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REPORT ON THE PROBLEMS OF THE STABILITY REQUIRED BY FISHING VESSELS

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NOMENCLATURE AND SYMBOLS

A = Lateral area of ship's profile, including erections, exposed to wind
AP = Aft perpendicular
B = Breadth or centre of buoyancy
B_l = Longitudinal centre of buoyancy, also LCB
BG = Height, centre of gravity above centre of buoyancy
BM_o = Height, metacentre above centre of buoyancy in the upright condition
C_b = Block coefficient, also δ
C_p = Prismatic coefficient, also φ
C_w = Waterplane area coefficient, also α
CB = Centre of buoyancy
CG = Centre of gravity
D = Depth
d = Draught, also T; distance between centre of wind pressure and centre of water pressure
d_W = Distance from centre of wind pressure of A to the surface of the water
d_A = Distance from centre of gravity of A to the surface of the water
$d_{T/2}$ = Distance between centre of gravity of A and a point at half of T
FP = Forward perpendicular
f = Freeboard
G = Centre of gravity
G_l = Longitudinal centre of gravity, also LCG
GM = Height, metacentric
GM_o = Height, metacentric in the upright condition
GZ = Stability lever
GZ_h = Heeling lever
GZ_r = Righting lever
GZ_s = Righting lever at φ_s
GZ_w = Heeling lever due to statical wind pressure
g = Acceleration due to gravity
I = Moment of inertia
IHP = Indicated horsepower
K = Keel, at midshipsection
KB = Height, centre of buoyancy above keel
KG = Height, centre of gravity above keel
KG_o = Maximum height of centre of gravity above keel for operational conditions
KG_s = Maximum height of centre of gravity above keel for stability criteria

KM_o = Height, metacentric above keel, upright condition
k = Radius of gyration
LBP = Length between perpendiculars
LCB = Longitudinal centre of buoyancy
LCG = Longitudinal centre of gravity
LOA = Length overall
l = vertical distance of the point of attack of the trawl warps or towing hook above G
M_{caps} = Maximum dynamical heeling moment a vessel can withstand either taking φ_o into consideration or not
M_h = Heeling moment (m. t.)
M_o = Metacentre in the upright position
M_{To} = Dynamical heeling moment due to towing (m. t.)
M_w = Wind pressure moment (m. t.)
$M\varphi$ = Metacentre at an angle of heel φ
$N\varphi$ = Intersection of line of action of buoyancy and centreline at an angle of heel φ
P = Trawl pull
P_b = Bollard pull
$P_{1,2,3}$ = Specific wind pressure (Kg. /m^2)
T = Draught, also d
T_a = Draught at aft perpendicular
T_f = Draught at forward perpendicular
T_l = Draught, loaded
T_o = Draught, light
T_r = Period of roll (go and back)
Δ = Displacement, weight in metric tons; small increment
ξ_w = Wind pressure coefficient (about 1.2-1.3)
ρ_a = Density of air (0.125 Kg. sec^2/m.^{4})
φ = Angle of heel
φ_{caps} = Angle at which M_{caps} acts
φ_e = Angle of heel at which the water can enter into the vessel
φ_o = Angle of roll
φ_r = Range of angles of heel giving positive righting levers
φ_s = Angle of heel of maximum righting lever

φ_w = Angle of heel due to steady wind

Introductory remarks

Safety at sea in general is dealt with by the Intergovernmental Maritime Consultative Organization (IMCO). This Organization acted as the Secretariat for the 1960 Conference for the International Convention for the Safety of Life at Sea; however, in principle, the subjects of the Convention are cargo ships of 500 G. T. and over and passenger ships which are engaged in the international voyage; and it was decided not to include fishing vessels in the Convention for the time being. Although a number of the internationally accepted safety regulations for ships of over 500 GT are applied by several countries also to ships of less than 500 GT and to fishing vessels, no type of government supervision on safety requirements exists for fishing vessels in many other countries.

Because ships of less than 100 GT are not included in the statistical tables of Lloyd's Register of Shipping, it is difficult to gain sufficient information on the extent of casualties to fishing vessels. However, Takagi (1960) has given an indication: the average percentage of total losses in Japan over the period 1950-55 was 1.79, the ships of the 5-50 GT class being considerably above that average. From further information provided by Takagi it can be gathered that a very important part of these losses is accounted for by stability casualties.

Stability is closely associated with seakindliness. As a result of this, the stability properties of fishing vessels determine to a high degree whether and how long fishing can be continued in worsening weather conditions. In the search for stability criteria for fishing vessels, account must be taken of the widely differing ways in which fishing is being practiced.

It should here be remarked that an excess of stability will result in the ship becoming "stiff" and in motions being so violent that working on deck is hampered so that fishing must be prematurely stopped.

The stability of fishing vessels must be sufficient for all conditions of loading. Attention is drawn in particular to the deck loads which are formed when a catch is so big that all of it cannot be stowed away in the hold. It is even more dangerous when, on ships operating with a factory ship, the catch is transferred from the hold to the deck during the time the fishing vessel is sailing to the factory ship, to cut down on discharging time.

Many skippers, mates, and crews of fishing vessels lack sufficient insight into the stability of their ships. Generally speaking, the training of crews of fishing vessels is not such as to enable them to make special calculations concerning the loading conditions in order to judge whether stability is adequate. This state of affairs is to be regretted; the skipper of a fishing vessel is nevertheless responsible. So long as these training conditions prevail, the designer or the safety control service will be inclined to include the chance of unforeseen circumstances due to injudicious loading in an excess of stability.

In order to judge whether stability is sufficient under all circumstances, a number of loading conditions will have to be studied - those which are more or less schematical but based on practical experience. We must take into account the differences in the type of vessel and working methods; intermediate loading conditions must not then be less favourable. Stability so computed will have to be compared with certain standards.

The stability should be such that (a) the safety of the ship and its crew is guaranteed; and (b) the ship will be able to continue fishing as long as possible. These two factors must be taken into account when establishing standards by which stability can be judged.

The standards by which stability is measured are twofold. Firstly there is the use of the metacentric height in the upright condition (GM_o). The general opinion is that this yardstick is inadequate to give sufficient insight into the amount of stability. The value GM_o provides only an indication of the initial stability. In cases where enough stability data of identical ships are available, GM_o can be used to check whether another ship is within the known limits, so that further stability data are not required.

Secondly, stability is judged with the aid of the curve of righting levers. This curve gives for the angles of heel φ the value of the righting levers GZ. The characteristic points on this curve are φs; the value of GZ at this angle and φr. The curve itself provides a statistical picture of the stability. Stability at sea is mostly a question of dynamics in consequence of seaway and wind. In order to deal with stability dynamically, use is made of the first integral of the curve of righting levers, showing the amount of work that must be done to give the ship an angle of heel φ.

Rolling experiments

For $\varphi < 3^\circ$ the metacentre M_o can be taken as constant. At larger angles M_o moves along the evolute to $M\varphi$ and is no longer situated on the centreline of the ship.

For two centuries the point M_o has been the point around which all treatises on stability revolve. It can be defined as the limit which must never be exceeded by the centre of gravity G (Bouguer, 1746). Although this definition does not always hold good, or need not hold good for the bigger types of ships - particularly passenger ships - it is evident from this definition that the distance between the metacentre and the centre of gravity is a yardstick for the judgment of the initial stability and the comparison of the stability of identical ships.

If the ship is considered as a pendulum, there proves to be a close relationship between the time taken by a ship to roll from one side to the other and back again, and the moment of inertia of the ship and the water moving along with it. This relationship can be expressed as follows:

$$GM = \left(\frac{2.\pi.K}{\sqrt{g}.T_r}\right)^2$$

In the foot system this can be written as follows (Traung, 1957)

$$GM = \left(\frac{1.108m.B}{T_r}\right)^2$$

the factor 1.108 sometimes being included in the m-coefficient.

Traung quotes the following values of m:

Hovgaard	- 0.44 incl.	1.108;	m = 0.398
Nickum	- 0.40 "	1.108;	m = 0.361

(75 percent of all cases lie between 0.348 and 0.370 and the remainder vary between 0.335 and 0.389.)

Möckel (1955) m = 0.40 for trawlers (departure)
m = 0.385 " " (arrival)

Takagi (1960) gives the m-values of Japanese ships:

for steel ships m = 0.39 to 0.45;
and for wooden ships m = 0.44 to 0.51

In the metric system $\frac{2\pi}{\sqrt{g}} = 2$ can be taken, so that

$$GM = \left(\frac{2.m.B}{T_r}\right)^2$$

In the metric system the factor 2 is also often included in m. So, Weiss (1953) writes the formula

$$GM = \left(\frac{k.B}{T_r}\right)^2$$

in which k = 0.71 - 0.83, average 0.76.

As regards the practical performance of the rolling experiment, attention should be drawn to Weiss's (1953) experience with ships (including fishing vessels) which during the period 1940 to 1945 had to be used as naval auxiliaries and for which extensive stability calculations were impossible, even although some sort of insight in these matters was necessary. This insight was gained by making use of the rolling experiment. Weiss notes:

(a) free surfaces of liquids were left out of consideration (completely or half filled tank ships are unsuitable for a rolling experiment);

(b) with ships having very round sections a higher initial stability was aimed at generally than with ships having straight frames;

(c) the large amount of material collected during all these rolling experiments showed that there is a relationship between the coefficient k and the waterline coefficient C_W. Moreover, it turned out that, purely accidentally, the value of k could be taken as being equal to C_W. For the time being, this proved possible only for naval auxiliaries and the conditions of loading in these cases.

If a reliable value of k is to be obtained, it will be necessary to collect data systematically and to study these in their relationship to α, δ, T/B ratio, BG, etc. In addition, it is strongly advised that a rolling experiment be performed at every inclining experiment for the calculation of GM, so as to find the value of k from the period of roll and calculated GM.

An initial insight into the stability of a ship can be gained from the rolling experiment; particularly in the case of small or very small ships it is often unknown what exactly the displacement is and where the points B, G and M_o are situated. None of these data are required for the calculation of GM by means of a rolling experiment.

Inclining experiment

The object of an inclining experiment is to give the ship a slight list by shifting a known weight (p) a known distance (e) across the deck. The angle of heel is determined by measuring the deflection of a pendulum having a known length. Deflection divided by length of pendulum gives tan φ.

$$p \cdot e = \Delta \, GM_o \cdot \tan\varphi \qquad \text{or} \qquad GM_o = \frac{p \cdot e}{\Delta \cdot \tan\varphi}$$

The values of KB and BM_o are found from the hydrostatic curves

$$KG = KB + BM_o - GM_o$$

The position of the centre of gravity (KG) is found with the help of the hydrostatic curves and the inclining experiment. The value so found is also used to find the position of the centre of gravity for various loading conditions of importance to the stability. The yardstick KG is exceedingly important and has substantial influence on the initial stability as a result of:

$$GM_o = KB + BM_o - KG$$

KG may vary strongly for different types of vessels. For purposes of comparison KG is usually expressed as a percentage of D.

Recent changes in the general arrangement and propulsion machinery cause a tendency for the KG of many types of fishing vessels to increase and to thus affect stability adversely. These changes are:

(a) less weighty propulsion machinery (Diesel engines instead of steam boilers and steam engines; high-speed Diesel engines instead of slow-running Diesel engines);

(b) increased crew's quarters and accommodation above deck and therefore a larger superstructure;

(c) more nautical equipment.

In view of the tendancy for KG to increase, it is important to collect accurate information about this value. We must be prepared for timely action to keep KG within certain limits. Takagi (1960) points out that KG/D for the light condition exceeds 0.8, and that in other vessels KG/D exceeds 0.8 even in the loaded condition. Because the position of the centre of gravity must be fixed as accurately as possible the inclining experiment too must be carried out as accurately as possible.

There are many factors which cause the accuracy to be reduced. During the inclining experiment φ must not exceed the very low value of 2 degrees. Measurement of the angle of heel φ must be accurate. Incorrect measuring gives rise to unreliable values for GM_o.

For various reasons the pendulum which is used for measuring the angle of heel may be very restless. Even if the only persons on board are those making the experiment and if they repeatedly take up their original positions in the course of recording the angle of heel, a slight movement in the water in which the ship floats, or a little wind, may cause the pendulum to have an oscillation amounting to 30 percent of the deflection. Motion is slowed down by fitting the pendulum weight with fins, and suspending it in water. In spite of this, variations in the results continue to exist.

It is often difficult to fill oil and water tanks completely. As the last air cannot always escape along the tank top when the tanks are being filled, there often remains, even when the tanks are full, a small air cushion which is sufficient to create a free surface of liquid. This influence, too, is noticeable in the movements of the pendulum. Much practice is required to find a reliable deflection from a constantly - and often irregularly moving - pendulum under the conditions often prevailing aboard smaller ships.

In order to eliminate the human element as much as possible, two or three pendulums can be used, while the deflections are recorded by two or three persons and, if necessary, the results averaged. Another method is that by which the deflections are recorded on a strip of paper. The long pendulum is replaced by a self-recording measuring instrument. Well-known in this respect are Techel's pendulum, the Stabilograph; the Naviclin has also begun to be used for this purpose. All this equipment records the movements of the pendulum at different deflections, and from this information a highly accurate average can be computed in the office (Fig. 1).

As the value of GM_o is valid only for the ship in the upright condition and as the point M moves along the evolute of the metacentre even at small angles, the intersection of the vertical line through $B\varphi$ and the centreline of the ship is the point $N\varphi$

$$GZ = N\varphi G \sin\varphi > GM_o \cdot \sin\varphi$$

This is also true if the inclining experiment is performed when the ship is not altogether upright. Seyderhelm (1939) has developed a method for finding the most reliable value of GM_o from the deflections measured which is possible:

$$GZ = N\varphi G \sin\varphi$$

For the inclining experiment: Moment of stability = Moment of heel. So,

$$\Delta . GZ = p. e. \cos\varphi$$

$$\Delta . N\varphi G \sin\varphi = p. e. \cos\varphi$$

$$N\varphi G = \frac{p . e}{\Delta . \tan\varphi}$$

This expression is more correct than the formula for very small angles given at the beginning of the present paragraph: $N\varphi G$ can be found at the respective angles of heel by measuring the angle of heel at the various instants of heel. When the values so found are set out as in Fig. 2, GM_o for the upright condition clearly results. This method gives an accurate value of GM_o also at a slight list.

Hydrostatic curves

When the value of the initial stability GM_o and the position of G has been found from the inclining experiment, this information is applicable to one condition of loading only which is usually not even the condition in which the ship goes to sea. To ascertain the stability, the GM_o for a number of conditions of loading must be found.

The characteristic conditions taken are as a rule: departure, arrival at and departure from the fishing grounds, and arrival back in the home port. Whether these four conditions are actually required depends to a large extent on the type of vessel. For instance four are likely to be required for trawlers which have to steam for days to reach the fishing grounds, whereas for ships making short trips one or two conditions of loading are sufficient, according to the general arrangement of the vessel (principally the location and form of the fuel tanks).

Nevertheless, for different conditions of loading, large differences in trim have to be anticipated. These differences are such that it is incorrect to consider that having hydrostatic curves for the vessel being on an even keel or parallel immersion at constant trim is sufficient. For each separate condition of loading, and starting from the condition at the inclining experiment, it is necessary to find the position of LCG with the aid of the consumed quantities of fuel and stores, of melting ice and fish caught.

This calculation, therefore, provides the weight of the ship plus cargo (Δ) and the position of LCG, and consequently of LCB. The hydrostatic curves must therefore be arranged so that not only the trim, but also KM_o can be found with the aid of Δ and LCB. The GM_o for every desired condition of loading can be calculated with the KM_o from the hydrostatic curves and the KG. In the Netherlands the method developed by Pommer (1952) is successfully used for the hydrostatic curves of fishing vessels. This method is based on the calculation of LCB, KB, KM_o and Δ for four or five conditions of trim. The two extreme conditions of trim must be chosen so that the maximum trim to be expected in operation is amply within the assumed extremes. In this way four or five sets of simplified hydrostatic curves are achieved. In each set the values of LCB, KB, KM_o are read off for one and the same Δ. With the help of these readings two diagrams can be made. The first of these is arranged so that Δ can be found when T_a and $T_a - T_f$ or $T_f - T_a$ are known. The arrangement of the second diagram must be so that the values of LCB and KM_o can be read off when $T_a - T_f$ or $T_f - T_a$ and the displacement are known. For the additional conditions of loading the trim, T_a and KM_o can be read off with the help of Δ and LBC (see Fig. 3).

Stability curves

1. Righting levers

When the correct trim has been found in the manner described above, it is possible to proceed to determining the curve of righting levers. For this purpose a body plan is drawn in the trim belonging to each condition of loading to be investigated. This is consecutively given a number of inclinations and at each inclination Δ and the position of $B\varphi$ are determined for a number of waterlines. Assuming that there is no change in the position of G, the righting lever GZ is found.

There are various methods of finding the shift from B to $B\varphi$. Some are mathematical methods, but there are others where use is made of the planimeter or integrator. These methods of Benjamin-Spence, Middendorf-Lidell, Fellows-Schulz and Wendel are described in various handbooks on naval architecture (for example in Henschke, 1959).

Several authors have recently drawn attention to the fact that the integrator method of Fellows-Schulz which is so popular and widely used, often gives rise to important mistakes (Jens, 1959, Prohaska, 1947).

The numerical methods, making use of the measurements taken from the body plan, have been receiving increased attention lately because of the possibilities offered by the electronic computer; whether such a machine can give us an absolutely reliable curve of righting levers is a matter for closer study.

The curve of righting levers has a number of characteristics which determine the quality of the stability of the ship concerned. As such the following may be mentioned:

(a) The beginning of the curve is determined by the amount of initial stability GM_o.

(b) φ_s broadly speaking is twice that of the angle at which the side of the deck enters the water. This angle is determined by the breadth of the ship and the freeboard.

(c) The maximum value of GZ.

(d) The angle φ_r.

The nature of the curve of righting levers is substantially influenced by the inclusion in the calculation of superstructures and hatchcoamings. If a superstructure has a good watertight sealing, such a superstructure improves stability. If, however, the sealing is not or is no longer watertight, such a superstructure affects stability adversely, because the water which has penetrated either remains stagnant on the deck within the superstructure or finds its way below.

When the superstructure can be included in the calculations for the heeling vessel, it is often done by levelling out at reduced height the length of the superstructure over the length of the ship. This method is not to be recommended for fishing vessels, because in this type there is little superstructure which extends from side to side, and because in fishing vessels the angle at which the deck enters the water constitutes an important point which must not be obscured by approximations. The influence of the forecastle is felt only at such large angles of heel that it is considered to be of little consequence for the curve of righting levers.

As it is exceedingly difficult to calculate accurately the levers of statical stability of small angles, a start can be made at $\varphi = 20$ degrees, the range of 0 to 20 degrees touching the tangent determined by GM_0 at its origin. For values in excess of 20 degrees, 10-degree intervals are to be taken; and between 30 and 50 degrees the intervals should possibly be 5 degrees.

2. Errors in the calculation methods

In the foregoing, attention has been drawn to the differences existing between calculations carried out in accordance with different methods. These differences are found also when different persons calculate the curve of righting levers according to the same method. (Prohaska, 1947; Schepers, 1956.) The last-named differences can probably be reduced to some extent when the number of ordinates is increased and the scale of the body plan is taken at not less than 1:25.

The increased accuracy of a calculation by means of electronic computers is achieved in the first place because the number of ordinates and waterlines can be large. With these machines this has no effect whatsoever on the time required for these calculations. Furthermore, the degree of accuracy achieved will depend to a large extent on the program drawn up for these machines.

Bonebakker (1957), for a coaster, found considerable differences between the curve of righting levers and the levers of statical stability obtained by a model experiment (Fig. 4). Like Paulling (1960) he draws attention to the fact that the stern is neglected by the calculation, and points in particular to the neglect of changes in trim owing to the list of the ship. Unless this change in trim is included in the program for electronic computers, its neglect will affect the calculations adversely. In view of this, the question can be raised whether more model tests should be carried out to obtain reliable curves of righting levers. These model tests with the moment-indicator have been described by, among others, Bonebakker (1957) and Werckmeister (1944).

3. Reduction of the righting levers in a seaway

(a) Waves. For a ship in a seaway, the curve of righting levers is subject to considerable changes (Grim, 1952; Wendel, 1954; Paulling, 1960) (Fig. 5). Generally speaking, the values of the curve of righting levers are reduced when the midships section of the ship is resting on a wave crest, and they increase when that part of the ship is in a wave trough.

When a ship is steaming head-on into the waves, there is little danger as the temporary reduction of the righting levers is of too short a duration to cause the ship to capsize. This situation becomes dangerous when the direction and the velocity of the waves are approximately identical to the course and the speed of the ship. Möckel (1955) has pointed to the danger of a following sea. Although the kind of action to be taken is primarily of a nautical nature, and is left to the discretion of the master (changes of course, reduction of speed), the question arises whether this situation should be taken into account when it comes to judging the stability of fishing vessels.

In this connection it should be remarked that wave heights of L/20 or L/15 and a wave length of L are assumed by numerous publications. As regards smaller ships, as fishing vessels usually are, the question can be raised whether this wave picture does apply to the different waters frequented by fishing vessels. It is an established fact that the wave length and wave height can vary widely. Conditions in closely neighbouring sea areas may also be highly varied. Thus, Neumann (1957) mentions for the Western Baltic and at wind force 8, wave heights of 6.6 ft. (2 m.) and wave lengths of 135 ft. (about 41 m.). At the same wind force wave heights of 8.2 ft. (2.5 m.) and wave lengths of 190 ft. (about 59 m.) were measured in the North Sea on the Elbe light vessel. Maximum wave heights of 9.5 ft. (2.9 m.) and maximum wave lengths of 79 ft. (24 m.) are indicated for the northern part of the Caspian Sea. For the southern part, the maximum values are 13-20 ft. (4-6 m.) and 255 ft. (78 m.), respectively.

Not until more information has become available about the seaway of the different fishing grounds and steaming routes can any definite conclusions be drawn regarding this point.

Finally, Grim (1952) points out that for a following sea the righting levers cannot be sufficiently accurately calculated, particularly in the case of large angles of heel when the deck enters the water. In this case, too, a wider use will have to be made of model tests. Stability is influenced not only by the waves of the open sea, but the wave created by the ship's own speed causes a change in the curve of righting levers (Fig. 6). Nutku (1960) mentions for a 46-49.3 ft. (14-15 m.) long fishing vessel, a loss of stability amounting to 10.2, 6.4 and 12 percent at $V/\sqrt{L}$ = 1.4, 1.2 and 0.9 respectively. If the boat is lifted by a stern wave, the stability loss amounts to about 13 percent.

(b) Icing. The other principal natural factors which have an adverse effect on the stability of a fishing vessel are icing, wind pressure and shipping quantities of water. Naturally, the first of these is of significance only in navigation in areas where spray and black frost cause ship and rigging to be covered with large quantities of ice. At a cross sea this icing is not always symmetrical. The added weight high up on the ship reduces GM_o and unsymmetrical icing results in an initial list.

Trawler icing experiments carried out by BSRA (1957), also reviewed by Lackenby (1960), have brought to light that an ice mass in excess of 100 tons can be formed on a typical British trawler, and that this results in a reduction of GM_o of about $1\frac{1}{2}$ ft. (0.45 m.). The phenomenon of icing has been taken into account in the stability regulations of some countries whose ships are exposed to the danger of icing (see Table I).

(c) Wind. A more generally occurring stability-reducing factor is wind pressure. The pressure of the wind and the distance between the centers of wind pressure and of water pressure are two factors which reduce stability. When, as a result of the wind pressure, the stability moment $\Delta . GZ$ is equal to or less than the heeling moment, a condition is created in which the ship, considered statically, capsizes ($\varphi 2$ in Fig. 7). Considered dynamically, a ship capsizes at φ_2, (Fig. 8), which angle is determined by taking the surfaces F_1 and F_2 equal. The angle $\varphi 2$ is therefore determined by the shape of the curve of righting levers and the curve of the heeling moment M_h which, for example, may be the wind pressure. Also, as a result of recent investigations (Kinoshita, 1957;

SRAJ, 1959), the formula for the wind pressure moment can be written as follows (Wendel, 1960):

$$M_W = \frac{\rho a}{2} . v_W^2 . A . d . \xi_W . f(\varphi)$$

in which v_W = wind velocity

Beaufort	6	8	10	12
Velocity knots	23	35	50	58
Velocity m/sec	12	18	25	30

A wind velocity of 115 knots (60 m/sec) has sometimes been recorded.

d = distance between the center of wind pressure and the centre of water pressure. In practice, this is taken as the vertical distance between the centre of the exposed area and a point at half-draught. Japanese investigations (Kinoshita, 1957; SRAJ, 1959) regarding the point through which the wind pressure acts, have shown that d_W may be strongly divergent from d_A. For fishing vessels it was found that:

$$d_W/d_A = 1.222 - 0.0096.\varphi \quad \text{for } -5^\circ \leqslant \varphi \leqslant 50^\circ$$

$$\text{and } d_W/d_A = 0.472 \quad \text{for } 50^\circ \leqslant \varphi \leqslant 70^\circ$$

The same experiments showed that the point through which the water pressure acts does not remain in its position either, when the ship is drifting laterally as a result of the wind pressure. The point through which the water pressure acts rises as the speed at which the ship is drifting increases. This is also the case when φ exceeds a certain angle. From this it follows that an increase in wind pressure does not always lead to an appreciable increase in the wind pressure moment.

$f(\varphi) = 0.25 + 0.75 \cos^3 \varphi$

Pa = density of air (0.125 Kg. sec^2/m^4)

(d) Shipping water. When a ship is shipping water, these masses cause the centre of gravity to rise, but the water is collecting at one side, which gives rise to a heeling moment. Unless the scuppers are big enough to get rid of this water quickly, the water on the deck may be the cause of a dangerous situation. On fishing vessels the tendency exists to keep the scuppers small, and even to fasten them, for the water that has been shipped and is drained via the scuppers often takes large parts of the catch along with it.

Pond boards found on trawlers on the one hand prevent the rapid draining, but on the other they prevent shifting of the easily-moving mass of fish on the deck.

In this respect the height of the bulwarks is of importance; ships having very poor stability will be affected favourably by the bulwarks, while in ships with sufficient stability bulwarks have an adverse effect upon stability, due to the free water on the deck (SRAJ, 1959).

(e) Fishing operations. The stability of fishing vessels is adversely affected by the heeling moment caused by the fishing itself or the loading of the catch. In a ship which is trawling, one is concerned during trawling operations with the moment which is determined by the pull of the warps and the position of the gallows through which these forces act. The danger is in the jamming of the net.

(f) Rudder pressure. As a last factor, mention should be made of the rudder pressure. When the rudder is put hard over, a couple comes into existence which is determined by the rudder pressure and the vertical distance between the point through which this pressure acts and G. If electric-hydraulic steering gear is used, putting the rudder hard over too quickly is possible, and this may constitute a danger factor.

Checking the stability during the design stage

In general, the initial stability GM_0 is checked during the design stage. This check, however, does not give any information on the righting levers when the ship begins to heel. It may be important to have at least some insight into the expected value of the righting lever in the position where this can be considered to have its maximum value, that is at 30 to 40 degrees.

Burgess (1943) compared the movement of the center of buoyancy during the heeling of a number of vessels with that of a prism having a transverse section of the same midship area and shape as that of the particular ship for which the comparison is made, except that the depth of prism is increased by one-third of the mean deck sheer. He suggests that the coefficients or, as he calls them, BR rations, derived therefrom will be of use in preliminary design, or in existing vessels for which there is little information.

Also, in view of the above-mentioned shortcomings of the methods for the calculation of righting levers, Prohaska (1947) proposed a method to determine this curve from what he calls the residuary stability (= $GZ - GM \sin\varphi$). For this purpose Prohaska gave for six angles of heel the curves for the determination of the coefficient $C_{RS} = \frac{\text{residuary stability.}}{BM_o}$ He determined the values of C_{RS} with the help of the ratios D/B and T/B. D is taken as the depth to the uppermost continuous deck, increased by one-third of the mean deck sheer. He is of the opinion that this method will be useful in the treatment of the following problems:

(a) design of righting arm curves;

(b) determination of the necessary metacentric height to fulfill given stability requirements;

(c) framing of stability requirements for ships of different types.

Prohaska believes that for ordinary ships this method gives results which are not any more uncertain than those obtained from the usual stability calculation, But he issues a warning as regards ships of extreme forms, which have not been dealt with in his investigations.

A method for the approximation of GZ at different angles of heel was published by SRAJ (1959). Let $r = BM_o$ and $m = GM$, then GZ is expressed by $GZ = F_1 . a + F_2 . b + F_3 . r + F_4 . m$, where F_1, F_2, F_3 and F_4 are coefficients given in Fig. 9 and a and b, as shown in Figs. 10 and 11, drawn with the parameters of C_b and C_w. This Japanese method of approximation is considered serviceable for checking the stability during the design stage.

With a view to checking the curve of righting levers at $\varphi = 30^o$ and 40^o, Krappinger (1958) developed a method in which he determines the co-ordinates of B at these two angles of heel. In this method an attempt is made to make greater allowance for the influence of the superstructures than is possible with other methods. Krappinger admits that he did not succeed in finding such a systematic method for the determination of the influence of the superstructure as would on the one hand be sufficiently simple and clear, and on the other do justice to all possibilities likely to occur.

Stability criteria

The elements which contribute to the overall picture from which stability is judged are as follows:

(a) the metacentric height for the upright condition GM_o;
(b) KG or height of centre of gravity above the keel;
(c) the freeboard;
(d) the maximum value of GZ, the angle of heel at which this maximum occurs, the angle of heel at which the curve of the righting levers cuts the abcissa;
(e) the superstructures;
(f) the moment set up by icing;
(g) the wind pressure moment;
(h) the towing pull moment;
(i) the dynamical stability.

When dealing with the factors which adversely affect stability, it has already been pointed out that the wind pressure moment is vitally important. In stability criteria the wind pressure moment is generally allowed to function as follows (see Fig. 12). The ship is allowed to roll as a result of the waves, while an even wind pressure is acting upon her. When the ship is at the maximum angle of heel to windward she is suddenly subjected to a gust. She then heels to leeward as a result of this pressure and capsizes, if the wind pressure exceeds the critical value. According to Fig. 12 the moment due to the wind pressure changes from M_w (due to the mean wind velocity), to $M_w + \Delta M_w$ (due to gust). The ship then heels to the extent that the work done by the wind pressure FGDB becomes equal to the work done by the righting moment ABIH. Accordingly, when $ABIH > FGDB$, it is considered that the ship can withstand this gust. This matter can also be expressed by $FJK' < ABC$ and this expression has been adopted for certain stability criteria (SRAJ, 1959).

A number of stability criteria have been collected in Table I. These criteria are partly those which have been accepted by the governmental safety control services in various countries, and partly they are criteria which have been proposed by various investigators. These criteria do not concern fishing vessels only, but the limit of the ship's length was established at about 200 ft. (60 m.) when a distinction was made as regards size. The various proposed criteria originate with Rahola (1939), Skinner (1951), Smit (1952), Nickum (1955), Roorda (1957), Takagi (1960), and Jablonski (1960).

TABLE I: Stability criteria in various countries

	Rahola (1939) (1)	Skinner (1951)	Smit (1952) (2)	Nickum (1955)
Type of Vessel or Service			Lifeboats	Fishing Vessels
GM_o			(3) Min. $GM_o = 0.05B^2 - 0.05B + 0.20$ GM_o and B in metres	(4) $GM_o \geqslant B/10$ or 2ft. (0.61m.)
Freeboard		$f = 0.25D$		(8) $\frac{f}{B} + \frac{FA}{L.B} \geqslant 0.15$
Curve of Righting Levers	$GZ_s = 5\frac{1}{2}$in (0.14m) at $\varphi\ 20^\circ$ $GZ_s = 7^7/9$in (0.20m) at $\varphi 30^\circ$ $\varphi_s \geqslant 35^\circ$			
Windpressure or pressure moment				
Towing Pull Moment				
Dynamical Stability	(17) Dynamical Lever = $3^1/8$ in (80mm) at φ perm.			

TABLE I: Stability criteria in various countries (cont'd)

Deutsche Schiffsrevision und Klassification (1956)	Polish Register (1957)	Min. of Transport Japan (1957)
1. Oceangoing 2. Coasting: North Sea and Baltic 3. Limited coasting 4. Navigation on shallows and inland navigation	1. Oceangoing 2. Extended coasting 3. Baltic 4. Coasting 20m from coast 5. Navigation in "Haffs" 6. Harbour vessels	Passenger Vessels
		(5) $GM_o \geqslant (1.1 A. h + \sum k. n. b) B / 100. f. \Delta$
		$f \leqslant {}^{B}/5.5$
$GZ_s > 0.82$ft (0.25m) at $\varphi 30^\circ$ (9) $\varphi_s = 30\text{-}45^\circ$ $\varphi_r \geqslant 60^\circ$ (φ_r icing $> 50^\circ$) $\varphi_e > 30^\circ$	$\varphi_s = 30\text{-}45^\circ$ $\varphi_r = 60^\circ$ φ_r icing $> 50^\circ$ GZ_s (Service 4) > 0.82ft (0.25m) at φ 30°	$GZ_s \geqslant 0.0215B$ or $GZ_s \geqslant 0.9$ft (0.275m)
$M_w = 0.001 p_2 \sum (\zeta_w . A. d_{T/2})$ (11)	$M_w = 0.001\ p_3 . d_A . A$ (12)	$GZ_w = \frac{K_1 . A. d_{T/2}}{\Delta}$ (13)
(15) $M_{TO} = P_b . l$	$M_{TO} = 0.01. EHP. l$	
$K = \frac{M_{caps}}{M_w} \geqslant 1$ (18) See Fig. 13	$K = \frac{M_{caps}}{M_w} \geqslant 1$ (18) See Fig. 13	$\frac{F_2}{F_1} > 1$ See Fig. 14

TABLE I: Stability criteria in various countries (cont'd)

Japanese Fisheries Agency (1950, revised in 1957)	Roorda (1957)
Fishing Vessels	1. Motor luggers 2. Small fluschdeck steam trawlers: 3. Large raised quarter steam trawlers: home-bound 4. Small seagoing yachts 5. Large Seagoing yachts
Min. value for load condition Purse seiners: the larger of the two values of $B/23 + .88$ft (.27m) and $L/120 + .88$ft (.27m) but not less than 1.48ft (0.45m) Skipjack pole-fishing boats: $B < 22.9$ft (7m): the larger of the two values of $B/25 + .49$ft (.15m) and $L/143 + .49$ft (.15m) but not less than 1.41ft (0.43m) $B \geqslant 22.9$ft (7m): the larger of the two values of $(B - 22.9\text{ft } (7\text{m}))/12 + 1.41$ft (0.43m) and $(L - 131.2\text{ft } (40\text{m}))/70 + 1.41$ft (0.43m) Other types of BOATS: $B < 22.9$ft (7m) the larger of the two values of $B/25 + .39$ft (0.12m) and $L/150 + .39$ft (0.12m) $B \geqslant 22.9$ft (7m) the larger of the two values of $(B - 22.9\text{ft } (7\text{m}))/12 + 1.3$ft (0.4m) and $(L - 138\text{ft } (42\text{m}))/72 + 1.3$ft (0.4m). With the majority of crew and catch on deck GM_o shall not be less than 1.31ft (.4m). GM_o may never become negative	1. $GM_o/B = 0.12 - 0.14$ 2. $GM_o/B = 0.131 - 0.138$ 3. $GM_o/B = 0.057 - 0.065$ 4. $GM_o/B = 0.085 - 0.107$ 5. $GM_o/B = 0.066 - 0.085$
Wooden vessels: $f = \frac{D}{15} + 0.66$ft (0.2m) Steel vessels: $f = \frac{D}{15} + 0.49$ft (0.15m) if $D < 14.8$ft (4.5m) $f = \frac{D}{10}$ if $D \geqslant 14.8$ft (4.5m)	

TABLE I: Stability criteria in various countries (cont'd)

U. S. S. R. Register (1959)	Takagi (1960)	Jablonski (1960)	U. S. Coast Guard
1. Vessels $>$ 80grt. ocean-going 2. Vessels for restricted service e. g. Baltic 3. Vessels for harbour and coastal traffic	Fishing Vessels	Fishing Vessels	Passenger Vessels
$GM_o \geqslant 0$ (free surfaces included)	(6)		(7) $GM_o = \frac{p. A. h.}{\Delta . \tan \varphi}$ in ft.
	$C_1 = \frac{GM_o + 2f}{BG \quad x \; B}$ $C_1 = 0.075$ loaded cond. $C_1 = 0.10$ light cond.		
Normal: (10) $GZ_s > 0.82$ft (0.25m) for $L < 328$ft. (100m) Icing: $GZ_s = 0.66$ft (0.2m) at $\varphi 25^o$ Service 2 and 3: $\varphi_r > 55^o$		$GZ_s \geqslant 7^7/_9$in (0.2m) at $\varphi_s = 30^o$ $\varphi_r \geqslant 60^o$	
$M_w = 0.001 \; p_l . d_A . A$ (14)			
(16) $M_{TO} = k. l. P$ High superstructures: M_{TO} has to be added to M_w			
$K = \frac{M_{caps}}{M_w} \geqslant 1$ (19) See Figs. 15 and 16			

Notes to Table I:

General

(1) The criteria set by Benjamin and Pierrottet are not mentioned here. As stated by de Wit (1955) Benjamin's and Pierrottet's papers are part of the base on which Rahola (1939) founded his criterium.

(2) Proposed at the second meeting of the International Standards Organization ISO/TC8 in 1952 and published by Burghgraef (1956).

GM_o

(3) If $B < 2.4$m (7. 85 ft.) the capacity coefficient shall be $\geqslant .68$ to ensure adequate GM-value. If $B \geqslant 2.4$m (7. 85 ft.) the capacity coefficient shall be $\geqslant .66$.

$$\text{Capacity coefficient} = \frac{\text{Cubic capacity}}{\text{L. B. D.}}$$

The mentioned value of minimum GM is for the fully-manned boat in the dry condition. For the 10 percent flooded and fully-manned boat a GM of 0. 6 of the minimum GM seems to give a reasonable standard.

(4) During the discussions at the First World Fishing Boat Congress Nickum was willing to accept a GM/B ratio of 0. 06 and probably 0. 05 in vessels familiar to him (Fishing Boats of the World, p. 368).

(5) In this formula

n = number of passengers in each accommodation space

b = average athwartship distance, within which the passengers are free to move, in each accommodation space (m)

k = 0. 134 (7 - n/a), where a = floor area in each accommodation space (m^2)

A = lateral area of the part of the ship above the waterline (m^2)

h = vertical height of the center of gravity of A above the half-draught point (m).

(6) In this formula BG = height of the center of gravity above the centre of buoyancy.

(7) $p = 0.005$ for unrestricted and coasting service (incl. winter on Great Lakes)

$p = 0.0033$ partially sheltered areas such as lakes, bays, etc. and Summer Freeboard Great Lakes

$p = 0.0025$ sheltered areas such as rivers, harbours, etc.

φ = permitted angle of heel until 0.5 freeboard, max. 14°

A and h = see (5).

Freeboard

(8) In this formula

FA = freeboard area (projected on a vertical plane through the centreline) between the waterline and the freeboard deck at the side

L = registered length

B = max. beam over planking or plating at the waterline

Curve of Righting Levers

(9) Icing is only considered for vessels of Service 1 and 2.

Weight increase:

open decks and hatches	30 kg/m^2
boats	10 kg/m^2
masts, rigging, etc.	5 kg/m^2

Icing is assumed to a height of only 32.7 ft. (10 m.)

Increase of A for bulwark, masts, boats, rigging, etc. 30 percent.

(10)

B/H	$K = \frac{M_{caps}}{M_w}$	φ_r	φ_s
< 2	> 1	$> 60^\circ$	$> 30^\circ$
2 to 2.5	1 to 1.5	$> 60^\circ - \Delta\varphi_1$ $\Delta\varphi_1 = 10 \frac{K-1}{0.5} - \frac{B/D-2}{0.5}$	$> 30^\circ - 0.5\Delta\varphi_1$
	> 1.5	$> 60^\circ - \Delta\varphi_2$ $\Delta\varphi_2 = 10 \frac{B/D-2}{0.5}$	$> 30^\circ - 0.5\Delta\varphi_2$
> 2.5	< 1.5	$> 60^\circ - \Delta\varphi_3$ $\Delta\varphi_3 = 10 \frac{K-1}{0.5}$	$> 30^\circ - 0.5\Delta\varphi_3$
	> 1.5	$> 50^\circ$	$> 25^\circ$

If there are superstructures the first hump of the GZ-curve $> 25^\circ$, Danckwardt (1959). Due to icing the weight increase is 30 kg/m^2 of the horizontal projection of the open-air deck area and 15 $kg.m^2$ for sailing area for vessels north of the Polar Circle. For other areas 50 percent of these figures is to be used. In the case of icing $\varphi_r > 55^\circ$ and vessels of service 1 and 2 $GZ_s = 0.2$ m at $\varphi_s > 25^\circ$.

Windpressure or windpressure moment

(11) $M_w = 0.001 . p_2 \sum (\zeta_w . A. d_{T/2})$

Values of p_2:

$d_{T/2}$	Service 1	2	3	4
1	53	40	35	33
3	84	63	57	52
5	105	77	68	61
7	118	87	76	65
9	130	97	83	--
11	140	106	--	--
13	150	115	--	--

These values of p_2 for round sections to be multiplied by 0.6.

(12) $M_w = 0.001\ p_3 . d_A . A.$

Values of p_3:

d_A (meters)	Service 1	2	3	4	5	6
1	110	90	45	23	15	7.5
3	173	145	72	35	22	12
5	210	180	90	44	27	16
$\geqslant 7$	240	200	--	--	--	--

These values of p_3 for round sections to be multiplied by 0.6.

(13) In this formula

A and h (see 5)

k_1 = 0.0514 for ocean going

= 0.0274 for general coasting

= 0.0171 for navigation in Seto Inland Sea or with scheduled voyage of less than two hours in the Coasting Area

$\varphi_o = \sqrt{138.5 \gamma . \delta} / N$, N = 0.02 for vessels with bilge keels

$\varphi = 0.73 + 0.60 \frac{OG}{d}$, OG = vertical distance from waterline to the centre of gravity of the ship (m) (positive above waterline)

(14) $M_w = 0.001\ p_1 \cdot d_A \cdot A$

Table for p_1-values:

d_A (meters)	Service 1	2	3
1	96	54	27
2	117	66	33
3	131	74	37
4	140	80	39
5	147	84	41
6	153	87	43
7	156	89	44

For round sections 0.6 of the above values is to be taken. For rigging, railings, etc. the area to increase by 5 percent and M_w 10 percent. For mastshrouds a special rule is given (see Danckwardt, 1959).

Towing pull moment

(15) M_{TO} has to be added to M_w. For fishing vessels with two nets or lines: $k = \frac{M_{caps}}{M_w + M_{TO}} \geqslant 1.0.$

(16) In this formula $k = 5$ for ihp $\leqslant 200$

$k = 4$ " " $\geqslant 500$

P = pull at a speed of 5 kt. but not less than 0.01 Ton/ihp

Dynamical stability

(17) $\varphi_{perm.}$ or permitted angle of heel is determined by the following conditions:

1. It should be equal to or smaller than φ at which GZ_r is max.
2. It should be equal to or less than 40°.
3. The non-watertight hatch coamings and doorways through which the water might flow into the ship may not be submerged with φperm.
4. If the cargo is liable to shift, the dynamical angle of shift must be determined.

(18) M_{caps} is without taking φ_o into consideration.

(19) $\varphi_o = x.y$

$$x = \frac{1}{f_1.\sqrt{f_2.GM_o/B}}$$

f_1 and f_2 are functions of $u = \mathcal{L}_w(1+B\ /\ 6T)$

u	0.8	1.0	1.2	1.4	1.6	1.8
f_1	1.69	2.34	3.02	3.74	4.48	5.30
f_2	0.672	0.430	0.298	0.220	0.168	0.133

y is a function of $\frac{\sqrt{GM}}{B}$

$\frac{\sqrt{GM}}{B}$	0.03	0.05	0.07	0.09	0.11	>0.13
Serv. 1	26	26.1	29.0	42.3	51.1	51.1
2 and 3	23.8	23.8	25.2	30.0	40.6	51.1

If there is a bilge keel or a vertical keel:

$$\varphi_{02} = K\varphi_0$$

K is a function of ψ

bilge keels $\psi = \frac{GK.}{T}\frac{S_1}{L.B}\left(\frac{d_1}{B}\right)^3.10^3$

vertic. keels $\psi = \frac{GK.}{T}\frac{S_2}{L.B}\left(\frac{d_2}{B}\right)^3.10^3$

ψ	0	1	2	3	4	5	6
K	1.0	0.93	0.87	0.80	0.74	0.67	0.61

S_1 is the total area of the bilge keels

S_2 is the projection of the vertical keel

If the bilge is not rounded but sharp $\varphi_{03} = 0.7\varphi_0$

Note: Under certain conditions it is permitted to estimate φ_0 by model experiments.

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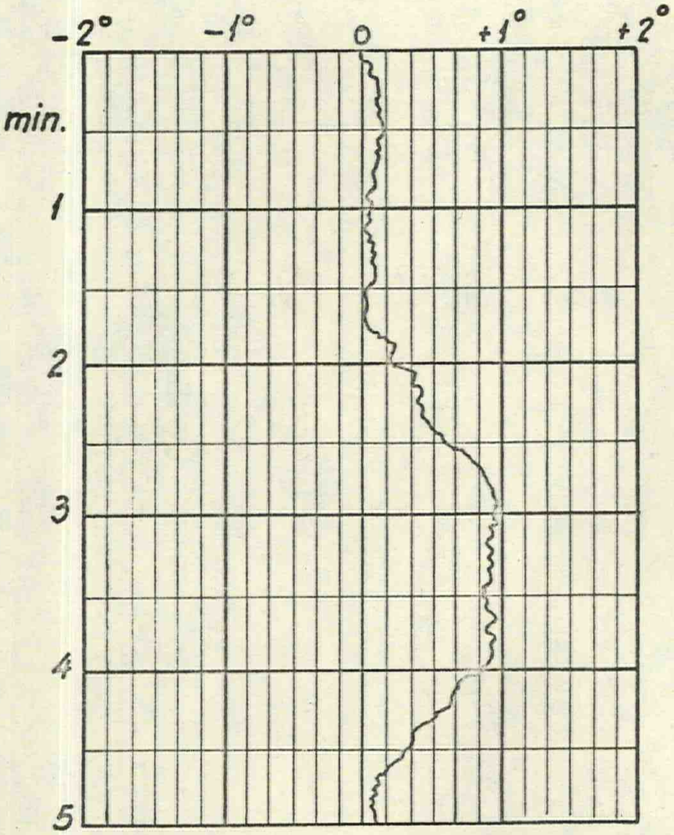


Fig. 1 - Enregistrement par le NAVICLIN d'une expérience d'inclinaison d'un ferry de 200 tonnes. A partir de la première position à 0°, six hommes ont transporté des poids de 30 Kg de l'autre côté. L'irrégularité du tracé est due au trafic intense sur le fleuve. Cet instrument emploie un niveau pour enregistrer l'inclinaison. L'utilisation d'un niveau à plus grande inertie au lieu du niveau standard donnerait une courbe plus régulière.

Fig. 1 - NAVICLIN record of an inclining experiment with a 200 ton ferry. After the first 0° position six men carried several 66 lb. (30 Kg.) weights to the other side. The unrest of the record is due to busy traffic on the river. This instrument makes use of a level to record the inclination. Using a more inert level instead of the standard level would result in a smoother curve.

Gráfica 1 - Registro con el NAVICLIN de un experimento de inclinación con un transbordador de 200 toneladas. Después de la primera posición a 0°, seis hombres trasladaron pesos de 30 kg. (66 libras) al otro costado. La movilidad del registro se debe al intenso trafico del río. Este instrumento utiliza un nivel para registrar la inclinación. Empleando un nivel de mayor inercia en lugar del nivel normal se obtendría una curva más suave.

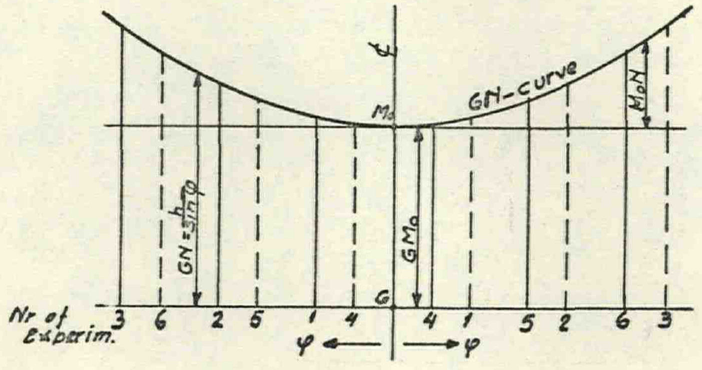
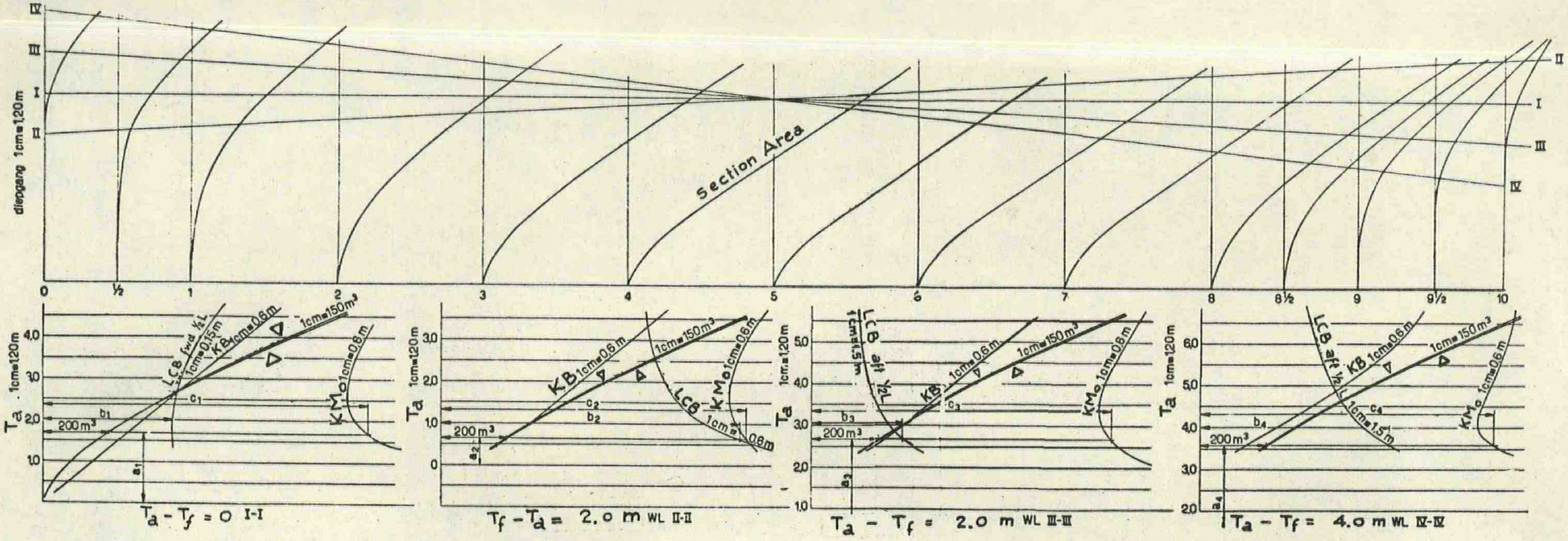


Fig. 2 - Seyderhelm's (1939) method for finding GM_o

Fig. 2 - Méthode de Seyderhelm (1939) pour trouver GM_o

Gráfica 2 - Método Seyderhelm (1939) para hallar GM_o

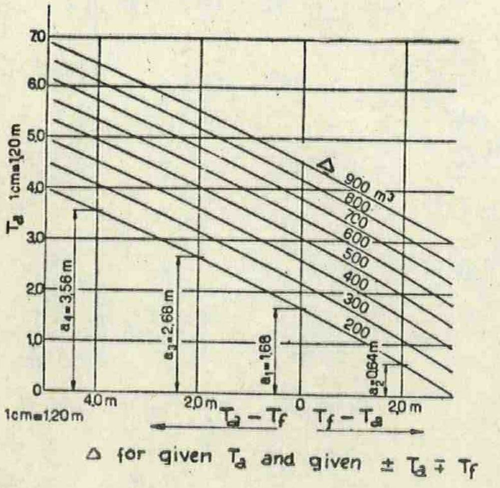


Ta - Tf = 0 I-I

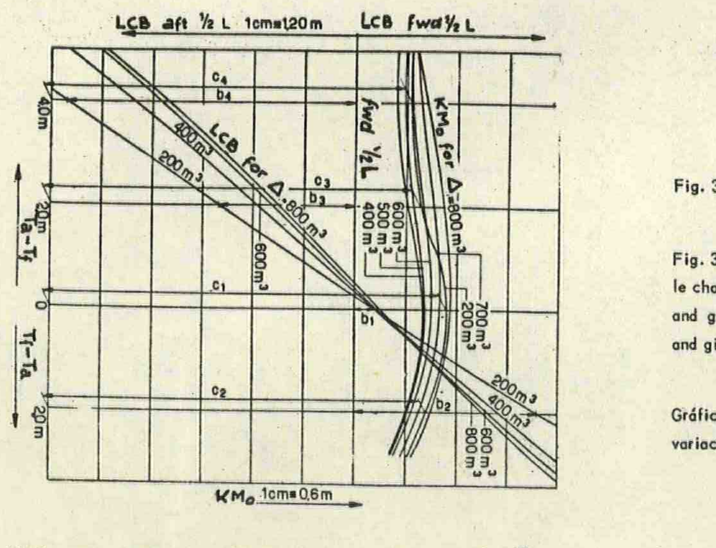
Tf - Ta = 2.0 m WL II-II

Ta - Tf = 2.0 m WL III-III

Ta - Tf = 4.0 m WL IV-IV



Δ for given Ta and given ± Ta ∓ Tf



KMo and LCB for given Δ and given ±Ta∓Tf

Fig. 3 - Hydrostatic curves for small ships with regard to trim alteration

Fig. 3 - Courbes hydrostatiques pour de petits navires en ce qui concerne le changement de l'assiette. (Section area; aire des couples) (for given Ta and given ± T_f ± Ta; pour Ta et ± T_f ± Ta donnés) (KM_o and LCB for given and given ± Ta ± T_f: KM_o et LCB pour et ± Ta ± T_f donnes)

Gráfica 3 - Curvas hidrostáticas para barcos pequeños en relación con las variaciones del asiento.

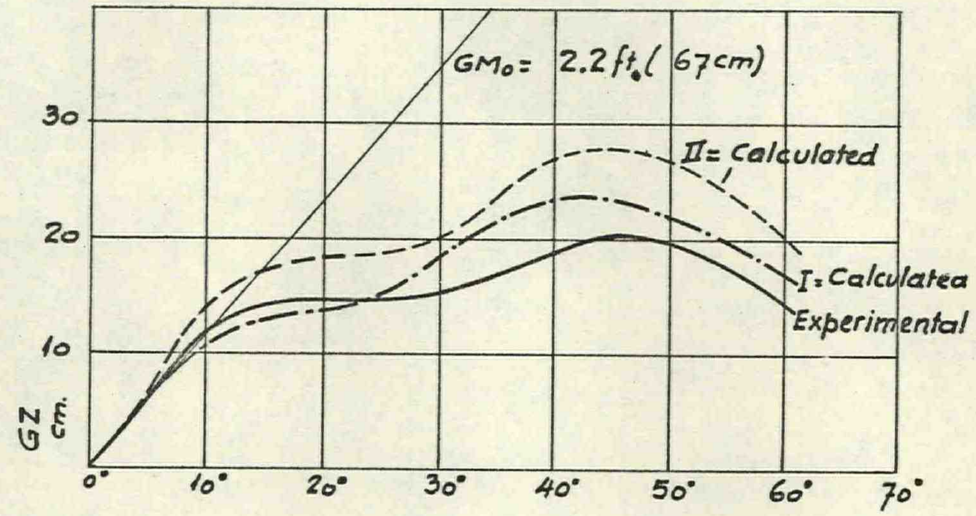


Fig. 4 - Difference between calculated curves of GZ and between calculated and experimental curves, according to Bonebakker, 1957.

Fig. 4 - Différences entre les courbes calculées de GZ et entre les courbes calculées et la courbe expérimentale, selon Bonebakker, 1957 (Calculated: calculée; Experimental: expérimentale)

Gráfica 4 - Diferencias entre la curva calculada de GZ y las curvas calculadas y las experimentales, según Bonebakker, 1957.

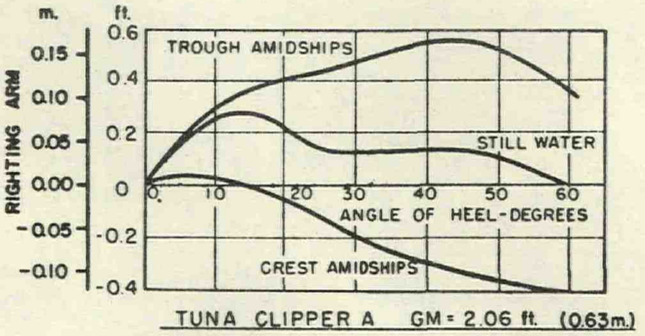


Fig. 5 - Transverse stability in a following sea, according to Paulling, 1960 (Fig. 535, FBW No. 2)

Fig. 5 - Stabilité transversale avec mer venant de l'arrière, selon Paulling. 1960. (Trough amidships: creux au milieu du navire; Still water: eau calme; Angle of heel-degrees: angle de gîte-degrés; Crest amidship: crête au milieu du navire; Righting arm: bras de levier de redressement; Tuna clipper A GM =2,06 ft: Tuna clipper A GM = 0,63 m.)

Gráfica 5 - Estabilidad transversal con mar de popa, según Paulling, 1960. (Trough amidships: seno en la medianía del barco; Still water: aguas tranquilas; Angle of heel-degrees: ángulo de escora - grados; Crest amidships: crestas en la medianía del barco; Righting arm: brazo del par de adrizamiento)

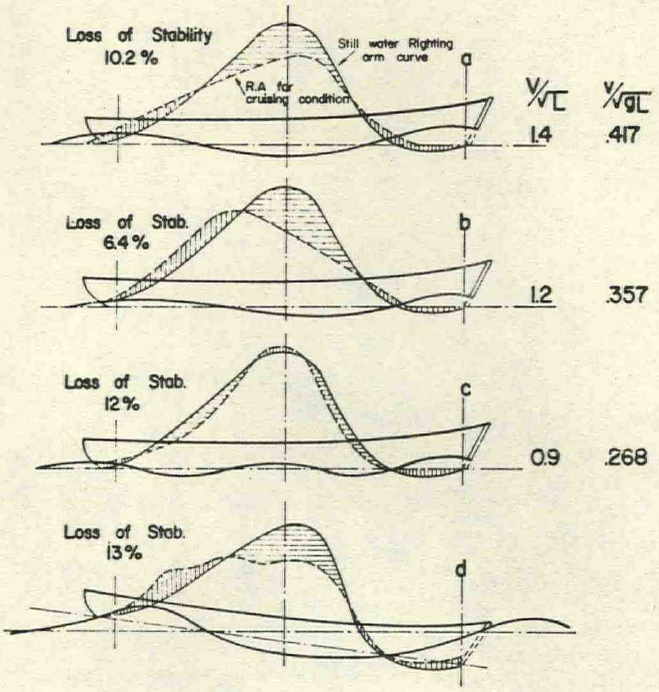
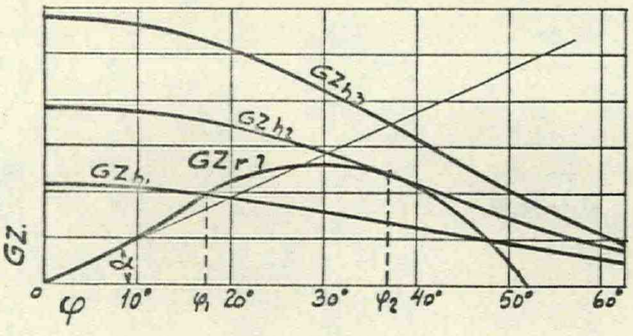


Fig. 6 - Loss of stability due to wave making, according to Nutku, 1960. (Fig. 627 FBW No. 2)

Fig. 6 - Perte de stabilité due à la formation de vagues par la coque, selon Nutku, 1960. (Loss of stability: perte de stabilité; Still water righting arm curve: courbe des bras de levier de redressement en eau calme; R.A. for cruising condition: bras de levier de redressement en condition de route)

Gráfica 6 - Pérdida de estabilidad debida a la formación de olas, segun Nutku, 1960. (Loss of stability: pérdida de estabilidad; Still water righting arm curve: curva de los brazos de palanca de adrizamiento en aguas tranquilas; R.A. for cruising condition: brazo del par de adrizamiento en condiciones de crucero)



tan α = metacentric height

Fig. 7 - Righting and heeling levers, according to Wendel, 1960 (Fig. 539 FBW No. 2)

Fig. 7 - Bras de levier de redressement et de chavirement selon Wendel, 1960. (tgα = hauteur métacentrique).

Gráfica 7 - Brazos de los pares de adrizamiento y de escora, segun Wendel, 1960. (tgα = altura metacéntrica)

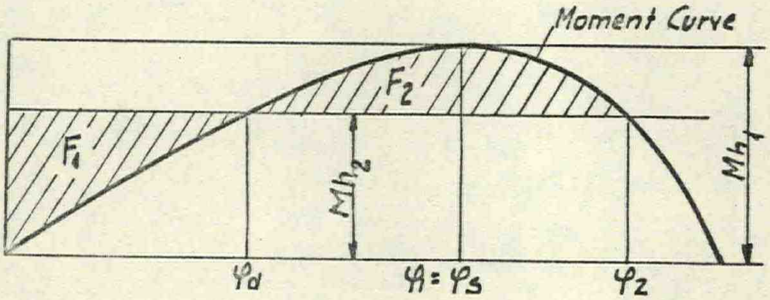
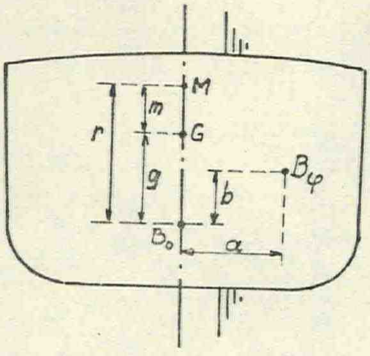


Fig. 8 - Statical and dynamical stability, according to Rahola, 1939

Fig. 8 - Stabilité statique et dynamique, selon Rahole, 1939
(Moment curve: courbe des moments)

Gráfica 8 - Estabilidad estática y dinámica según Rahola, 1939
(Moment curve: curva de momentos)



$GZ = F_1a + F_2b + F_3r + F_4m$

$F_{1.2.3.4}$ see Table below

a: see Fig. 10; b: see Fig. 11

	15°	30°	45°	60°	75°	90°
F_1		0.5458	1.2221	1.2835	0.7174	0
F_2		-0.2193	-0.4021	-0.1967	0.3462	1
F_3	0.0093	-0.3148	-0.8248	-1.0980	-1.0877	-1
F_4	0.2588	0.5	0.7071	0.866	0.9659	1

Fig. 9 - Approximation of GZ at different angles of heel, according to SRAJ, 1959

Fig. 9 - Approximation de GZ à différents angles de gîte, selon SRAJ, 1959

Grafica 9 - Aproximación de GZ a diferentes ángulos de escora, según SRAJ, 1959

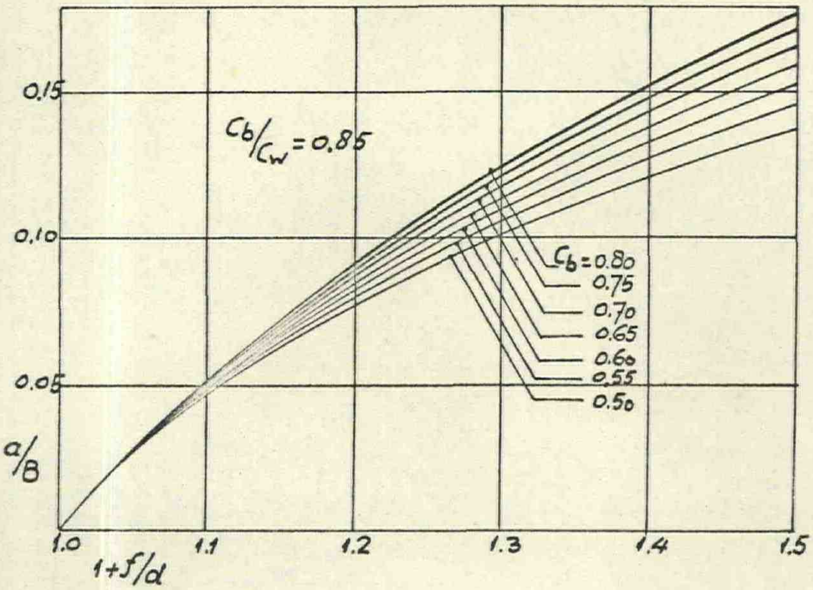


Fig. 10 - Approximation of GZ at different angles of heel, according to SRAJ, 1959: value of a

f = if f exceeds B/5.5, it is taken as B/5.5

Fig. 10 - Approximation de GZ à différents angles de gîte, selon SRAJ, 1959: valeur de a

f = si f dépasse B/5.5, on utilise la valeur B/5.5

Gráfica 10 - Aproximación de GZ a diferentes ángulos de escora, según SRAJ, 1959: valor de a

f = si f excede de B/5.5, se toma como B/5.5

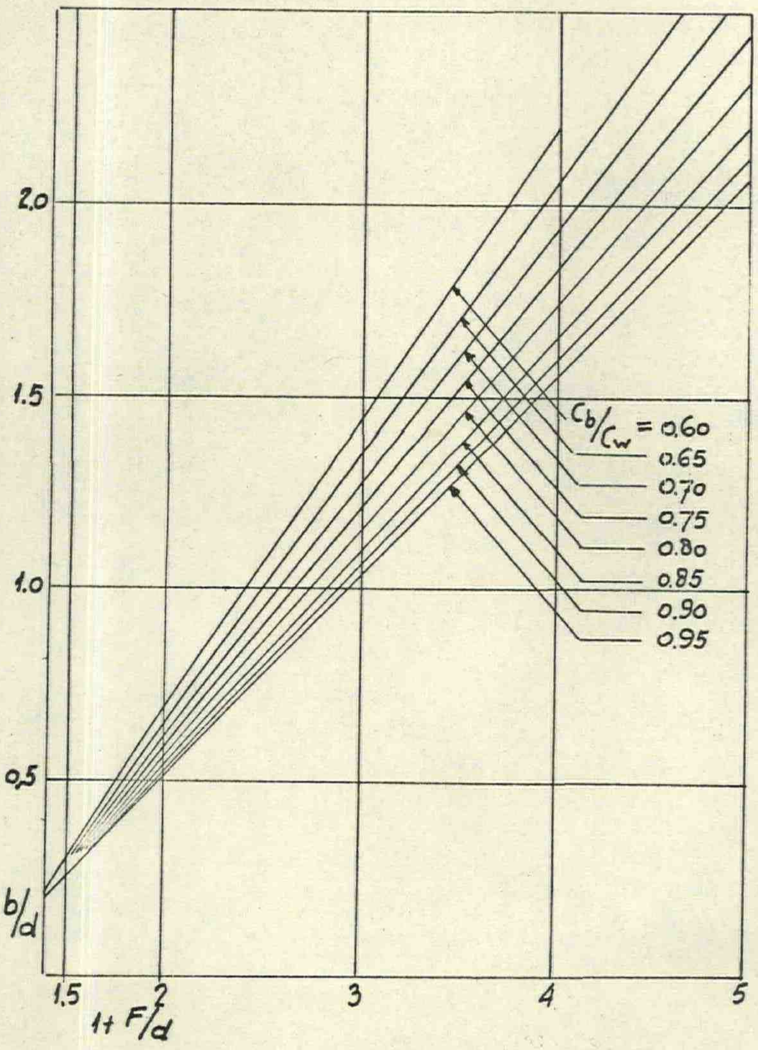


Fig. 11 - Approximation of GZ at different angles of heel, according to SRAJ, 1959: value of b

F = effective freeboard

Fig. 11 - Approximation de GZ à différents angles de gîte, selon SRAJ, 1959: valeur de b

F = franc-bord efficace

Gráfica 11 - Aproximación de GZ a diferentes ángulos de escora, según SRAJ, 1959: valor de b

F = francobordo efectivo

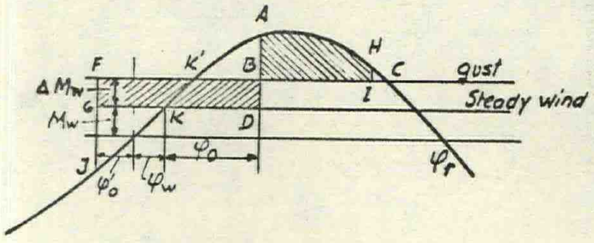


Fig. 12 - Effect of wind pressure on stability

Fig. 12 - Effet de la pression du vent sur la stabilité
(Gust: coup de vent; steady wind: vent stable)

Gráfica 12 - Efecto de la presión del viento sobre la estabilidad
(Gust: golpe de viento; steady wind: viento uniforme)

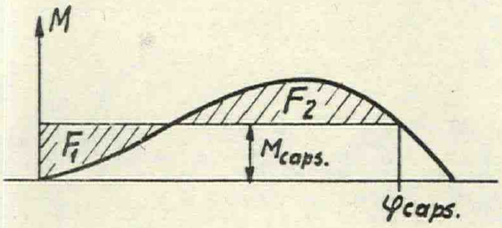


Fig. 13 - Dynamical Stability, according to Deutsche Schiffsrevision und Klassifikation and Polish Register

Fig. 13 - Stabilité dynamique, selon le Deutsche Schiffsrevision und Klassifikation et le Registre polonais

Gráfica 13 - Estabilidad dinámica según el Deutsche Schiffsrevision und Klassifikation y el Registro polaco

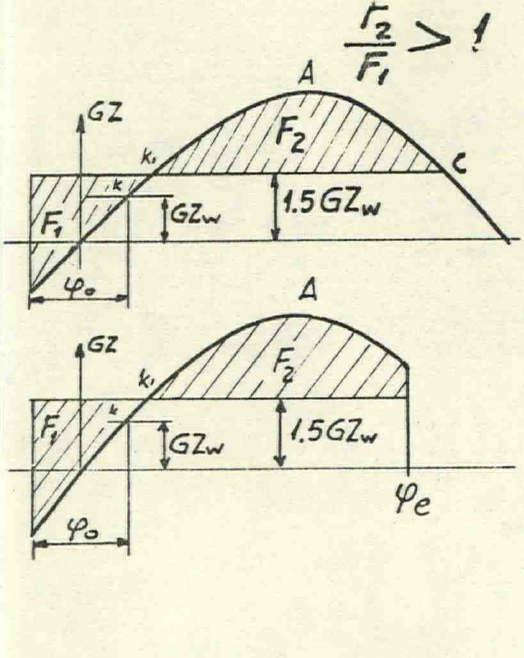


Fig. 14 - Dynamical Stability, according to Ministry of Transport of Japan

Fig. 14 - Stabilité dynamique, selon le Ministère des transports du Japon

Gráfica 14 - Estabilidad dinámica según el Ministerio de Transportes del Japón

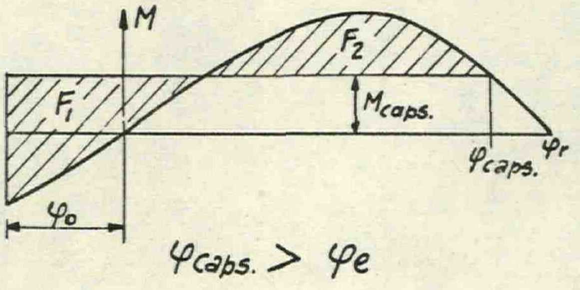


Fig. 15 - Dynamical stability, according to U.S.S.R. Register

Fig. 15 - Stabilité dynamique, selon le Registre de l'URSS

Gráfica 15 - Estabilidad dinámica según el Registro de la U.R.S.S.

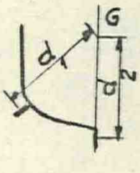


Fig. 16 - Dynamical stability, according to U.S.S.R. Register; value of d_1 and d_2

Fig. 16 - Stabilité dynamique, selon le Registre de l'URSS; valeurs de d_1 et de d_2

Gráfica 16 - Estabilidad dinámica según el Registro de la U.R.S.S.; valores de d_1 y d_2