DRAUGHT MARGINS

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The January 1966 issue of the *International Hydrographic Review* included a paper by Dr. P.O. Fagerholm entitled "Concerning the margins between the draughts of ships and the depths of fairways". He mentioned in this paper that the Swedish Board of Shipping and Navigation had initiated the setting up of a Working Group to study this problem. Dr. Fagerholm acted as Chairman of the Working Group, but in January 1967 when he was engaged for work with the United Nations in Ceylon, the present writer (Forsström) took over as Chairman. The work was sponsored by Malmfonden, a Swedish foundation for research. The final report was submitted in December 1968 [1], and it deals especially with the increase in draught of ships due to squat and to wind waves.

In the case of squat the report makes special mention of the results obtained by Janssen-Schijf [2] and Sjoström [3]. At the request of the Working Group, studies of the increase in draught due to waves were carried out by the Swedish State Shipbuilding Experimental Tank and the Division of Ship Hydromechanics at the Chalmers University of Technology.

On the basis of these studies the report put forward a method for determining the probable maximum increase in draught at the bow when heading into an irregular sea provided the average wave period and significant wave height have been measured or computed. The use of this method implies that amplitude operators (*) have been obtained for the ship in question either by means of tests on models in a regular sea or else by calculation. A certain procedure is then applied to combine these operators with Pierson-Moscowitz wave spectra to obtain response spectra. On the basis of these response spectra it is possible to lay down non-dimensional spectrum operators expressing the relationship between wave height and change in draught on the same level of probability as a function of the average period of the wave spectrum. A diagram can then be

(*) Mathematic formulae for computing the amplitude of the vertical movement.

prepared in which the average wave period and significant wave height can be used to read off the most probable maximum increase in draught at the bow during, for example, 1 000, 1 500, 3 000, 6 000, and 12 000 wave encounters.

When calculating the amplitude operators, consideration may be given to the increased damping in shallow waters down to a ratio of 1.5 between water depth and ship draught.

This has been pointed out by KIM [4] and [5], but unfortunately his method does not converge for values of this ratio smaller than 1.5. Later TASAI and KIM [6] made experiments that confirm KIM's theory, and they also extrapolated the results down to a depth/draught ratio of 1.1, which is a lower value than KIM's theory admits. As could be expected the motions of the ship decrease with decreasing values of this ratio.

The method of calculation presented applies only to changes in draught at the bow when heading into irregular sea. It should not therefore be precluded that the increase in draught may be larger at some other point on the ship, such as the turn of the bilge, when running at a different angle to the waves. It ought also to be possible to determine such an increase in draught by the same basic procedure, but additional model tests would be required to obtain the amplitude operators.

The results obtained by the Working Group are based entirely on theoretical calculations. It would be desirable for these results to be verified by practical tests. This has not been possible, however, owing to limited financial resources.

The authors of the Dutch report to the 1969 PIANC Congress in Paris [7] considered the same basic solution, but the results are not yet published. Since in the Netherlands there is the capability for carrying out the necessary model tests, it will be very interesting to study the results obtained in that country which are expected to be published shortly.

Whilst awaiting this information, a short report on the results of the Swedish investigation may be of interest. These results are presented in the form of various diagrams.

The diagrams apply to ships of different sizes provided that they are geometrically similar, and have the same block coefficients and L/B (Length/Breadth) and B/T (Breadth/Draught) ratios indicated in the diagrams. The diagrams are based on the Pierson-Moscowitz wave spectra, and can be applied anywhere. Local conditions will be reflected by the values for the average wave frequency and significant wave height. These later parameters must be obtained by measurement or calculation.

The diagrams have been prepared by one of the present writers (WAHL) and are utilized as indicated by the families of curves shown.

Diagram No. 1 shows the effect of speed on the increase in draught for different values of the Froude number $v/\sqrt{gL}$, where v = velocity of the ship, g = acceleration due to gravity, and L = length of the ship.

Diagram No. 2 shows the effect of the radius of gyration, k_{yy}, where $k_{yy} = 0.25$ L approximately corresponds to a normally loaded ship, k_{yy} =

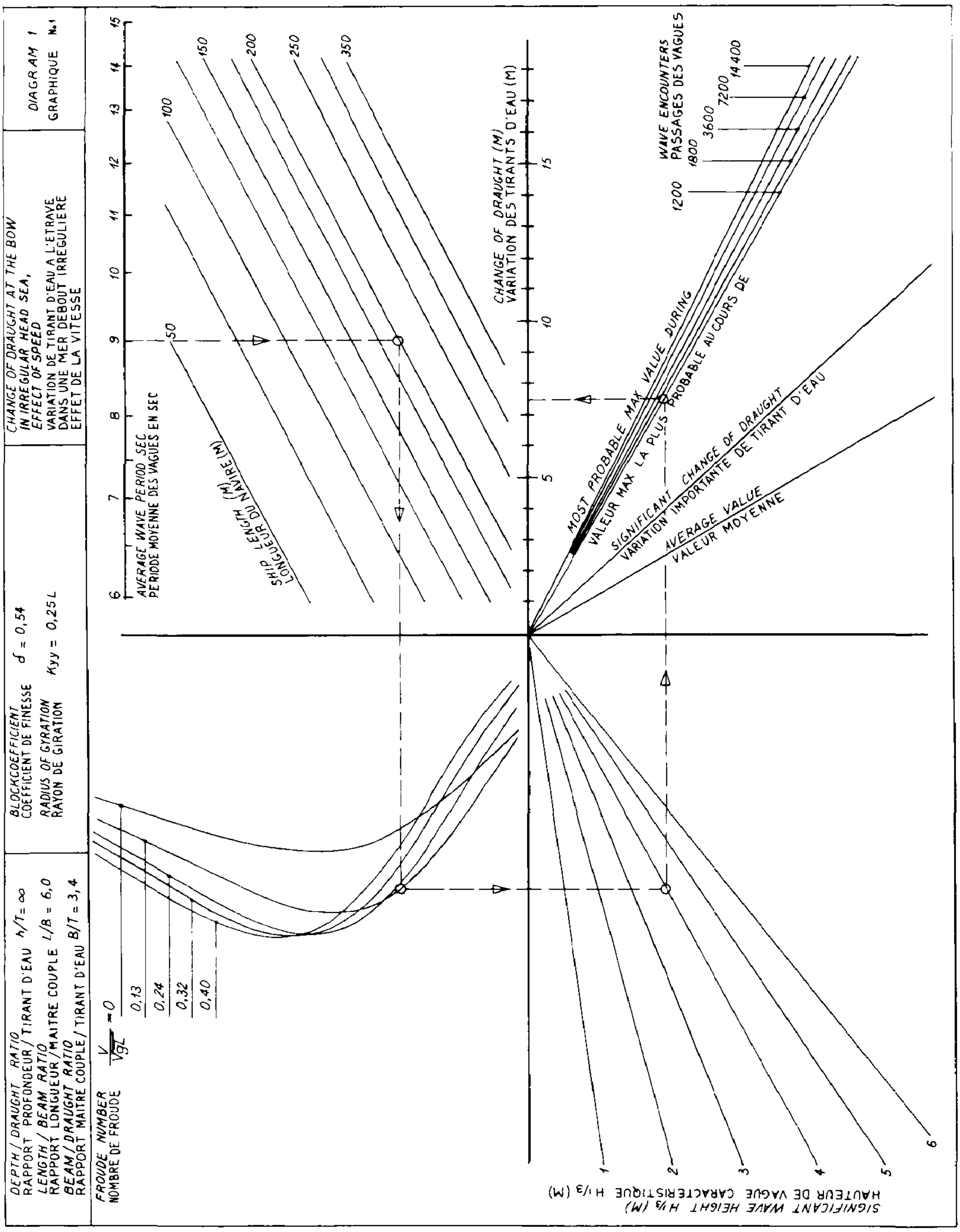
DIAGRAM 1
GRAPHIQUE N.1
CHANGE OF DRAUGHT AT THE BOW IN IRREGULAR HEAD SEA, EFFECT OF SPEED
VARIATION DE TIRANT D'EAU A L'ETRAVE DANS UNE MER DEBOUT IRREGULIERE EFFET DE LA VITESSE
BLOCKCOEFFICIENT COEFFICIENT DE FINESSE δ = 0,54
RADIUS OF GYRATION RAYON DE GIRATION Kyy = 0,25 L
DEPTH / DRAUGHT RATIO RAPPORT PROFONDEUR / TIRANT D'EAU h/T = ∞
LENGTH / BEAM RATIO RAPPORT LONGUEUR / MAITRE COUPLE L/B = 6,0
BEAM / DRAUGHT RATIO RAPPORT MAITRE COUPLE / TIRANT D'EAU B/T = 3,4
FROUDE NUMBER NOMBRE DE FROUDE
0,13
0,24
0,32
0,40
AVERAGE WAVE PERIOD SEC
PERIDDE MOYENNE DES VAGUES EN SEC
SHIP LENGTH (M)
LONGUEUR DU NAVIRE (M)
CHANGE OF DRAUGHT (M)
VARIATION DES TIRANTS D'EAU (M)
WAVE ENCOUNTERS
PASSAGES DES VAGUES
MOST PROBABLE MAX VALUE DURING
VALEUR MAX LA PLUS PROBABLE AU COURS DE
SIGNIFICANT CHANGE OF DRAUGHT
VARIATION IMPORTANTE DE TIRANT D'EAU
AVERAGE VALUE
VALEUR MOYENNE
SIGNIFICANT WAVE HEIGHT H1/3 (M)
HAUTEUR DE VAGUE CARACTERISTIQUE H1/3 (M)

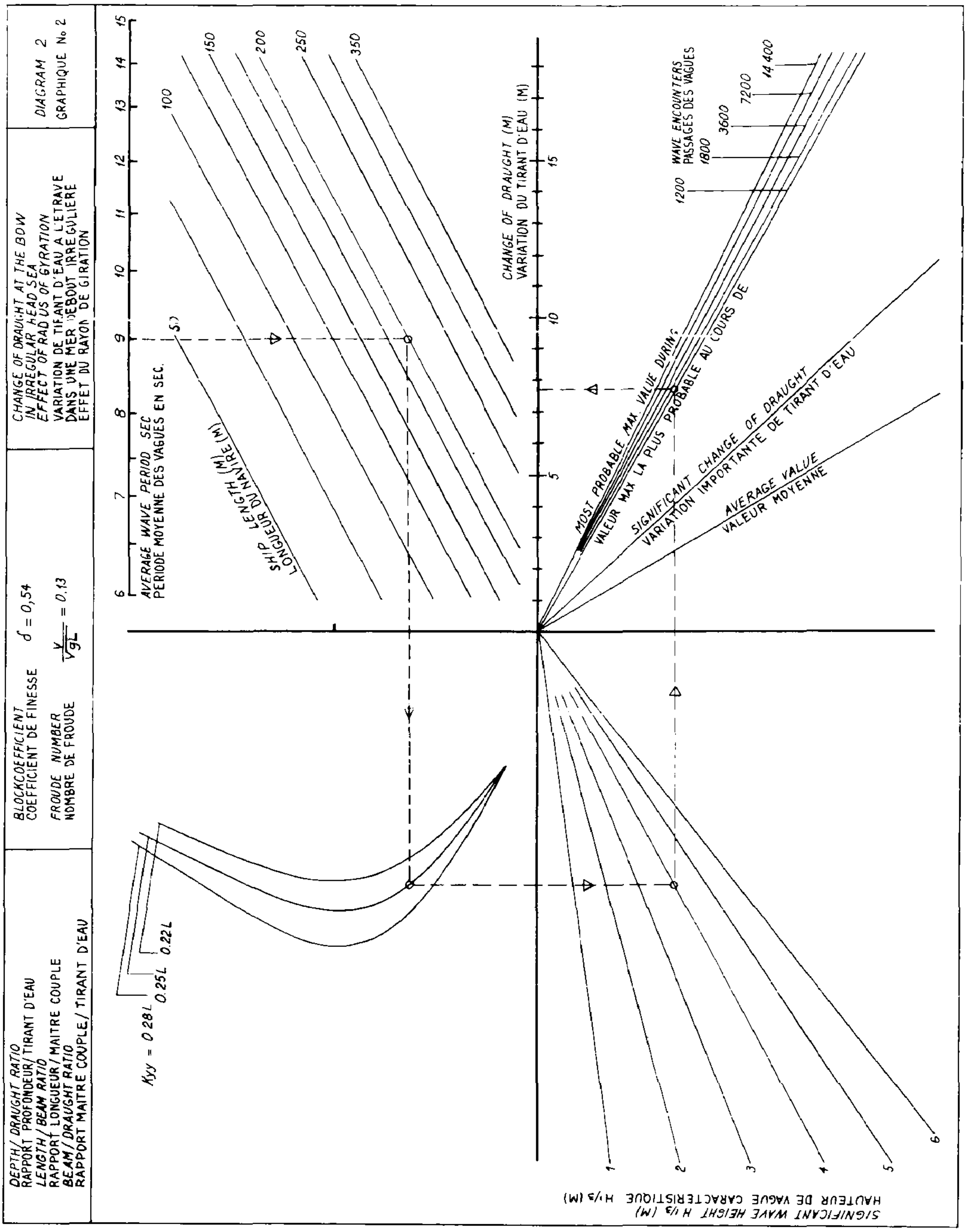
DIAGRAM 2
GRAPHIQUE No 2
CHANGE OF DRAUGHT AT THE BOW IN IRREGULAR HEAD SEA
EFFECT OF RADIUS OF GYRATION
VARIATION DE TIRANT D'EAU A L'ETRAVE DANS UNE MER DEBOUT IRREGULIERE
EFFET DU RAYON DE GIRATION
BLOCKCOEFFICIENT
COEFFICIENT DE FINESSE
δ = 0,54
FROUDE NUMBER
NOMBRE DE FROUDE
$\frac{V}{\sqrt{gL}} = 0.13$
DEPTH/DRAUGHT RATIO
RAPPORT PROFONDEUR/TIRANT D'EAU
LENGTH/BEAM RATIO
RAPPORT LONGUEUR/MAITRE COUPLE
BEAM/DRAUGHT RATIO
RAPPORT MAITRE COUPLE/TIRANT D'EAU
AVERAGE WAVE PERIOD SEC
PERIODE MOYENNE DES VAGUES EN SEC.
SHIP LENGTH (M)
LONGUEUR DU NAVIRE (M)
50
100
150
200
250
350
CHANGE OF DRAUGHT (M)
VARIATION DU TIRANT D'EAU (M)
WAVE ENCOUNTERS
PASSAGES DES VAGUES
1200
1800
3600
7200
14400
MOST PROBABLE MAX. VALUE DURING
VALEUR MAX LA PLUS PROBABLE AU COURS DE
SIGNIFICANT CHANGE OF DRAUGHT
VARIATION IMPORTANTE DE TIRANT D'EAU
AVERAGE VALUE
VALEUR MOYENNE
Kyy = 0.28L
0.25L
0.22L
SIGNIFICANT WAVE HEIGHT H 1/3 (M)
HAUTEUR DE VAGUE CARACTERISTIQUE H 1/3 (M)

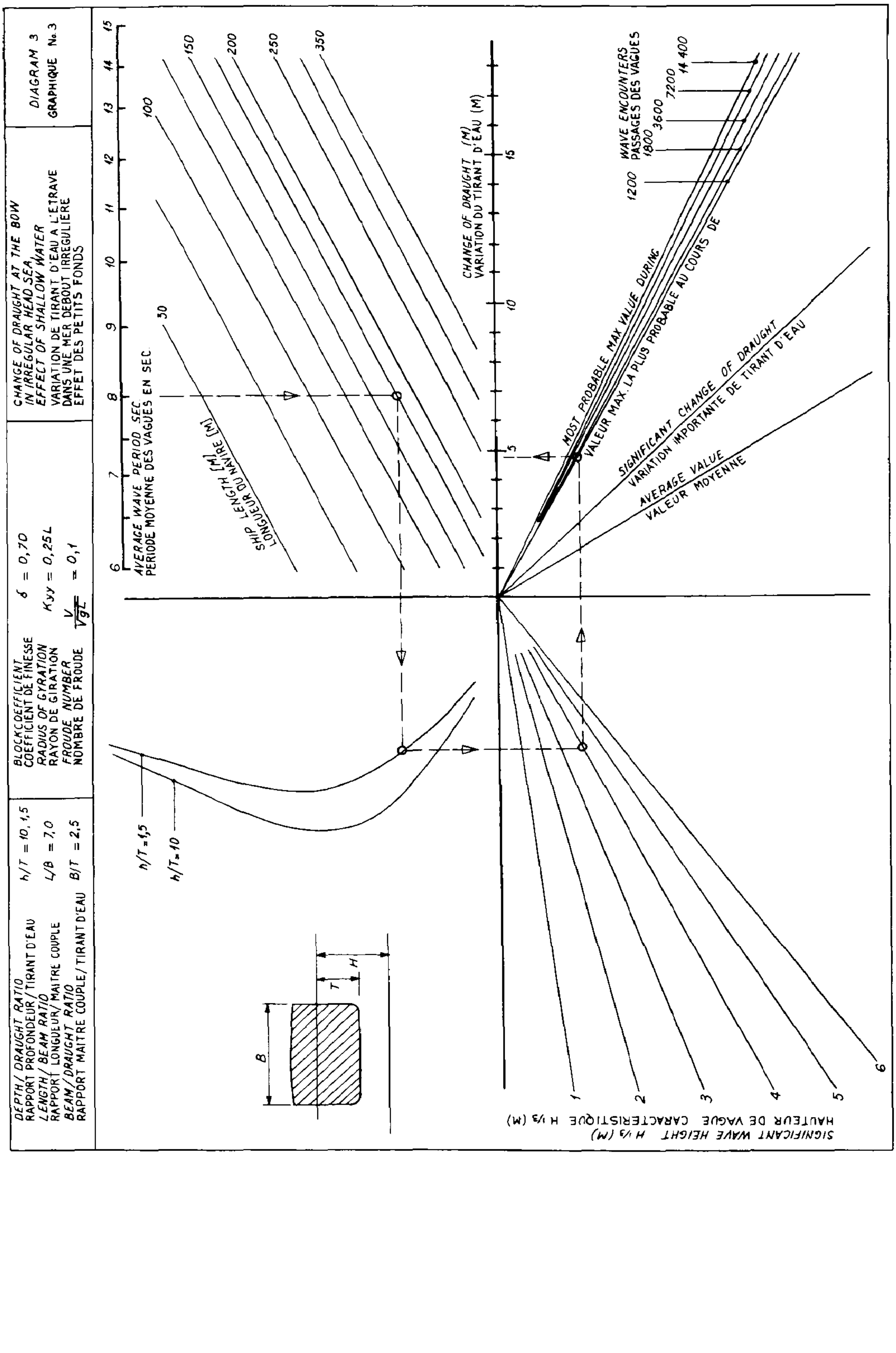
DIAGRAM 3
GRAPHIQUE No. 3
CHANGE OF DRAUGHT AT THE BOW IN IRREGULAR HEAD SEA, EFFECT OF SHALLOW WATER
VARIATION DE TIRANT D'EAU A L'ETRAVE DANS UNE MER DEBOUT IRREGULIERE EFFET DES PETITS FONDS
BLOCKCOEFFICIENT
COEFFICIENT DE FINESSE
δ = 0,70
RADIUS OF GYRATION
RAYON DE GIRATION
Kyy = 0,25 L
FROUDE NUMBER
NOMBRE DE FROUDE
V/√gL = 0,1
DEPTH/DRAUGHT RATIO
RAPPORT PROFONDEUR/TIRANT D'EAU
h/T = 10, 1,5
LENGTH/BEAM RATIO
RAPPORT LONGUEUR/MAITRE COUPLE
L/B = 7,0
BEAM/DRAUGHT RATIO
RAPPORT MAITRE COUPLE/TIRANT D'EAU
B/T = 2,5
AVERAGE WAVE PERIOD SEC.
PERIODE MOYENNE DES VAGUES EN SEC.
6 7 8 9 10 11 12 13 14 15
SHIP LENGTH [M]
LONGUEUR DU NAVIRE [M]
30 100 150 200 250 350
CHANGE OF DRAUGHT (M)
VARIATION DU TIRANT D'EAU (M)
5 10 15
WAVE ENCOUNTERS
PASSAGES DES VAGUES
1200 1800 3600 7200 14 400
MOST PROBABLE MAX VALUE DURING
VALEUR MAX. LA PLUS PROBABLE AU COURS DE
SIGNIFICANT CHANGE OF DRAUGHT
VARIATION IMPORTANTE DE TIRANT D'EAU
AVERAGE VALUE
VALEUR MOYENNE
h/T = 1,5
h/T = 10
B
T
H
1 2 3 4 5 6
SIGNIFICANT WAVE HEIGHT H 1/3 (M)
HAUTEUR DE VAGUE CARACTERISTIQUE H 1/3 (M)

0.28 L to a ship with a hogging load, and $k_{yy} = 0.22$ L to a ship with a sagging load.

Diagram No. 3 shows the effect of shallow water. Unfortunately the calculations do not converge for values of h/T (ratio of water depth to ship draught) lower than 1.5. (See above.)

Diagram No. 4 shows the increase in draught at the bilge due to pure rolling in an irregular short-crested sea for different main wave directions.

Finally, diagram No. 5 shows how each individual ship may be given a simplified diagram that applies to it alone. Here it is possible to plot the curves with regard to the damping effect down to a h/T ratio of 1.5. (This *particular* diagram, however, only applies to deep water.) The diagram included here applies to a normally loaded ship.

Diagrams Nos. 1, 2, and 5 apply to modern container ships with a block coefficient of 0.54, an L/B ratio of 6.0 and a B/T ratio of 3.4, while diagrams Nos. 3 and 4 apply to tankers with a block coefficient of 0.70, an L/B ratio of 7.0 and a B/T ratio of 2.5.

If verified by full-scale measurements, the results obtained may give reason for hoping that in the not too distant future all ships can be given diagrams similar to diagram No. 5, but indicating for each its own maximum increase in draught when running in a head sea, bow sea, beam sea, quartering sea, or following sea. At the same time there is of course the dream that every critical section of a channel will be equipped with a recording wavemeter which continuously and automatically calculates the mean wave period and significant wave height, and in addition indicates the main wave direction, and all this information the ship's master would obtain simply by calling a certain telephone number. If he could then obtain information on the height of the water and the direction of the current in the same manner, and also has access to a table giving the squat of his ship at different speeds and water depths, this would mean that all aids are provided to enable the master to assess with good reliability the risks in negotiating a critical section of channel under the prevailing weather conditions. If the channel depth has been determined by means of the sweep-bar method, all the necessary background data will then be available for a meaningful discussion on which safety margins to apply in the various channels, particularly with regard to the statistical distribution of the wave heights.

It may be of interest to examine a few examples of the magnitude of changes in draught at the bow in a head sea, as determined by the calculation method just outlined.

The calculations concern a section of channel at the entrance to the Baltic from the Great Belt, just south-east of the Danish island Mön, where the charted depth is 17 - 18 metres. The calculations refer to fully loaded tankers of 10 000 to 150 000 tons d.w., with a block coefficient of 0.70 an L/B ratio of 7.0, and a B/T ratio of 2.5, and using a water depth/draught ratio of 1.5. They apply to the specific conditions of a well-established sea and for east-north-easterly winds of either 15 or 25 m/s. Wave characteristics (height, H, and period, T) were determined theoretically, with the following results :

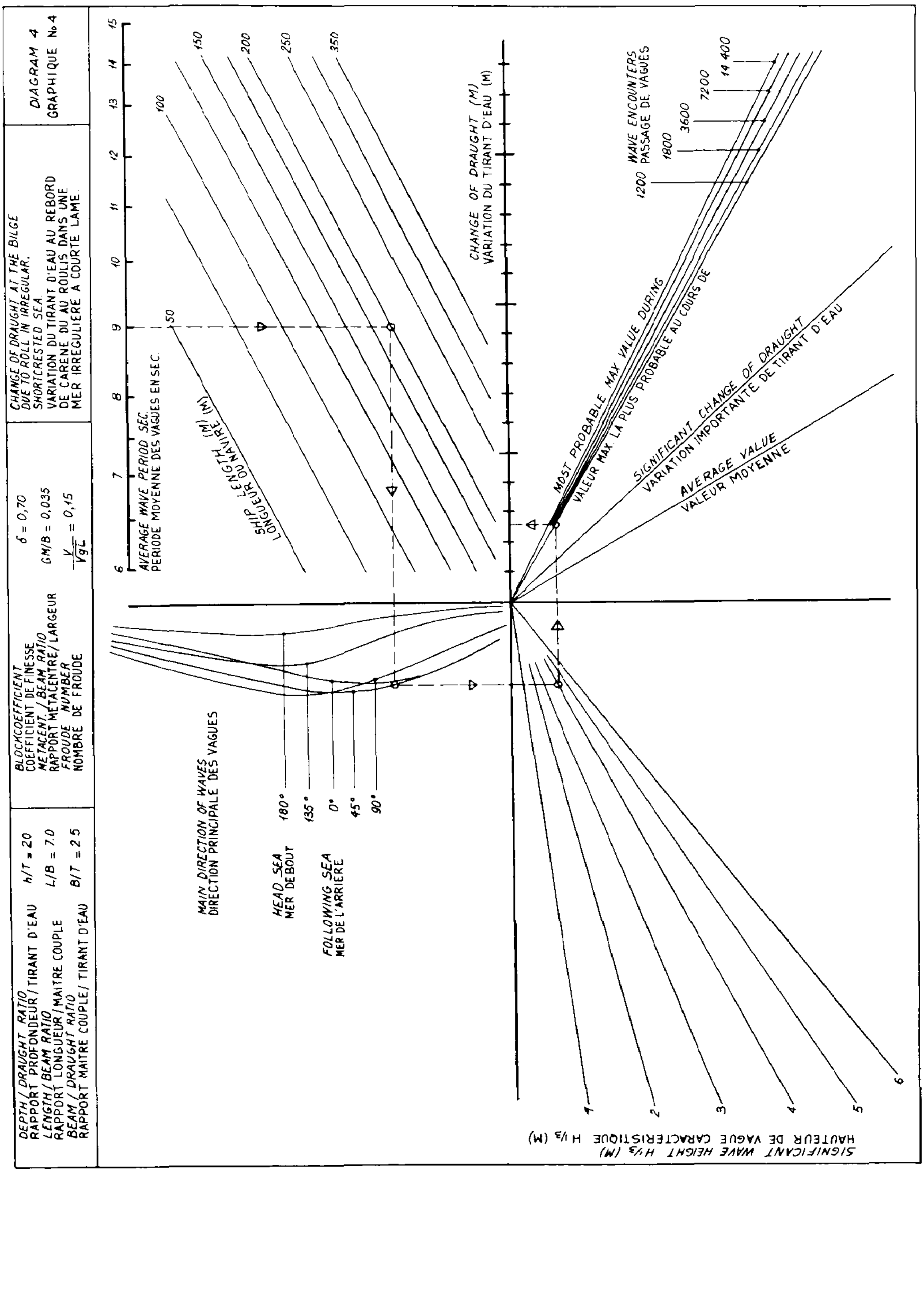
DIAGRAM 4
GRAPHIQUE No 4
CHANGE OF DRAUGHT AT THE BILGE DUE TO ROLL IN IRREGULAR, SHORTCRESTED SEA.
VARIATION DU TIRANT D'EAU AU REBORD DE CARENE DU AU ROULIS DANS UNE MER IRREGULIERE A COURTE LAME.
BLOCKCOEFFICIENT
COEFFICIENT DE FINESSE
METACENT./BEAM RATIO
RAPPORT METACENTRE/LARGEUR
FROUDE NUMBER
NOMBRE DE FROUDE
δ = 0,70
GM/B = 0,035
$\frac{v}{\sqrt{gL}}$ = 0,15
DEPTH/DRAUGHT RATIO
RAPPORT PROFONDEUR/TIRANT D'EAU
LENGTH/BEAM RATIO
RAPPORT LONGUEUR/MAITRE COUPLE
BEAM/DRAUGHT RATIO
RAPPORT MAITRE COUPLE/TIRANT D'EAU
h/T = 20
L/B = 7.0
B/T = 2.5
AVERAGE WAVE PERIOD SEC.
PERIODE MOYENNE DES VAGUES EN SEC.
6
7
8
9
10
11
12
13
14
15
SHIP LENGTH (M)
LONGUEUR DU NAVIRE (M)
50
100
150
200
250
350
CHANGE OF DRAUGHT (M)
VARIATION DU TIRANT D'EAU (M)
WAVE ENCOUNTERS
PASSAGE DE VAGUES
1200
1800
3600
7200
14 400
MOST PROBABLE MAX VALUE DURING
VALEUR MAX. LA PLUS PROBABLE AU COURS DE
SIGNIFICANT CHANGE OF DRAUGHT
VARIATION IMPORTANTE DE TIRANT D'EAU
AVERAGE VALUE
VALEUR MOYENNE
MAIN DIRECTION OF WAVES
DIRECTION PRINCIPALE DES VAGUES
180°
135°
0°
45°
90°
HEAD SEA
MER DE BOUT
FOLLOWING SEA
MER DE L'ARRIERE
1
2
3
4
5
6
SIGNIFICANT WAVE HEIGHT H1/3 (M)
HAUTEUR DE VAGUE CARACTERISTIQUE H1/3 (M)

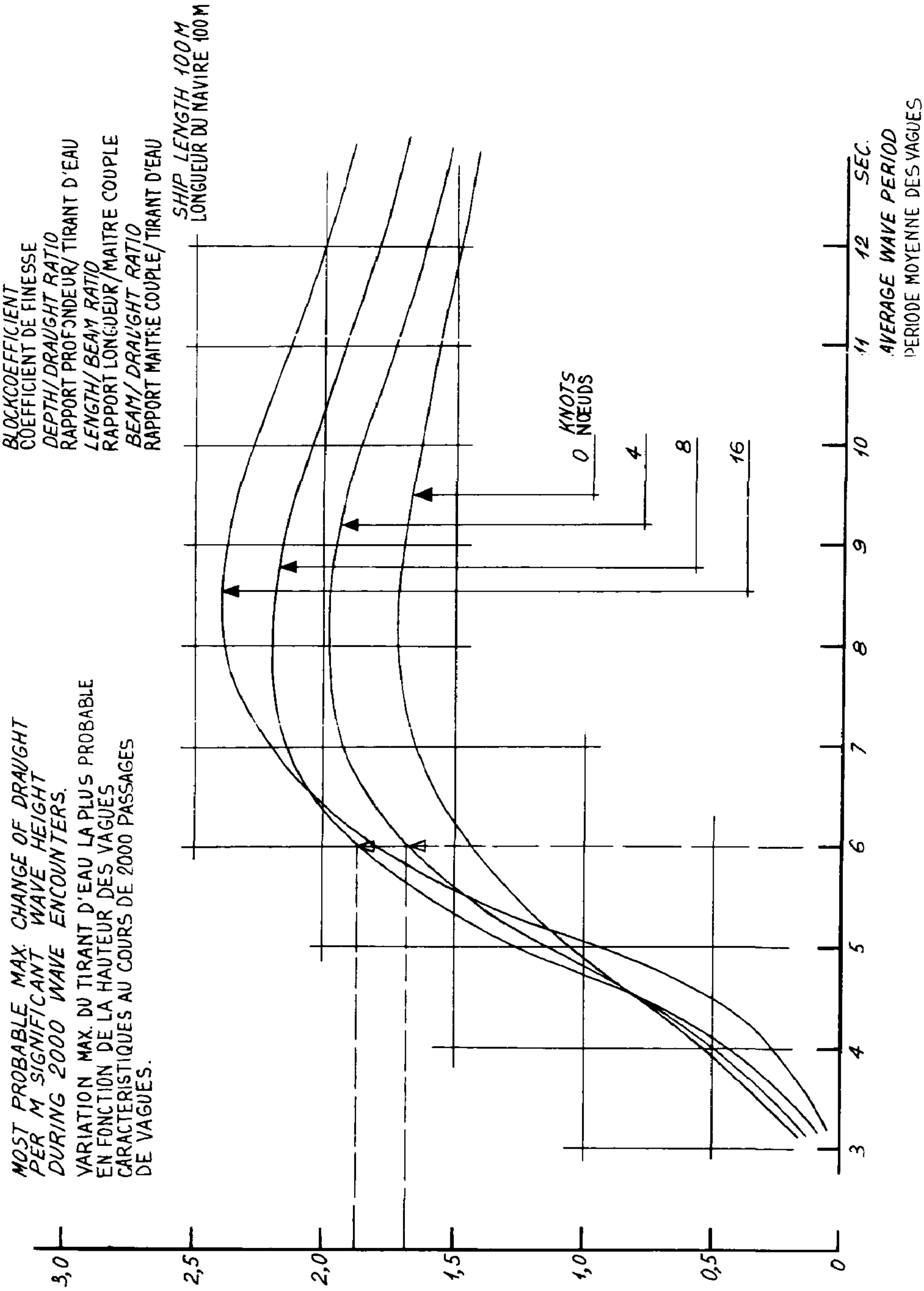
DIAGRAM 5
GRAPHIQUE No.5
MOST PROBABLE MAX. CHANGE OF DRAUGHT PER M SIGNIFICANT WAVE HEIGHT DURING 2000 WAVE ENCOUNTERS.
VARIATION MAX. DU TIRANT D'EAU LA PLUS PROBABLE EN FONCTION DE LA HAUTEUR DES VAGUES CARACTERISTIQUES AU COURS DE 2000 PASSAGES DE VAGUES.
BLOCKCOEFFICIENT
COEFFICIENT DE FINESSE
DEPTH/DRAUGHT RATIO
RAPPORT PROFONDEUR/TIRANT D'EAU
LENGTH/BEAM RATIO
RAPPORT LONGUEUR/MAITRE COUPLE
BEAM/DRAUGHT RATIO
RAPPORT MAITRE COUPLE/TIRANT D'EAU
SHIP LENGTH 100M
LONGUEUR DU NAVIRE 100 M
0 KNOTS
NŒUDS
4
8
16
3,0
2,5
2,0
1,5
1,0
0,5
0
3
4
5
6
7
8
9
10
11
12
SEC.
AVERAGE WAVE PERIOD
PERIODE MOYENNE DES VAGUES

15 m/s : $H_{sign.} = 2.9$ m $T_{average} = 6.9$ s

25 m/s : $H_{sign.} = 4.4$ m $T_{average} = 9.1$ s

Unfortunately it has not yet been possible to carry out any wave measurements to verify these results.

On the basis of a knowledge of the conditions in other parts of the Baltic the wave heights appear to be of the correct magnitude, while the wave periods may seem somewhat too long.

Based on the values indicated above, the following most probable maximum increases in draught at the bow have been obtained for 1 200 wave encounters corresponding to an approximate 2-hour period in the channel in question for an average wave period of 6.9 seconds and a speed of 8 knots.

TABLE 1

Estimated increase in draught at the bow due to squat and to irregular head sea passing the fairway in the Baltic SE of the Danish island Mön (water depth 17-18 m).

Wind direction ENE, well established sea at wind speeds of 15 and 25 m/sec.
Type of ship : tanker
Block coefficient : 0.7.

L/B = 7.0
B/T = 2.5
h/T = 1.5

Size of ship tons d.w.	Ship's speed knots	Ship's draught m	Squat at a depth of 17.5 m	Most probable max. change of draught at the bow in irregular head sea during 1200 wave encounters (corresponding to about a 2-hour passage through this fairway) 15 m/sec m	25 m/sec m	Most probable max. draught at the bow below calm water level in irregular head sea during 1200 wave encounters (squat included). 15 m/sec m	25 m/sec m
10 000	3.6	8	0.05	2.3	5.4	10.4	13.5
10 000	7.2	8	0.15	2.5	5.9	10.7	14.1
10 000	10.8	8	0.35	2.4	6.2	10.8	14.6
20 000	4.0	10	0.05	1.7	4.8	11.8	14.9
20 000	7.9	10	0.20	1.7	5.2	11.9	15.4
20 000	12.0	10	0.60	1.6	5.3	12.2	15.9
50 000	4.4	12	0.10	1.2	4.4	13.3	16.5
50 000	8.8	12	0.35	0.9	4.2	13.5	16.7
50 000	13.3	12	0.95	0.9	4.2	13.9	(17.2)
100 000	4.9	15	0.10	0.8	2.9	15.9	(18.0)
100 000	9.8	15	0.50	0.7	3.1	16.2	(18.6)
100 000	14.8	15	1.70	0.6	2.9	(17.3)	(19.6)
150 000	5.1	16	0.15	0.7	2,6	16.9	(18.8)
150 000	10.2	16	0.65	0.6	2.7	(17.3)	(19.4)
150 000	15.3	16	2.05	0.5	2.4	(18.6)	(20.5)

As could be expected, the magnitude of any increase in draught is greatly reduced with increased ship size. In the case of larger ships the increase in draught is also reduced somewhat with increasing speed. This difference, however, is not significant.

As mentioned above the increase in draught is likely to be even smaller for the larger ships, due to greater damping, for a depth/draught ratio of less than 1.5.

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