cargo than other problems.

The growing of the vessel types, the reducing of the crew has brought forward a remarkable and exhaustive change and load planning has become a shore-based job. In most cases container or ferry loadings are today a work of professionals. A great number of people involved in the maritime transportation system of cargo rely on the skill of these loading authorities. In most cases, these persons are former Masters and Chief Officers, with great experience in loading. Because of the high speed of the operations today, the ship personnel does not have enough control over the loading procedure. Therefore, only well trained personnel should carry out all precautionary measures with regard to the preparation of loading plans. This shows the importance of the training not for the loading but for all the persons involved in the maritime transportation.

5.1.2. Some remarks about the training curriculum

To have an idea about how the ship stability is taught in maritime academies, some course syllabi have been taken here to highlight our point of view. The syllabuses of the USSR, SWEDEN, FRANCE and the FEDERAL REPUBLIC OF GERMANY are given in the tables on the following pages. The Stability is not in most cases a course on itself but integrated in other courses. This can be understood if we assume that a voyage planning is a combination of all data aiming to navigate safely in the encountered weather. The safety of the ship will depend on how the ship's personnel will handle the iteration between the ship and the environment in which they may proceed.

The different syllabuses lead all to deep sea going Mate Certificates (or unlimited Mate Certificate). After graduated as Mate some countries do not have any supplementary courses before the acquisition of Master Certificate.

a- Syllabus for 3d mate deep sea going in the U.S.S.R.

	Subject	total of hours	percent per subject
1.	Socio-economic disciplines	430	9.69
2.	English	446	10.05
3.	Higher mathematics	442	9.96
4.	Engineering graphics	70	1.58
5.	Physics	246	5.55
6.	Theory of mechanics	231	5.21
7.	Electrical engineering	70	1.58
8.	Computer	87	1.96
9.	Mathematical basic of navigation	84	1.89
10.	Marine transport economics	70	1.58
11.	Physical training	292	6.58
12.	Civil defence	50	1.13
13.	Theory of construction of ship, and ship maintenance	175	3.94
14.	Electronic navigation instruments and wireless communication	186	4.19
15.	Navigation aids	288	5.14
16.	Ship handling	220	4.96
17.	Labour and environment protection	42	0.96
18.	Safety at sea	90	2.03
19.	Automation of navigation	117	2.64
20.	Ship propulsion machinery and electrical equipment	70	1.58
21.	Soviet law. maritime law	102	2.30
22.	Marine transportation technology	70	1.58
23.	Nautical geography	48	1.08
24.	Merchant navy management its commercial operation	116	2.61
25.	Navigation and pilot boob	210	4.73
26.	Celestial navigation	140	3.16
27.	Hydrometeorological aspects of navigation	70	1.58
29.	Introduction into speciality	34	0.77
	Grand total	4436	100

5 years and 6 months including 15 months sea training (ship board training)

b- SYLLABI FOR CAPTAINS STUDIES*
at Kalmar Merchant Marine Academy (SWEDEN)

SUBJECT	POINTS	PERCENT PER SUBJECT
1. Mathematics	11	9.2
2. Computer and data	2	1.7
3. Physics	2	1.7
4. Swedish language	3	2.5
5. English language	10	8.3
6. Personnel administration	3	2.5
7. Labour market and laws	1.5	1.2
8. Business economics	5	4.2
9. Technics	4	3.3
10. Ship building and stability	5.5	4.6
11. Ship maintenance	4	3.3
12. Fire protection and fighting	2	1.7
13. Medical care	4	3.3
14. Environment technics	4	3.3
15. Communication	5	4.2
16. Cargo handling and transport	14	11.7
17. Seamanship	8	6.7
18. Maritime law	4	3.3
19. Navigation	11.5	9.6
20. Nautical instruments	5.5	4.6
21. Meteorology and oceanography	3.5	2.9
22. Bridge work	3.5	2.9
23. Project paper (own research)	4	3.3
Total	120	100

* The syllabus covers three (3) years theorical study.
Monovalent

c- Syllabus for 1st class Mate studies in France *

Courses	Hours/year			
	1st	2nd	3rd	4th
1. Mathematics	3.0			
2. Electricity	1.5	2.0	1.5	1.5
3. Nautical Astronomy	1.5			
4. Navigation	4.0	4.0	2.25	1.25
5. Thermodynamics, Ship's Machinery	4.0			1.5
6. English Language	3.0	3.0	3.0	3.0
7. Maritime Law	1.0	.75		
8. Ships Technology and equipment	1.0			
9. Workshop Technology and Machinery	2.5			
10 Technical Drawing	3.0	3.0		
11. Electronic Data processing	2.0	2.0		
12. Mechanics and Strength of Materials		3.0		
13. Radioelectricity, Electronics		1.5	1.5	2.5
14. Fluid Mechanics and ship's Machinery		4.0	5.0	
15. Ship construction		.75		
16. Automation		1.0	2.0	2.5
17. Ship stability			.75	1.5
18. Ship protest				1.5
19 Radar Simulation				1.5
20. Ship's Accidents, Damage Repair			1.5	1.5
21. Maritime Trade				1.0
22. Claims and Accountancy				1.5
23. Ship handling	1		.25	.75
24. Commercial law			1.0	
Cargo handling	0.75		.75	1.0
25. Meteorology			1.0	
26. Shipsanitation				0.5
27. Colreg			.5	2.5
LABORATORY				
28. Ship' machinery	2.00	1.5	1.0	
29. Engine practice			3.0	
30. Electricity	1.0	1.5	3.0	1.5
31. Electronics		.5	1.0	3.0
32. Navigation	.5	1.0	1.0	1.5
33. Automation		1.0	1.0	
34. Shipboard sanitation	1			0.5
35. Visits			1.0	2.0
36. Communication	.5			
TOTAL	**33.25**	**30.50**	**32.00**	**32.50**

*The syllabus covers four (4) years study in polyvalent ENMM of LE HAVRE

d) **COURSE SYLLABUS Master Foreign Going (AG)**

Bremen Polytechnic Department of Nautical Studies

Subject	hours per subject	percent per subject
1. Communications	102	4.38
2. Medical training	68	2.92
3. Sociology	68	2.92
4. Psychology	34	1.46
5. Mathematics	68	2.92
6. Physics (mechanics)	68	2.92
7. Physics (electricity)	68	2.92
8. Chemistry	34	1.46
9. Informatics EDP	68	2.92
10 Climatology/Oceanography	68	2.92
11 Basic Maritime Law	34	1.46
12 Economic Fundamentals	68	2.92
13. Shipbuilding	34	1.46
14. Operation of Ship Engines	68	2.92
15. English Language for Mariners	102	4.38
16. Personnel Management	68	2.92
17. Automation	68	2.92
18. Shipping Management	102	4.38
19. Weather Routeing	102	4.38
20. Terrestrial Navigation	102	4.38
21. Celestial Navigation	102	4.38
22. Electronic Navigation	136	5.84
23. Marine Labour Law	34	1.46
24. Marine Trade Law	68	2.92
25. Sea Traffic Law	102	4.38
26. Stability/Trim	68	2.92
27. Dangerous Cargoes	51	2.19
28. Stowage of Cargo	68	2.92
29. Manoeuvring	68	2.92
30. Ship Safety	34	1.46
31. Terrestrial Navigation(simulation)	34	1.46
32. Radar Simulation (anticollision)	34	1.46
33. Navigation Lights Simulation	17	0.73
34. Shiphandling Simulator	34	1.46
35. Seminar Passage Planning	102	4.38
Total	2329	100.00

The syllabus is on six (6) semesters Monovalent course

The importance and hours allocated to Stability in officers' training vary from one country to another. It also depends on the duration of the course. But what is important is to see how much time is allocated to the Stability course. The first difference is the appellation of the course in different countries. The following list will then deal with the same subjects.

France : Ship Stability
The FRG : Stability and cargo securing
The Netherlands : Cargo handling Technology
Sweden : Shipbuilding and Stability
The U.K. : Marine Transportation - Ship Stability
The USA : Principles of Naval Architecture
The USSR : Ship Handling

The subject outline from different countries is nearly the same as in the Principles of Naval Architecture:

* Numerical quadrature and numerical analysis
* Ship geometry and definition;
* Ship form calculations, hydrostatic properties and curves of form;
* Weight properties and calculations;
* Initial stability and trimming problems;
* Large angle of Stability;
* Damaged stability, floodable length, ship's strength, and ship resistance and propulsion

It is clear that every school does not assign the same number of hours to Ship Stability; there is no way to say that the students of this school are better trained than others. The only thing to say is that there is a disparity in the training philosophy of every school. It is known that nowadays, because of new subjects to be taught, time does not permit enough number of hours to every subjects. But we think that Ship Stability and Ship Handling are still of the utmost importance.

5.1.3. The impact of computer on the training

For economical reasons, the Maritime Education and Training faces today the need of extensive knowledge base, the way of inculcating the different skills needed in shorter period. There are two different ways in which the introduction of microcomputer in training may improve of the forming of a ship's officer. Firstly, the understanding of the reliability and limitations of microcomputers will have direct benefits in assessing and evaluating the shipboard equipment such as loading computers.

Secondly, microprocessor technology in the form of microcomputers and simulators can have a simulating role in developing best shipboard managing skills in aiding information transfer. Computer assisted learning and simulation are two basic techniques in which computers are mainly used in maritime education and training.

5.2 NEED FOR IMPROVEMENT OF STABILITY COURSE IN MARITIME COLLEGES

The way in which ships are operated and managed are developing rapidly. Whether the effects of technology will contribute to efficiency or disaster will largely depend on those who work with this new technology. It will also depend on their capability to nourish their potential and anticipate their weakness. In recognising this it is possible to define a new philosophy for maritime education. In 1978 the International Maritime Organization (IMO) defined the minimum standards of training for ship officers in a reference document called the International Convention on standards of training, certification and watchkeeping (STCW). The importance of securing safety of life and property at sea and protecting the marine environment brought IMO Member countries to come to this convention. Furthermore the diversity of ships and goods being carried at sea together with sharp reduction of manning levels call for new view on training. This must be more realistic and more relevant than it has traditionally been.

One must recognize that the work done by ship's officers today does no more cover the same finality as was some thirty years ago. Because of the important flood of computers in the people's life with the capability of intensive data management and also the improvement of realiability of navigational equipment and satellite communication, the scope of officer's job has shifted from executing to planning and evaluating. He should be able to understand the steps taken by a loading computer before giving information he is looking for, to appraise and determine the limitations of the equipment used.

Therefore the training objectives must aim to help the students to acquire necessary psychological and technical dispositions to perform his duty. The course must bring up competent future officers by a comprehensive professional education on the operation of today's technically advanced new ships. We believe that ships cannot be operated safely on machinery alone, even if they are equipped with the most highly modernized automatic instruments. The role of Officers is still crucial in this. Behind the theorical knowledge, the adequate ability of the merchant marine officers would consist in the practical applicability of the knowledge. The lack of practical knowledge, skills or the proper mental attitude of the officer will annihilate our expectation of the safe operation of the ships.

5.3 INCORPORATION OF IMO MODEL COURSES IN MARITIME ACADEMIES SYLLABUS

5.3.1. IMO Model Short Courses

The IMO Model Courses have been produced in various fields of maritime training supplement instruction provided by maritime academies and permit administrators and technical specialists employed in maritime administrations, ports and shipping companies to improve their knowledge and skills in certain specialized fields. It is also said in the introduction of the courses that the purpose is to assist maritime training institutes and their teaching staff in organizing and introducing new training courses, or in enhancing, updating or supplementing existing training material where the quality and effectiveness of the training courses may thereby be improved.

For the Basic Stability course 1.17, it provides training at a basic level for those whose responsibilities include the loading and safe operation of <u>small ships of sizes up to 200 gross register tons</u>. The scope of the course is apparent and it is designed for those responsible for very small ships. On some points of view this may not be a solution for most maritime academies. Because very few people are willing to follow training for these kinds of ships. The point here is that those academies which want to use these short courses for their students must clearly understand the limitations of the course.

This course can however help maritime academies trainers in developing their courses to not miss out the basic materials needed for their students. It will also highlight the main elements on which teachers must focus the trainers attention in order to reach the objectives.

5.3.2. IMO Training Courses for Masters and Chief Mates

We can be pleased to know that the SUB-COMMITTEE ON STANDARDS OF TRAINING AND WACHKEEPING of the IMO is currently developing model training courses based on the 1978 STCW Convention for the following:

- Master and Chief Mate
- Officer in Charge of Navigational Watch
- Chief Engineer Officer and Second Engineer Officer
- Engineer Officer in Charge of an Engine Room Watch

The final drafts of the model training courses have been circulated at various stages of its preparation to the Validation Group - Norway and United Kingdom (representing shipowners), Finland and United States (representing seafarers) and Denmark and India (representing IMO). The Model Course 7.01 is for Master and Chief Mate and 7.02 for Chief Engineer Officer and Second Engineer Officer. Each course comprising the course outline and a detailed teaching syllabus is divided into 4 parts:

- Learning Objectives;
- Teaching aids;
- IMO references; and
- Textbooks.

This work demonstrates the highest priority given to the development of global standards for maritime training. The implementation of these courses will improve training standards to comply with IMO Conventions and Protocols.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

There are three groups of parameters the ship Master must take into account when assessing the ship Stability:

Ship design parameters;
Dynamic properties; and
Environment parameters.

Stowage planning cannot be done properly when one cannot evaluate accurately these parameters. Investigation has identified the most important influential parameters from the point of view of stability assessment as well as the sensitivity of stability to change in these groups of parameters. Of the investigated parameters, KG (height of centre of gravity) and L/B (length-to-breadth ratio) were found to have the most important influential parameter on stability. That would lead to too much simplification. But the KG on itself does not mean anything, it must be related to the ships' particular dimensions although it is the fundamental element in Initial Stability (GM) calculations. therefore one must always take into account the dimensions' influence supported by L/B and environment factors.

On other hand the minimum stability requirements set up by authorities cannot include all risks imaginable. They also do not define clearly the operational conditions on which they are based. This leaves the ship Master alone in front of an ever changing marine environment. The main problem he will face is the ship behaviour at sea.

With respect to ship stability, he is concerned about safety from capsizing and about high accelerations on the cargo. There are a few things to do when the ship encounters very high seas which may lead to unexpected rolling or resonance:

General Steps to avoid Mathieu Resonance

1) Determine natural roll period.
2) Determine encounter period.
3) The single or the double encounter period should not coincide or be close to the natural roll period of the vessel.
4) Measures under critical roll conditions in following or aft quatering seas to avoid Mathieu resonance:
   - change heading
   - change speed
   - change of GM by modifying of ballast
5) It is highly recommended to keep records of any observed large roll, and on the corresponding ship and seaway conditions, in order to gather experience data.

At the moment there is a need to provide improved information to the Master and the practical set-up of information data aboard must be improved. The fact is that some modern ships designs actually resulted in poor seakeeping and they tend to sail close to the limit of the minimum stability requirements. Here are a few points to be taken into account to improve operational stability: (I will refer to Prof. Kastner's paper "Operational Stability of Ships and Safe Transport of Cargo").

Quote"

Measures to improve operational stability

1) rethinking in the design of ships with respect to the seaway behaviour
2) develop information to the master given aboard on the ship motions
3) Standardize the securing measures for the large variety of non bulk cargo
4) stowage of cargo
5) actual size of stability parameters for ship operation, its estimation and accuracy, and improved testing procedures
6) ballasting of ship
7) damping of roll motion
8) long-term operations
   - weather routeing, operational analysis
9) short-term operations by the ship master
   - speed reduction and change of heading
   - short-term weather routeing
10) support of ship motion gauges and processors, data reduction and indication of action parameters on operational ship stability
11) improved training of masters on ship motions and safety of cargo, and on prevention of extremes
12) sample and evaluate experience and accidents internationally
13) agree on observation chart on severe ship motion and extreme lashing forces /9/
14) develop international "Code of Safe Practice" by IMO to include the above general pattern.

"Unquote

Beside this, one of the most important elements which needs to be highlighted is the human factor. The main problem is to have the necessary knowledge in order to perform the right task in the right way. The training of the future ship Masters has to be on the level of the new technology if not every thing will be a mess. It is time to call for a new philosophy on the training. We feel that it is time to provide a perspective to update the knowledge of marine personnel in the light of new technology in shipping and in methods of teaching and certification. In this situation, it becomes necessary to train present seafarers so that they can obtain the knowledge and the skills to man automated vessels. Training is the only way to reinvigorate the maritime industry. The maritime industry will benefit by securing a reliable supply of well-trained marine personnel; the students will benefit by having some career guarantee and International Organizations will be satisfied that maritime institutes are serving international interest by decreasing marine disasters.

Throughout this dissertation we have been discussing development of new technology in the maritime industry. From the point of view of ship owners, a technically advanced ship is synonym to cheap and effective whereas seafarers think of sophisticated. It has been proved that the principal key to the improvements of maritime and environmental safety lies in enhancing the education and training of all personnel involved in the international shipping. We feel that training, in maritime academies, of ship Masters, does not insist on the appraisal of ship stability and behaviour at sea. Today the concept of the overall maritime training must fit into the new technology development.

With the implementation of automatic controls and computer devices onboard ships, nowadays Officers are relieved from repetitive calculations as found in stability calculations. Training can be defined as the systematic development of attitudes, knowledge and skills required by an individual in order to perform adequately a given tasks and jobs. Therefore whenever the tasks or job change, the training must change. Taking into account the new trend of shipboard management, there are three areas into which the training must be improved:

a) Training of Masters on ship motions and safety.

The affects of marine environment on the ship behaviour at sea are, in most institutes, absent in the training curriculum. With the inflation of ship cost and decreasing of transport freight, ship Masters must be aware of ship loss. Therefore any environment factors affecting the ship motions are needed to be learned properly. Moreover ship motions and behaviour are subordinate to the forces acting on the cargo. Training is the only means to improve shiphandling.

b) Improve the skill in Stability assessment.

The fact is that today, on the new container ships, the planning of the stowage is done ashore. The problem is that often the shore people do not have enough information about tanks and the late alterations on the disposition of weights onboard. Although computers and database management have taken the primary calculations of the stability, it is fundamental to the ship Master to clearly identify any difference between the ship's data and the computerised result. We know that every instrument has its disadvantages. The results given by computers must be evaluated by the person responsible for the load planning and detect any error which may filtrate into the data. The use of computer is a need in today's modern ship operations but the connection between shore and ship operations must be concrete to have desired results.

Furthermore, we have seen that the accuracies of much information supplied for the calculations are in most cases very bad. After completion of loading process, the ship master needs to assess accurately his ship's stability. He must receive an adapted training to perform this task. We have also seen that a powerful tool in assessing the ship stability is the In-Service Inclining Experiment. Therefore he must be trained on how to execute the experiment and be aware of its limitations.

c) Full use of shiphandling simulators.

With the advent of new ships into the shipping industry, it is difficult for every officer to know exactly the affects of marine environment on ship behaviour at sea. The least expensive means to test various conditions at sea is the use of advanced simulation techniques. Besides the cost, there are some other advantages which make simulators a powerful instrument:

- The facility for the trainee to see exactly what is happening to his ship in response to helm and engine orders and environmental forces.
- Retention of the important psychological value of

seeing and feeling the effects of incorrect ship handling manoeuvres.

- The increase of training time offered by scaling up simulator response time compared to the real ship.
- The ability to structure the exercises so that any required sequence of shiphandling tasks can be presented.
- The ability to repeat unsuccessful manoeuvres.

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ANNEX I

On the Accuracy of Ship Inclining Experiments

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1. Task

The International Maritime Organisation (IMO) has only recently (1988) pointed to the need for a high degree of accuracy for transverse stability calculations of ships and for the inclining experiment used to determine the vertical center of gravity of ships. In the worst case, large inaccuracies can more than offset the inherent safety margins of stability criteria. Therefore, the Operational Ship Inclining experiment (OSI) for ships in service is suggested to improve accuracy of stability estimates.

2. Historical Background

2.1 First Inclination Recorders

The first one known to suggest inclining experiments before ship departure was Sir Archibald *Denny (1887)*. In Germany it was planned in 1943 to test recorders for inclination of ships to be delivered at the yard and in port during ship operation. It is still revealing to read the remarks of *Horn et al. (1943)* on the difficulties to measure the ship's heel while using too long chord pendulums. Horn pointed out the dynamic drawbacks of large chord lengths of 10 m and more, which even at small vessel motion can result in disturbed pendulum motion. Horn recommended a shorter pendulum combined with paper recordings. He then described two laboratory pendulum gauges combined with mechanical recording. The chord length of the pendulum gauge designed by Techel was merely 0.8594 m, *Horn et al. (1943)*.

2.2 Wendel's Apparatus for Operational Stability Measurements in 1958

Wendel (1958) carried further the idea of OSI. He concluded that vertical moment calculations are not accurate enough for limiting states of ship stability due to insufficient knowledge of weights and centres of gravity of partial loads. He pointed out the advantage of the ship's master being able to measure the metacentric height of the vessel during loading and unloading before leaving the port.

Subsequently, Wendel's group at the Hannover and Hamburg universities, in cooperation with industry, developed an apparatus performing an automatic inclining experiment, with electro-mechanical draft measurement and pumping of water into special heeling tanks, supplemented by a mechanical analog computer for evaluation, and with a central display on the bridge, *Hebecker (1958)*.

2.3 Current Situation

Now, about 30 years later, the reasoning of *Wendel (1958)* still holds, but the OSI has not been established in common ship operation. New ship types and new ways of ship loading have sharpened the need for an experimental check of transverse stability due to the tendency, e.g. in container ships and Ro-Ro ferries, to operate close to the stability limits set by authorities.

To analyze the practical aspects of OSI, a large number of operational inclining experiments with container vessels in port have been carried out by *Kaps and Kastner (1989)*. This work was done in collaboration between the departments of Nautics and of Naval Architecture and Ocean Engineering at Bremen Polytechnic in 1987 and 1988. As a result, OSI is still held to be a very powerful tool to estimate the actual ship stability. It can be a simple and reliable procedure if a number of conditions easy to fulfil are taken into account.

OSI should and can comply with the following requirements:

1. Whole procedure to be short in time
2. No need for high technology tools
3. Reliable measurements with useful results
4. Clear and uniform directions for the procedure
5. Guidelines to cope with external disturbances and admissible limits of environmental effects
6. Inclusion of OSI into the ship loading process
7. Definition of decision structure based on the results from OSI
8. Software for correcting righting levers (GZ-curves) according to OSI results
9. Uniform documentation and evidence of OSI

In this respect, the required accuracy of the inclining gauges or recorders has been investigated.

3. Theoretical Background

According to the common formula for evaluating ship inclining experiments,

$$GM = \frac{p \cdot e}{\nabla \tan |\phi_I - \phi_{II}|} \qquad (1)$$

the following quantities must be measured in OSI:

- displacement mass ∇, generally derived from draught measurements and hydrostatic particulars
- heeling mass moment $p \cdot e$ from horizontally shifting the mass p by the distance e
- heeling angle ϕ of the ship before and after applying the heeling moment. Only measuring the heeling angle requires a special gauge.

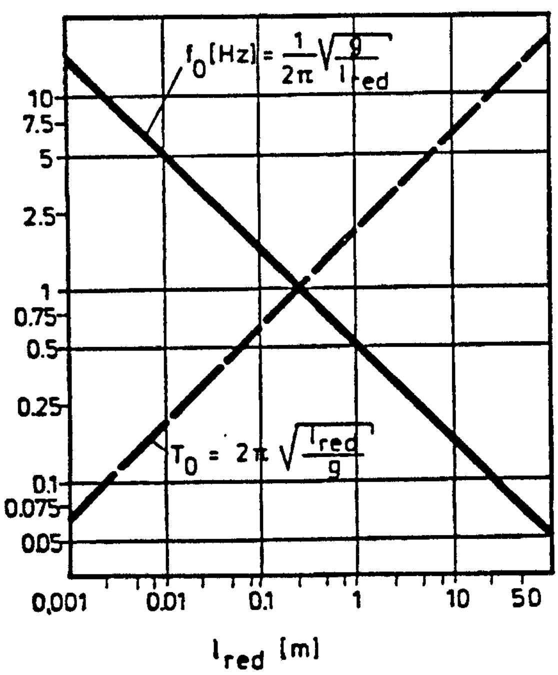

Fig. 1. Natural frequency and period versus length of pendulum

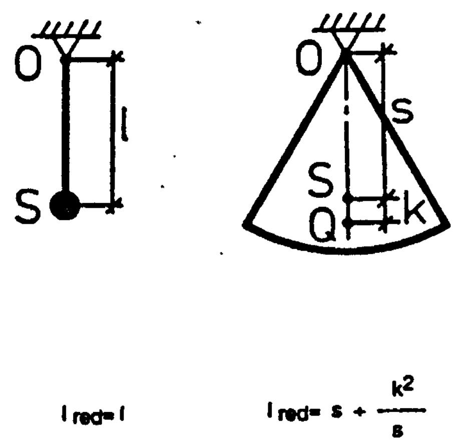

Fig. 2. Mathematical and physical pendulum

3.1 Theory of Inclining Measurements with a Pendulum

From the linear equation of motion, the squared natural frequency of a 'mathematical' pendulum (i.e. a point mass at a massless soft thread) of length ℓ follows for small deflections:

$$X_0^2 = \frac{g}{\ell} \tag{2}$$

with g = acceleration of gravity. Fig. 1 shows X_0 and the corresponding natural period $T_0 = 2\pi/X_0$ versus the pendulum length ℓ. (2) is valid for any type of pendulum if we replace the pendulum length ℓ by the so-called reduced length $\ell_{red} = s + k^2/s$ (Fig. 2), where s is the length from the pivot to the center of gravity, and k is the radius of inertia with respect to the center of gravity. A simple chord pendulum is nearly a mathematical pendulum; however, the geometrical reading length ℓ_a (Fig. 3) differs from ℓ. The natural frequency X_0 and the corresponding pendulum length ℓ_{red} govern the dynamic reaction of the pendulum due to unavoidable slight roll motions during the measurements.

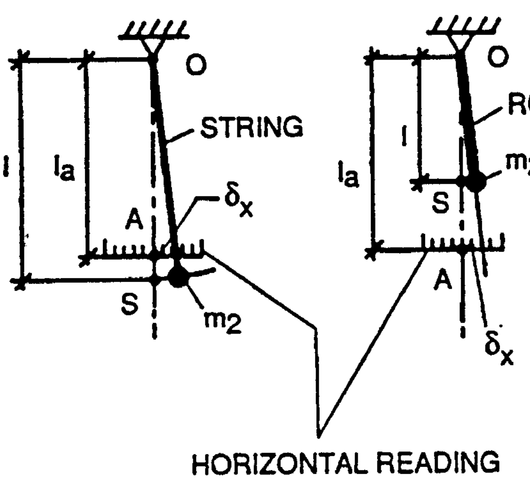

Fig. 3. Definition of lengths ℓ and ℓ_a

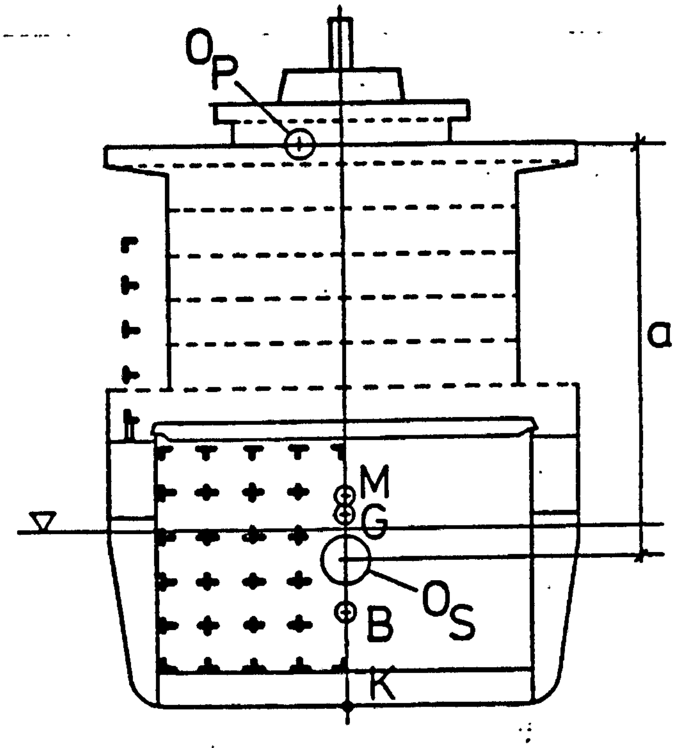

Fig. 4. Location of inclinometer aboard container vessel

3.2 Location of Pendulum Gauge Aboard

Usually it is not feasible to position the pendulum at the vessel's longitudinal axis of rotation O_s (Fig. 4) which varies with draught and loading condition. Having the gauge for the OSI right on the bridge is most convenient. At this location O_p the pendulum experiences simultaneous horizontal and vertical motions in case of ship roll motions. The mechanical system formed by the pendulum and the vessel is equivalent to a so-called double-pendulum (Fig. 5).

From the coupled differential equations of ship roll ϕ_1 and pendulum motion ϕ_p

$$\begin{aligned} a_1\ddot{\phi}_1 + a_{12}\ddot{\phi}_p + b_1\dot{\phi}_1 + c_1\phi_1 &= d_1 \\ a_2\ddot{\phi}_p + a_{12}\ddot{\phi}_1 + b_2\dot{\phi}_p + c_2\phi_p &= 0 \end{aligned} \tag{3}$$

with the harmonic solution

$$\begin{aligned} \phi_1 &= \phi_{1m} \sin(X \cdot t) \\ \phi_p &= \phi_{pm} \sin(X \cdot t + \varepsilon) \end{aligned} \quad (4)$$

the transfer function of the pendulum motion comes out as follows:
Response Amplitude Operator (RAO):

$$Y_{1p} = \frac{\phi_{pm}}{\phi_{1m}} = \frac{a_{12}X^2}{\sqrt{(c_2 - a_2X^2)^2 + b_2^2X^2}} \quad (5)$$

Phase shift:

$$\varepsilon = \arctan \frac{-b_2 \cdot X}{c_2 - a_2X^2} \quad (6)$$

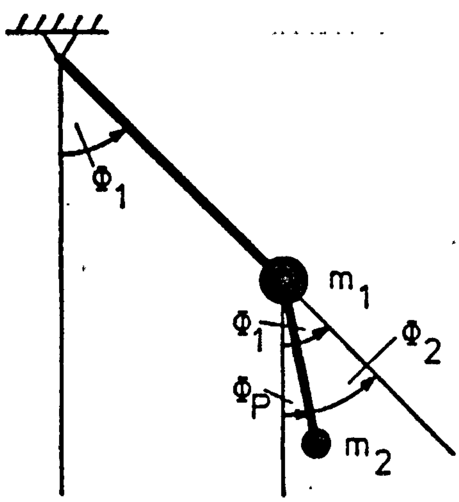

Fig. 5. Double pendulum (ship and inclinometer)

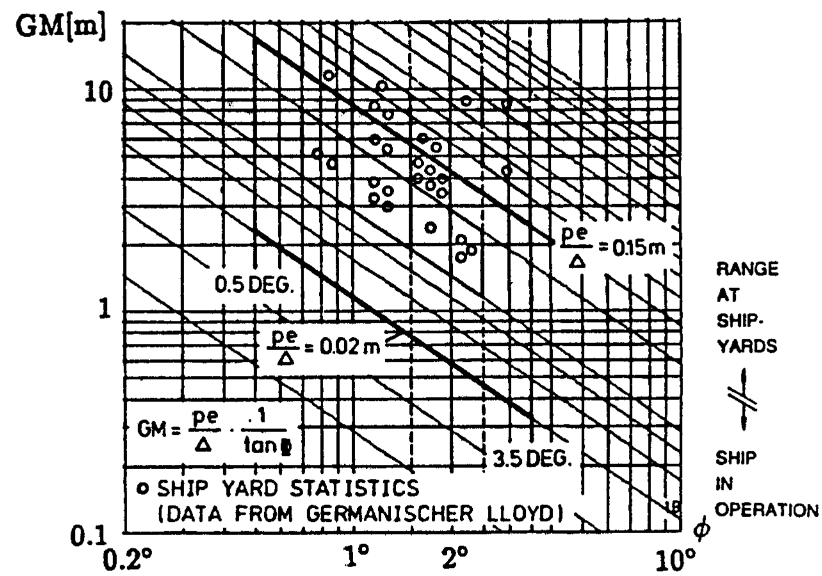

Fig. 6. Metacentric height GM versus inclining angle depending on pe/∇

The inclination of the pendulum measured with respect to the ship-borne coordinate system is (Fig. 5)

$$\phi_2 = \phi_1 - \phi_p \quad (7)$$

Thus the RAO of the measured pendulum motion with roll excitation results in

$$Y_{12} = \frac{\phi_{2m}}{\phi_{1m}} = 1 - \frac{\phi_{pm}}{\phi_{1m}} = 1 - Y_{1p} \quad (8)$$

With the particular data of a simple undamped pendulum of mass m_2 and chord length ℓ, we obtain

$$\begin{aligned} c_2 &= m_2 \cdot g \cdot \ell \\ a_2 &= m_2 \cdot \ell^2 \\ a_{12} &= m_2 \cdot a \cdot \ell \\ b_2 &= 0\,, \end{aligned} \quad (9)$$

and the RAO comes out as

$$\frac{\phi_{2m}}{\phi_{1m}} = 1 - \frac{aX^2}{g - \ell X^2} \tag{10}$$

3.3 Measuring Errors

A quantity Y is supposed to depend on values X_j as follows:

$$Y = k \cdot X_1^a \cdot X_2^b \cdot X_3^c \ldots \tag{11}$$

The quantities X_j are supposed to be measured with inaccuracies defined by relative root mean square (rms) errors

$$e_{x_j} = \frac{\text{rms error of } X_j \text{ measurement}}{X_j} \tag{12}$$

We further suppose that the rms errors are much smaller than the corresponding X_j and that the e_{x_j} are statistically independent from each other. An approximation y of Y is derived by inserting the measured values approximating X_j into (11). Then y has a relative rms error e_Y which, by the Gaussian law of error propagation, is related to the e_{x_j} by

$$e_Y^2 = a^2 e_{x_1}^2 + b^2 e_{x_2}^2 + c^2 e_{x_3}^2 + \ldots \tag{13}$$

Due to the squaring of errors, the influence of the largest error is always paramount.

Supposing that the errors are normally distributed, with a safety of 95% the true value of Y is between the limits $y(1 - 2e_Y)$ and $y(1 + 2e_Y)$.

3.4 Accuracy of Measuring the Heel Angle

According to (1), for the ship inclining experiment the application of the Gaussian error propagation formula (13) results in the following relative rms error e_{GM} of the metacentric height GM depending on the rms relative errors e_x of the measured quantities:

$$e_{GM}^2 = e_p^2 + e_e^2 + e_\nabla^2 + e_{\phi_I}^2 + e_{\phi_{II}}^2 \tag{14}$$

Assuming equal accuracy for both inclination measurements before and after applying the heeling moment,

$$e_\phi = e_{\phi_I} = e_{\phi_{II}} \tag{15}$$

the relative rms error of the angles measurement necessary to obtain a given relative accuracy e_{GM} is

$$e_\phi^2 = \frac{1}{2}\left(e_{GM}^2 - (e_p^2 + e_e^2 + e_\nabla^2)\right) \tag{16}$$

In order to analyze the impact of measuring errors of the variables p, e, ∇, GM and ϕ, numerical values for these quantities will be chosen. Thus, we do not test statistically which errors actually exist, but we look for the impact of measuring errors in order to know the required accuracy at ship inclining to get reliable results for the actual stability status of the vessel.

Fig. 6 shows the heeling angle ϕ versus GM according to (1) in double-logarithmic plotting, with different numerical values for the combined parameter pe/∇. Data evaluated by Germanischer Lloyd on Ship Yard Inclining experiments (SYI) from 1976 through 1987 have been depicted by circles.

In general, OSI is performed with smaller GM-values, i.e. in the lower range of circles in Fig. 6. For pe/∇ a value of 0.15m is representative for the SYI, and a value of 0.02m for the OSI.

A relative total error of 0.5% for the factor pe/∇ can be reached at OSI reasonably well:

$$e_{pe/\nabla} = \sqrt{e_p^2 + e_e^2 + e_\nabla^2} = \sqrt{0.002^2 + 0.002^2 + 0.004^2} = 0.5\% \tag{17}$$

With this in mind, it is sufficient to look solely at the error relationship of angle ϕ with metacentric height GM. For a heeling angle between 0.5° and 3.5° (current German regulations ask for a heel at ship inclining between 1.0° and 3.5°), we calculate from (14) and (17) that, with a statistical safety of 95%, the measured GM is within the range of

0.086m ... 0.114m for a true GM equal to 0.10m,

2.36 m ... 2.64 m for a true GM equal to 2.50m.

This result is based on the assumption that, with 95% safety, the accuracy of the angular reading is within ±0.02° (i.e. that the rms error is 0.01°). It complies with the common conception that for larger GM values larger errors are permissible for OSI.

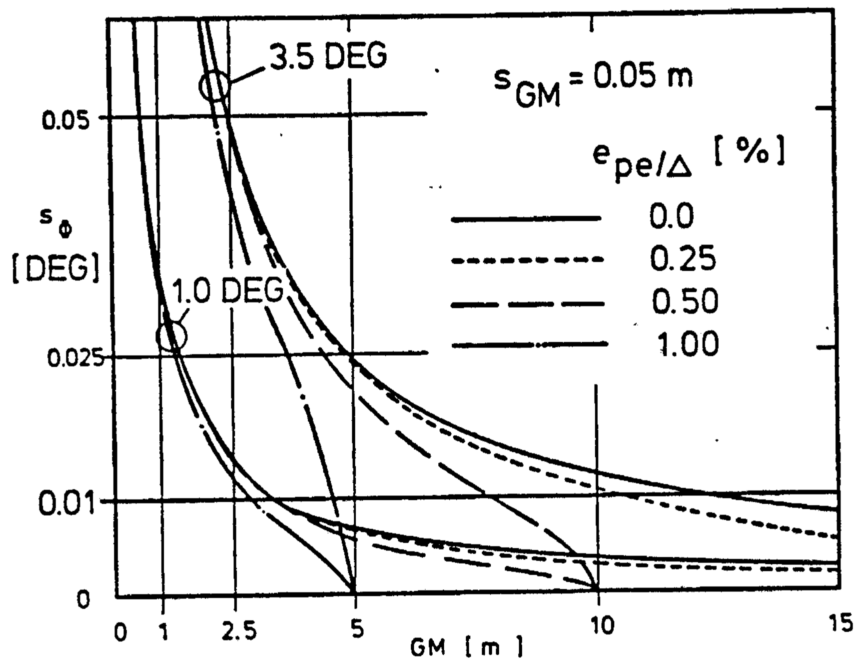

Fig. 7. Allowable error of angle measurement at ship inclining experiment

3.5 Accuracy of Angle Measurement for Ship Yard Inclining Experiments

Fig. 7 shows the permissible rms error s_ϕ of the angle measurement versus GM for different relative errors $e_{pe/\nabla}$ according to the following equation derived from (12) and (16):

$$s_{\phi_{perm}} = \phi e_{\phi_{perm}} = \phi\sqrt{0.5(e_{GM}^2 - e_{pe/\nabla}^2)} \tag{18}$$

The permissible angle error decreases as GM increases.

Fig. 7 is based on a constant permissible rms error of the GM estimate $s_{GM} = 0.05$m independent of GM. This is a reasonable requirement for SYI, as the resulting GM forms the basis for calculating GZ-curves for any other loading condition. The figure shows that for small GM-values it is easier to cope with the required accuracy of angle measurement. For a large GM of e.g. 10m and with an rms error of angle measurements of 0.01°, the combined standard deviation of the errors for p, e and ∇ may not be larger than 0.25% if the heel is at the upper limit of 3.5°. The required accuracy of 0.01° can be accomplished by using a relatively short pendulum of e.g. 1.146m. For $GM < about 2.5m$, an angle rms error of 0.01° is always sufficient, even with heeling angles < 1°, and with a 1% rms error for pe/∇.

For a quick estimate of the maximum permissible error in the angle measurement, we may use the limit curves (full lines in Fig. 7) resulting from the assumption of $e_{pe/\nabla} = 0$, i.e. no error in heeling moment and displacement measurements. These curves follow from (18):

$$s_{\phi_{max}} = \phi \cdot e_{\phi_{max}} = \phi \cdot e_{GM}/1.414 \qquad (19)$$

With small rms error $e_{pe/\nabla}$, i.e. with accurate heeling moment and displacement measurements, we come close to the limiting angle accuracy $s_{\phi\, max}$. According to (18) the permissible error in angle measurements can be improved, i. e. increased, by increasing ϕ, by increasing the permissible error e_{GM}, and by decreasing the combined error $e_{pe/\nabla}$.

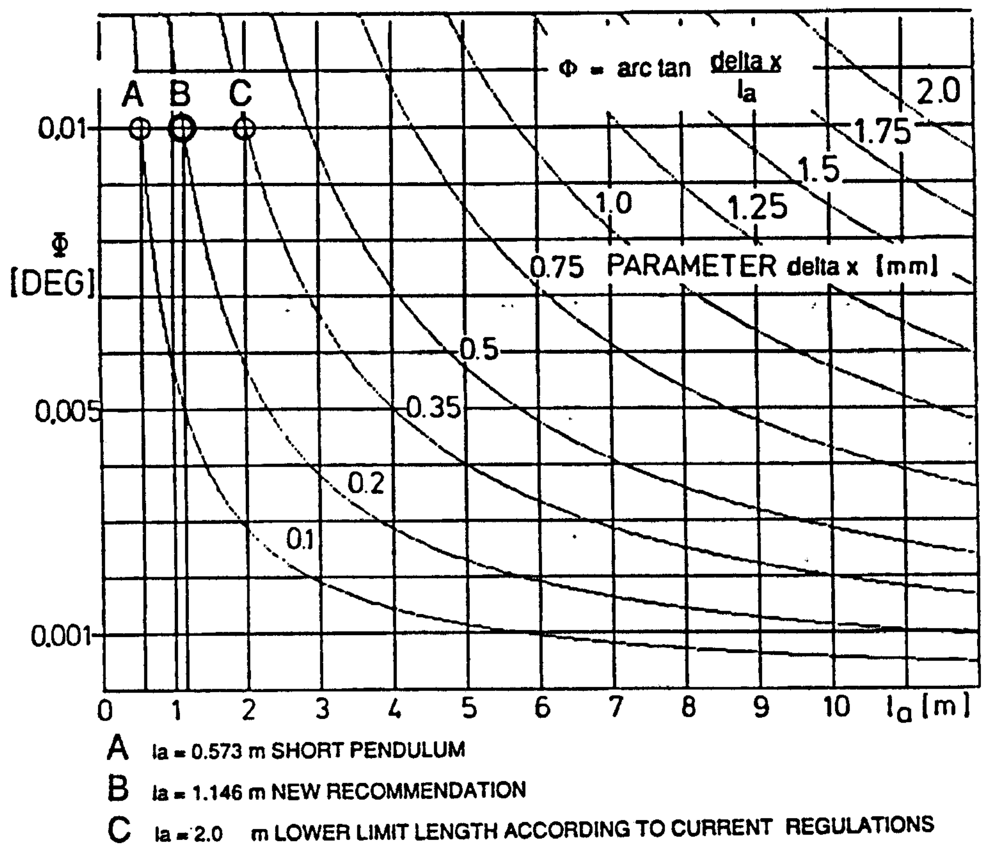

Fig. 8. Geometric resolution of simple chord pendulum

3.6 Practical Length of Pendulum

The pendulum length is governed by 3 conditions:

- Sufficient pendulum deflection at heel to realize the required reading accuracy
- Minimum alteration of heel angle measurement by dynamic effects
- Practical operational conditions aboard the vessel

Fig. 8 shows the accuracy of angle measurements with a string or chord pendulum as a function of the accuracy of deflection measurements δx and of pendulum reading length ℓ_a defined in Fig. 3. The chord length of 1.146m (according to a proposal by *Kaps and Kastner (1989)* because this leads to the ratio x/ϕ = 20mm/°) results in a deflection reading accuracy of 0.2mm in order to reach an angle resolution of 0.01°. With careful reading, this accuracy can be assumed to be the rms error.

With respect to geometric resolution, we must choose the pendulum length as large as necessary. However, the length should not be increased further because the dynamic response of the pendulum to ship motions will affect the reading more the longer the pendulum is. Fig. 9 depicts the transfer function of a pendulum suspended 10m above the roll centre of the vessel for different lengths of the pendulum according to (10), i.e. without damping. With increasing pendulum length the resonance frequency decreases, leading to a larger *RAO* due to the vicinity of resonance and thus more disturbance of angle readings due to ship motions even at very small motion frequencies.

Thus, a short pendulum such as that of the proposed length of 1.146m is not only very useful for OSI, but can serve well also for SYI. This shorter length improves the dynamic behaviour of the pendulum, while the geometric accuracy is still sufficient.

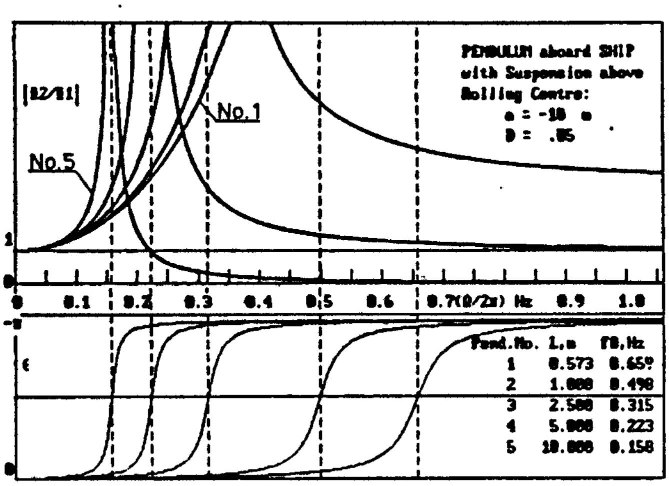

Fig. 9. Calculated transfer function for different length of pendulum

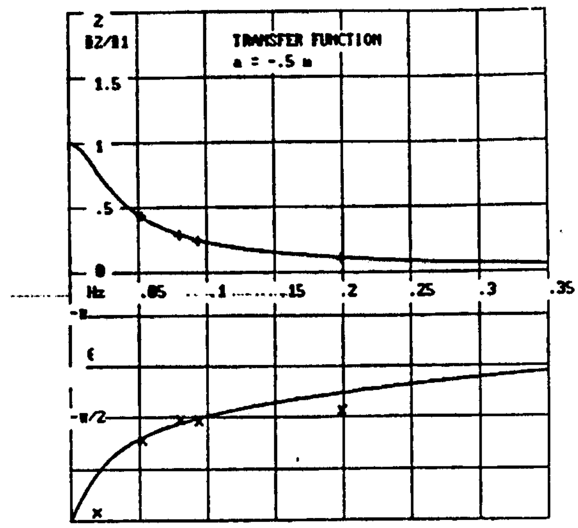

Fig. 10. Measured and calculated roll transfer function of inclinometer (example)

4. Laboratory Testing of Gauges for Angle Measurement

4.1 Static Test Bench

In the Bremen Ship Hydromechanic Laboratory a static test bench has been set up in order to measure the accuracy of different angular gauges and recorders. The resolution of this static inclination table is at least 10^{-3} degree, i.e. a factor 10 more accurate than the required gauge resolution.

4.2 Rotary Swing-Table for Dynamic Testing of Gauges

In order to test the dynamic response of inclination gauges, a special swing-table has been developed in our laboratory. The gauge is fastened to the table, which performs a forced roll motion. This sinusoidal motion is controlled electronically. By a mechanical gear, it covers the low frequency range from 0.05Hz to 1Hz. The roll amplitude can be chosen up to 30°. The suspension point of the gauge at the swing-table can be varied from +0.5m to −0.5m. Measured *RAO* and phase shift have been compared with the theoretical result according to (5), (6) and (8). Fig. 10 shows an example.

The purpose of the static and dynamic testing procedures is to allow an objective valuation of different gauges to measure ship inclination. A standard testing procedure in the laboratory has been developed, and different inclining recorders of the market have been tested.

5. Inclination Recording

For general studies aboard container vessels, in addition to the chord pendulum, an electronic inclination pick-up together with a common analog yt-recorder has been used. This was to prove the whole test process with heel deviations and superimposed roll motions. In addition, a small light-weight data processor has been developed to allow digital storage and quick numerical evaluation. This is of advantage with respect to a frequency analysis of the superimposed roll in order to establish the source and magnitude of any disturbance.

6. Conclusions

Our test experience leads to the following conclusions:

- A simple pendulum of 1.146m reading length is completely sufficient for the operational ship inclining experiment (OSI).
- If electronic equipment is used to support OSI, time recording of the inclination for clear evidence is recommended.
- The measured data from ship inclining should be used for loading and stability calculations on ship-borne data processors .
- OSI improves the accuracy of practical stability estimates.

A relatively short pendulum has the advantage to be less sensitive to dynamic disturbances by ship motions. Therefore, the pendulum length should not be larger than necessary with respect to the required static resolution.

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ANNEX II

ANNEX

DRAFT CODE OF INTACT STABILITY FOR ALL TYPES OF SHIPS COVERED BY IMO INSTRUMENTS

THE ASSEMBLY,

RECALLING Article 15(j) of the Convention on the International Maritime Organization concerning the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

RECOGNIZING the need for the development of an internationally agreed code of intact stability for all types of ships covered by IMO instruments, which would summarize the work carried out by the Organization so far,

HAVING CONSIDERED the recommendation made by the Maritime Safety Committee at its fifty-fourth session,

1. ADOPTS the Code of Intact Stability for All Types of Ships Covered by IMO Instruments, the text of which is contained in the annex to this resolution, and which supersedes the following recommendations:

(a) Recommendation on intact stability for passenger and cargo ships under 100 metres in length (resolution A.167(ES.IV));

(b) Amendments to the recommendation on intact stability for passenger and cargo ships under 100 metres in length (resolution A.167(ES.IV)) with respect to ships carrying deck cargoes (resolution A.206(VII));

(c) Recommendation on intact stability of fishing vessels (resolution A.168(ES.IV));

(d) Recommendation on a severe wind and rolling criterion (weather criterion) for the intact stability of passenger and cargo ships of 24 metres in length and over (resolution A.562(14));

2. INVITES all Governments concerned to take steps to give effect to the recommendatory provisions of the Code with regard to their design, management and operational aspects as a minimum basis for standards of safety, unless their national stability requirements ensure higher levels of safety;

3. RECOMMENDS Governments concerned to ensure that inclining tests are conducted in accordance with the guidelines specified in the Annex to this resolution;

4. AUTHORIZES the Maritime Safety Committee to amend the Code as necessary in the light of further studies and experience gained from the provisions contained therein.

ANNEX

CODE OF INTACT STABILITY FOR ALL TYPES OF SHIPS COVERED BY IMO INSTRUMENTS

CONTENTS

PREAMBLE

1 This Code, assembled on the basis of existing IMO instruments, has been developed to provide an international standard for intact stability for all ships of 24 m in length and above unless otherwise specified. [Its application will facilitate design and operation of ships and result in a satisfactory level of safety for personnel on board, as required for all ships engaged on international voyages.]

2 Criteria included in the Code are based on the best "state of art" concepts taking into account sound design and engineering principles and experience gained from operating such ships. Furthermore, design technology for modern ships is rapidly evolving and the Code should not remain static but be re-evaluated and revised, as necessary. To this end, the Organization will periodically review the Code taking into consideration both experience and further development.

3 Throughout the development of the Code it was recognized that in view of a wide variety of types, sizes of ships and their operating and environmental conditions, problems of safety against accidents related to stability have generally not yet been solved. In particular, the safety of a ship in a seaway involves complex hydrodynamic phenomena which up to now have not been adequately investigated and understood. Ships in a seaway should be treated as a dynamical system and relationships between ship and environment conditions like wave and wind excitations are recognized as extremely important elements. It is recognized that development of stability criteria, based on hydrodynamic aspects and stability analysis of a ship in a seaway, poses, at present, complex problems which require further research.

[4 The Code is not intended to prohibit the use of an existing ship simply because its design does not conform to the requirements contained herein. Many existing ships have operated successfully and safely for extended periods of time and their operating history should be considered in evaluating their suitability to conduct international operations.]

5 The Code is a recommendatory, non-mandatory document which includes intact stability requirements contained in existing IMO instruments. However, some of the requirements included in the Code have been extracted from mandatory IMO instruments and these are identified with an asterisk.

CODE OF INTACT STABILITY FOR ALL SHIPS

CHAPTER 1 - GENERAL

1.1 Purpose

The purpose of the Code of Intact Stability for All Ships, hereinafter referred to as the Code, is to recommend stability criteria and other measures for ensuring the safe operation of all ships to minimize the risk to such ships, to the personnel on board and to the environment.

1.2 Application

1.2.1 This Code contains intact stability criteria for the following types of ships and other marine vehicles of 24 m in length and above unless otherwise stated:

- cargo ships
- cargo ships carrying timber deck cargo
- cargo ships carrying grain in bulk
- passenger ships
- fishing vessels
- special purpose ships
- offshore supply vessels
- mobile offshore drilling units
- pontoons
- dynamically supported craft
- [container ships]
- [open-top container ships]

1.2.2 The coastal State may impose additional requirements regarding the design aspects of vessels of novel design or vessels not otherwise covered by the Code.

1.3 Definitions

For the purpose of this Code the definitions given hereunder apply. For terms used, but not defined in this Code, the definitions as given in the 1974 SOLAS Convention apply.

1.3.1 Administration means the Government of the State whose flag the ship is entitled to fly.

1.3.2 A passenger ship is a ship which carries more than twelve passengers as defined in regulation 2 of the 1974 SOLAS Convention, as amended.

1.3.3 A cargo ship is any ship which is not a passenger ship.

1.3.4 A fishing vessel is a vessel used for catching fish, whales, seals, walrus or other living resources of the sea.

1.3.5 A special purpose ship means a mechanically self-propelled ship which, by reason of its function, carries on board more than 12 special personnel as defined in paragraph 1.3.3 of the IMO Code of Safety for Special Purpose Ships (resolution A.534(13)), including passengers (ships engaged in research, expeditions and survey; ships for training of marine personnel; whale and fish factory ships not engaged in catching; ships processing other living resources) of the sea, not engaged in catching or other ships with design features and modes of operation similar to ships mentioned above which, in the opinion of the Administration may be referred to this group).

1.3.6 An offshore supply vessel means a vessel which is engaged primarily in the transport of stores, materials and equipment to offshore installations and designed with accommodation and bridge erections in the forward part of the vessel and an exposed cargo deck in the after part for the handling of cargo at sea.

1.3.7 A mobile offshore drilling unit (MODU) or unit is a vessel capable of engaging in drilling operations for the exploration or exploitation of resources beneath the sea-bed such as liquid or gaseous hydrocarbons, sulphur or salt:

.1 a column-stabilized unit is a unit with the main deck connected to the underwater hull or footings by columns or caissons;

.2 a surface unit is a unit with a ship or barge-type displacement hull of single or multiple hull construction intended for operation in the floating condition;

.3 a self-elevating unit is a unit with moveable legs capable of raising its hull above the surface of the sea.

1.3.8 A dynamically supported craft (DSC) is a craft which is operable on or above water and which has characteristics so different from those of conventional displacement ships, to which the existing international conventions, particularly SOLAS and Load Line, apply, that alternative measures should be used in order to achieve an equivalent level of safety. Within the aforementioned generality, a craft which complies with either of the following characteristics would be considered a DSC:

.1 if the weight, or a significant part thereof, is balanced in one mode of operation by other than hydrostatic forces;

.2 if the craft is able to operate at speeds such that the Froude number is equal to or greater than 0.9.

1.3.9 An air-cushion vehicle is a craft such that the whole or a significant part of its weight can be supported, whether at rest or in motion, by a continuously generated cushion of air dependent for its effectiveness on the proximity of the surface over which the craft operates.

1.3.10 A hydrofoil boat is a craft which is supported above the water surface in normal operating conditions by hydrodynamic forces generated on foils.

1.3.11 A side wall craft is an air-cushion vehicle whose walls extending along the sides are permanently immersed hard structures.

1.3.12 Container ship means a ship which is used primarily for the transport of marine containers.

1.3.13 An open-top container ship [definition to be developed]

[1.4 Exemptions

The Code is not intended to prohibit the use of an existing ship simply because its design does not conform to the requirements of this Code. Any such vessel, however, should comply with safety requirements which, in the opinion of the Administration, are adequate for the service intended and are such as to ensure overall safety of the vessel. The Administration which allows any such exemption should list such exemption on the letter of compliance and communicate to the Organization the particulars, together with the reasons thereof, so that the Organization may circulate the same to other Governments for the information of their officers.]

[1.5 Equivalents

1.5.1 Where the Code requires that a particular procedure or arrangement should be complied with, the Administration may allow any other procedure or arrangement to be made in that vessel, if it is satisfied by trial thereof or otherwise that such procedure or arrangement is at least as effective as that required by the Code.

1.5.2 When an Administration so allows and procedure, arrangement, novel design or application to be substituted hereafter, it should communicate to the Organization the particulars thereof, together with a report on the evidence submitted, so that the Organization may circulate the same to other Governments for the information of their officers.]

[1.6 Letter of compliance

Any ship which complies with the provisions of the Code should be considered eligible for issuance of a letter of compliance in accordance with this Code.]

ANNEX III

Module 7 - Ship Construction, Stability and Damage Control

Part B - Subject Outline

Subject area		Hours Lecture	Hours exercises
1	Ship Construction		
1.1	Shipbuilding materials	3	1
1.2	Welding	4	2
1.3	Bulkheads	3	1
1.4	Watertight and weathertight doors	3	2
1.5	Corrosion and its prevention	5	2
1.6	Surveys and dry-docking	3	2
		21	10
2	Stability		
2.1	Approximate calculation of areas and volumes	5	5
2.2	Effects of density	2	1
2.3	Calculation of free surface effect	3	2
2.4	Stability at moderate and large angles of heel	4	2
2.5	Simplified stability data	2	2
2.6	Trim and list	6	4
2.7	Dynamical stability	4	3
2.8	Approximate GM by means of rolling period tests	1	1
2.9	Inclining test	2	1
2.10	Recommendation on intact stability for passenger and cargo ships under 100 metres in length	3	1
2.11	Intact stability requirements for the carriage of grain	3	3
2.12	Rolling of ships	3	1
2.13	Dry-docking and grounding	3	2
2.14	Shear force, bending moments and torsional stress	8	6
		49	34
3	Damage Control		
3.1	Flooding of compartments	3	1
3.2	Effect of flooding on transverse stability	5	4
3.3	Effect of flooding on trim	6	4
		14	9
	Subtotals	84	53
	Total	137	

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