Polski Rejestr Statków

RULES

PUBLICATION NO. 6/P

STABILITY

2006
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Publications P (Additional Rule Requirements) issued by Polski Rejestr Statków complete or extended the Rules and are mandatory where applicable.

GDAŃSK

Publication No. 6/P – Stability – 2006 is an extension of the requirements contained in *Part IV – Stability and Subdivision* of the *Rules for the Classification and Construction of Sea-going Ships.*

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1 INCLINING TEST

1.1 General

The inclining test (experimental determination of the ship's centre of mass) is to be carried out in the presence of PRS' Surveyor. Angles of heel are measured by means of pendulums or special measuring devices approved by PRS.

1.2 Weather Conditions and Mooring Arrangements

Where possible, the inclining test is to be performed in a calm, sheltered area free from extraneous forces such as propeller wash from passing vessels, sudden discharges from shore-side pumps, etc. It is recommended that the wind velocity should not exceed 3 m/s.

Where tidal currents are present, the inclining test is to be conducted at or around slack tide.

The inclining test is not to be carried out under the influence of wind and currents if the accuracy of the test cannot be assured.

The depth of water is to be sufficient to ensure that the hull will be entirely free of the bottom during the test.

Prior to the test, the depth of water is to be measured in as many locations as necessary to ensure that the above requirement will be complied with, taking into account tide differences, if applicable.

Mooring lines should be free of any transverse tension during the reading after each weight shift.

The ship is to be moored by bow and stern lines on both sides attached at or near the centreline of the ship. Longitudinal mooring lines are to be as long as practicable.

A ship may be moored by bow and stern lines on one side only and supplemented by spring lines.

PRS' Surveyor may accept a single bow or stern line, provided he is satisfied that the ship's freedom of movement will not adversely affect the conduct of the inclining test.

1.3 Preparations for the Inclining Test

The ship to be tested is to be, where possible, in light ship condition – (see sub-chapter 1.3, *Part IV – Stability and Subdivision*). All components of the equipment and spare parts are to be in place.

All objects which may shift when the ship heels are to be secured. All tanks for water, water ballast, oil, fuel oil (except for fuel oil settling tanks) and other liquids are to be generally completely empty.

Boilers are to be filled with water up to their working level. Where the boilers are empty, the mass of water in the boilers is to be included in the list of mass to be added.

Prior to the inclining test, it is to be ensured that all holds and the engine room are drained and cleaned and that all objects on board have been taken into account.

In exceptional case, when emptying the tanks completely is not practicable, the value of free surfaces and the free surface effect are to be precisely calculated and taken into account in the calculation of metacentric height.

Particular tanks on the ship may be completely filled, but in such case appropriate measures are to be taken to preclude formation of air pockets in the tanks.

In flat bottom ships, after pumping out liquids from the hull, the liquids remaining below the strainers are to be completely drained off.

In ships with deadrise, having inclined bottom, in which liquid cannot be pumped out dry, water in a quantity up to 0.05 m in depth is permitted to remain amidships in the wedge shaped part of the ship. In winter, the inclining test may be performed, provided the ship's hull is not iced. Snow or ice accumulated on the ship should be removed prior to the test. The inclining test shall not be conducted in heavy snow.

Prior to the test, the ship is to be upright. An initial list of the ship not exceeding 0.5° is permissible. The ship's trim is to correspond to the light ship trim (see sub-chapter 1.3, *Part IV – Stability and Subdivision*).

1.4 Test Weights

The total mass of test weights used is to be sufficient to provide a minimum heel angle of 1° and a maximum heel angle of 4° to each side, from upright.

Test weights are to be compact and of such configuration that their centre of gravity may be accurately determined, e.g. sandbags (impervious to water), boxes, etc. Each test weight is to be marked with an identification number.

The value of particular test weights is to be known, should have been weighed in presence of PRS' Surveyor, attending the test on instrument with valid verification certificate

The test weights are to be located on the upper deck along the ship's sides, divided into not less than four groups, approximately equal in mass, symmetrically with respect to the centre of gravity of the actual warterline.

The total inclining mass to be used for the test is to correspond to the calculated mass within accuracy of 0.5%.

Use of water ballast transfer to incline the ship may be permitted only in cases where it is absolutely impractical to incline the ship using solid weights. In such case testing procedure is to be submitted to PRS for approval.

1.5 Masses to be Deducted and Masses to be Added

Prior to the inclining test, a list is to be prepared which will contain masses to be deducted and masses to be added in relation to the masses provided in the light ship condition, specifying their location on board – the distance from the base plane and the midship (see Tables 6 and 7 – an example of the inclining test report, para. 2.2). The values and coordinates of masses to be added are to be determined with the greatest possible accuracy. The total value of masses to be added is not to exceed 2% and the total value of masses to be deducted (without test weights) is not to exceed 4% of the light ship displacement. For small ships, the percentage of the total masses to be deducted and added may be increased, subject to the agreement of PRS' Surveyor.

1.6 Determination of Heeling Angles

To determine the angles of heel, plumb lines (pendulums), U-tubes, inclinometers or other measuring devices may be used.

If a plumb line used consists of a weight suspended from a cord (hereinafter referred to as a pendulum), its length is to be as great as possible for a given ship. It is recommended that for large ships, the pendulum lengths be 4–6 m and for smaller ships – at least 1.5 m. The pendulum weight is to be placed in a through filled with water or oil to dampen the oscillations of the pendulum. A winged plumb bob is to be used.

A minimum two pendulums are to be used; the use of three pendulums is recommended. The places of pendulums suspension are to be arranged lengthwise. To take readings of heeling angles, a horizontal wooden batten provided with a scale is to be mounted close to the plumb bob.

The extreme deflections of the pendulum to the right and left for 4–5 full swings are to be recorded in the relevant form. An arithmetic mean of 8–10 records of the pendulum extreme deflections to one side and to the other side is to be accepted as the actual reading.

The pendulum length l is to be measured from its point of suspension to the recording batten on which deflections are read.

When using other measuring devices, the angles of heel are to be recorded according to instructions supplied with each device.

1.7 Measurement of Draught and Calculation of Displacement

The draught of the ship is to be precisely measured at draught marks immediately before the inclining test. In addition, at least 4 check freeboard readings are to be taken (on portside and starboard side). All personnel who will be present on board during the test should be on board during these readings.

For small ships, the draught and freeboard readings are to be taken from a small boat. Where it is necessary to take the draught and freeboard readings from the ship's side, the list and trim effects of the measuring persons are to be counterbalanced in such a way that they move simultaneously along the ship's side in opposite (towards the bow and stern) directions.

To facilitate the draught measurement in a slightly waved sea, it is advisable to use a glass tube open on both ends, immersing one end of the tube in water.

The draught and freeboard readings are to be taken on each side of the ship. To eliminate the effect of initial heeling, the arithmetic mean is to be taken. The draught is to be measured to 0.01 m accuracy.

To control the correctness of draught measurements, two waterlines are to be plotted on the lines drawing – by draught marks and by measured values of the freeboard. With correct measurements, both waterlines should coincide. If there is a slight difference between the waterlines, the average position of the waterline is to be taken. In the case of greater differences, the draught and freeboard readings are to be retaken. A document confirming correctness of draught marks is to be available on board.

Prior to the test, soundings of tanks are to be executed. Sea water density is to be determined – samples are to be taken from a sufficient depth of the water and the water density is to be determined by a hydrometer.

Account is to be taken of the fact that certain ship hulls are subject to sagging and hogging. Such ship hull deformation is to be taken into consideration in displacement calculations.

Ship displacement is to be determined using the drawing of hydrostatic curves calculated with regard to trim or is to be calculated using Bonjean scale. The draught readings are to be corrected with respect to the base plane for which hydrostatic curves have been calculated.

Ship displacement D is to be determined from the formula:

$$D = \rho \cdot V \cdot k$$

ρ – water density, [t/m^3];
V – volume displacement, [m^3];
k – dimensionless coefficient taking into account displacement of appendages and shell plating.

1.8 Performance of Inclining Test by Shifting Test Weights

The sequence of shifting four test weights is to be as indicated in Fig. 1.8.

During each inclination make sure that nothing interferes with the heeling of the ship. For large ships, six test weights may be used. In such case, testing procedure is to be separately agreed with PRS.

On completion of the test, the following are to be entered in the inclining test report: absolute values of the pendulums deflections, the value of the shifted weights, the shifting arm for each reading and draught values (example of the inclining test report – see para. 2.2).

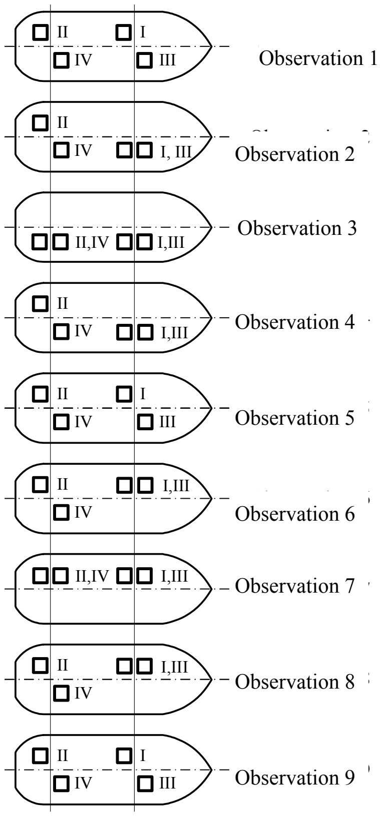

Fig. 1.8 Test weights shifting sequence

1.9 Use of Inclinometers

Not less than two inclinometers are to be used. The devices are to be placed in different spaces athwarthips at a distance not greater than 0.25 of the ship's length *L* from the midship close to the centreline, on tables efficiently secured to the hull.

Inclinometers are to be prepared for the test in accordance with operating instructions and are to be provided with a valid calibration certificate.

1.10 Test Error

The metacentric height is to be taken as the arithmetic mean value obtained from individual inclinations (observations 2, 3, 4, 6, 7 and 8 according to Fig. 1.8). The method of determining the metacentric height and the probable absolute error of the test result is given in para. 2.3 (an example of the inclining test results elaboration).

During the test performance, some readings may be found, for various reasons, inaccurate; when elaborating the test results, such readings should be neglected. To discover inaccurate readings, a control diagram may be constructed; the values of the heeling moments are to be plotted along the axis of ordinates and the corresponding tangents of the heeling angles, measured for pendulum separately – along the axis of abscissa. The plotted points should lie on an inclined straight line passing through the origin of the coordinates. The points lying significantly far from the straight line are indicators of inaccurate readings. An example of control diagram is shown in Fig. 1.10.

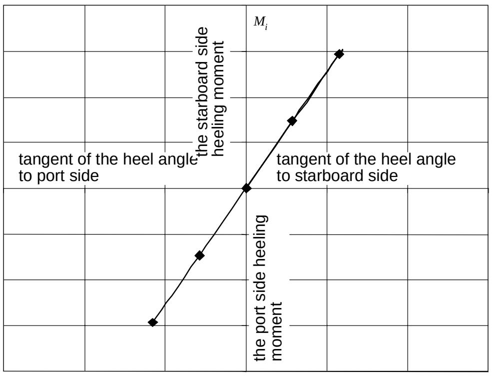

Fig. 1.10 A control diagram of the inclining moment M_i, versus tangent of the heeling angle φ

1.10.1 Relative mean square error of the initial metacentric height ε_{GM} is to be calculated from the formula:

$$\varepsilon_{GM} = \frac{1}{GM_{sr}} t_{\alpha n} \sqrt{\frac{\Sigma(GM_i - GM_{sr})^2}{n(n-1)}} \qquad (1.10.1)$$

where:

n – number of readings; $n = 6$.

$t_{\alpha n}$ – coefficient resulting from the assumption that distribution of error probability density corresponds to Student's *t* distribution with *n* degree of freedom; for $n = 6$, $t_6 = 1.13$, and for $n = 8$, $t_8 = 1.09$ (mean square error confidence level = 68.3%),

GM_i – metacentric height for the subsequent reading, [m],

GM_{sr} – arithmetic mean of the initial metacentric heights from particular readings (6 readings), [m].

1.10.2 Mean square error in ship displacement determination, ε_D, is to be calculated from the formula:

$$\varepsilon_D = \frac{\rho \cdot g \cdot F \cdot \Delta T}{D\sqrt{3}} \qquad (1.10.2)$$

where:

ρ – water density, [t/m^3],

g – acceleration of gravity, [m/s^2],

F – area of waterline, [m^2],
D – ship displacement during the test, [t],
ΔT– draught reading error (to be taken not greater than 0.01 m).

1.10.3 The total test relative mean square error ε is equal to:

$$\varepsilon = \pm\sqrt{\varepsilon_{GM}^2 + \varepsilon_D^2} \tag{1.10.3-1}$$

Test absolute error is to be calculated from the formula:

$$\Delta GM = \pm\varepsilon\, GM_{sr} \tag{1.10.3-2}$$

where:
GM_{sr} – mean metacentric height under test conditions.

1.11 Trim Effect Consideration

If the ship' trim during the inclining test differs by more than 0.005*L* from the trim on which hydrostatic curves have been based, these curves cannot be used for test results elaboration. In this case, coordinates of the ship' s centre of mass in the xz axes connected with ship as shown in Fig. 1.2.3.1, *Part II – Hull*, under test conditions, are to be determined from the formulae:

$$x_G = x_{F\psi} \pm \left(r_\psi - GM_0\right)\sin\psi \tag{1.11-1}$$

sign „+" for trim by the stern,
sign „–" for trim by the head.

$$z_G = z_{F\psi} + \left(r_\psi - GM_0\right)\cos\psi \tag{1.11-2}$$

The coordinates $x_{F\psi}$ and $z_{F\psi}$ are to be determined using Bonjean scale and the integral curves of statical moments of the cross-section areas with respect to the base plane.

The metacentric radius r_ψ taking into account the ship's trim is to be calculated from the lines drawing containing the actual waterline; calculations are to be performed using the following formulae:

$$r_\psi = \frac{I_{x\psi}}{V_\psi}\text{, [m],} \tag{1.11-3}$$

$I_{x\psi}$ – transverse moment of inertia of waterline area, [m^4];

$I_{x\psi} = \frac{2}{3}\Delta L \Sigma y^3{}_\psi$,[m^4];

ΔL – station spacing [m];
y_ψ – actual waterline ordinate, [m];
V_ψ – ship displacement determined by Bonjean scale, with the draught up to the actual waterline (without taking into account appendages), [m^3];
GM_0 – calculated value of metacentric height, [m];
ψ – angle between *x* axis and horizontal line.

2 INCLINING TEST REPORT AND THE TEST RESULTS

2.1 Use of Test Results

Inclining test report constitutes part of the ship's stability booklet – see the *Rules for the Classification and Construction of Sea-going Ships, Part IV – Stability and Subdivision*, para. 1.6.11.6.9.

If preliminary calculations of stability are available for a ship under construction, alteration or repair, etc. and it is verified that the light ship mass and the height of the light ship centre of mass, determined during the inclining test, do not differ by more than 2% and 0.04 m or 2% (whichever is the lesser) from the predetermined values, the preliminary calculations may constitute a basis for the preparation of stability booklet.

2.2 Example of Inclining Test Report

Ship's principal dimensions: L = ……………….. [m]; B = …………… [m]; H = ……………….. [m]

1. Date of the test:
Test began at: ……..………………..., completed at: ……………………………………………...

2. Place of the test: ……………..…………………… Depth of water: …………..………………… [m]

3. Weather conditions: …………………………Wind velocity and direction: …………………… [m/s]

Condition of water surface (e.g. light swell, current, etc.): ……………………………………………..
Water temperature t = …………………….... [°C] Water density ρ = …………………….... [t/m^3]
Error in determining water density $\Delta\rho$ = ……………………………….. [t/m^3]

4. Composition of the team conducting the test and responsible for the accuracy of the test results:

Team principal: …………………………………………………………………………..….
Members: ……………………………………………………………………………….....
The test was conducted in the presence of PRS' Surveyor:……………………………………..…..

5. Pendulums observers: ……………………………………………………………

6. Other particulars (e.g. ship's position, initial heel, method of inclination, etc.):
……………………………………………………………………………………………

7. Ship's draught from the base plane during the test ....…...................…..................................
Ship' draughts measured from a boat on both sides by draught marks, checked with freeboard measurements and corrected for non-coincidence of draught marks with the positions of fore and aft perpendiculars and for the position of the base plane:

- at fore perpendicular:: T_d = ………….. [m];
- amidships: $T_{\otimes}$ = ……….. [m];
- at aft perpendicular: T_r = ………… [m].

Error in draught measurement due to condition of water surface ΔT = ……………………………..[m]

Note: It is advisable to supplement the report with an annex containing all intermediate measurements of draught.

8. Short specification of the ship's loading condition: ………………………………………………

9. Test weights
Test weights used: ……………………………………………………………………………
Prior to the test, the test weights were weighed using instrument with valid verification certificate, marked with on identification number, divided into 4 groups and placed on the deck as follows:

Table 1

Group No.	Longitudinal position of CM	Mass [t]	Shifting arm [m]	Height of CM above base plane [m]
I				
II				
III				
IV				

Error in weighing each test weight group ΔP = ± …………….. [kg]

10. Sequence of test weight shifting:

Table 2

Measurement No.	Test weight group No.		Shifting arms [m]
	Port	Starboard	
1	I, II	III, IV	
2	II	I, III, IV	+
3	–	I, II, III, IV	+
4	II	I, III, IV	–
5	I, II	III, IV	–
6	I, II, III	IV	–
7	I, II, III, IV	–	–
8	I, II, III	IV	+
9	I, II	III, IV	+

Error in determining shifting arms Δe_i = ± …………… [m].

11. Location of pendulums

Number of pendulums: …………………….

Location and lengths of pendulums:

Table 3

Pendulum No.	Location	Length, [mm]
1		
2		
3		

12. Pendulum deflections

Table 4

Item	Pendulum No. .... Length = ... mm Observer (surname)										Total	Mean x_i [mm]
	1		2		3		4		5			
	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port	Starboard		
1												
2												
3												
4												
5												
6												
7												
8												
9												

13. Moments of inertia of free surface of liquids on board during the tests:

Table 5

Item	Tank	Position (fr. No.)	Width of free surface b_T, [m]	Length of free surface c_T, [m]	Moment of inertia of free surface $i = \frac{c_T b_T^3}{12}$, [m^4]	Density of liquid ρ, [t/m^3]	Product $\rho\, i$, [tm]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1							
2							

14. Masses to be deducted:

Table 6

Item	Mass	Position of mass (fr. No.)	Mass, [t]	Arms, [m]		Moments, [tm]	
				x from amidships or *AP*	*z* from base plane	M_x	M_z
1							
2							
Σ							

15. Masses to be added:

Table 7

Item	Mass	Position of mass (fr. No.)	Mass, [t]	Arms, [m]		Moments, [tm]	
				x from amidships or *AP*	*z* from base plane	M_x	M_z
1							
2							
Σ							

16. Signatures: …………………………………………………………………..

2.3 Example of inclining test results elaboration

CALCULATION OF SHIP DISPLACEMENT AND COORDINATES OF THE CENTRE OF MASS FROM THE INCLINING TEST RESULTS

1. Calculation of ship displacement, coordinates of the centre of mass and the metacentric radius under the inclining test conditions:
   The ship's displacement and coordinates of the centre of buoyancy were determined from the curves of section areas and the statical moments of section areas, drawing No.: ………..[*].
   The moment of inertia of the waterline plane was determined from the lines drawing, No.: …………..
   Data for calculations:
   1.1 Ship's draught at perpendiculars from base plane under test conditions:
   T_d = ... m;
   T_r = ………………. m;

   1.2 Station spacing: ΔL = …………….. m.
   Volume displacement, with no account of appendages (see Table 8):
   $V = \frac{2}{3} \cdot \Delta L \cdot \Sigma_1 =$ ……….. m^3;
   Mass displacement with appendages taken into account:
   $D = 1.005 \rho V =$ ……….... t

   Abscissa of the centre of buoyancy x_F $\quad x_F = \Delta L \frac{\Sigma_2}{\Sigma_1} =$ ……… m;

   Height of the centre of buoyancy z_F $\quad z_F = \frac{\Sigma_3}{\Sigma_1} =$ ………… m;

   Metacentric radius (small): $r_B = \frac{2\Sigma_4}{3\Sigma_1} =$ ……….. m.

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[*] With the ship's trim less than 0.005*L*, these values can be determined from hydrostatic curves. With the ship's trim greater than 0.005*L*, these values are to be determined from hydrostatic curves calculated with regard to the ship's trim.

Table 8
Calculation of displacement, coordinates of the centre of buoyancy and the metacentric radius taking account of the ship trim

Frame No.	Frame areas ω, [m^2]	Simpson's multiplier	Product of (2)×(3)	Factor	Product of (4)×(5)	Moments of areas M_z [m^3]	Product of (7)×(3)	Waterline ordinates y, [m]	y^3 [m^3]	Product of (10)×(3)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0		.		.						
		.		.						
		.		.						
				2						
4		1		1						
5		2		0						
6		1		1						
.		.		2						
.		.		.						
10		.		.						
			Σ_1		Σ_2		Σ_3			Σ_4

2. Calculation of heeling moments due to test weights shifting and the total heeling moment:

Table 9

Item	Test weight position		Shifting mass [t]	Shifting arm [m]	Shifting moment [tm]	Heeling moment [tm]	
	P	SB				P	SB
1.	I, II	III, IV					
2.	II	I, III, IV					
3.		I, II, III, IV					
4.	II	I, III, IV					
5.	I, II	III, IV					
6.	III, I, II	IV					
7.	IV, III, I, II						
8.	III, II, I	IV					
9.	I, II	III, IV					

3. When measurements are made using an inclinometer, this table is to be replaced by a diagram.

Table 10

Item	Pendulum No. 1 L_1 = Pendulum length				Pendulum No. 2 L_2 = Pendulum length				Column (5) + Column (9)	Mean $tg_i\varphi = \frac{1}{2}(10)$
	Mean pendulum readings x_{1i}	Mean pendulum readings from tests No. 1, 5 and 9	Pendulum deflections $\lvert a_{1i}\rvert = x_{1i} - (3)$	$tg\varphi = \frac{\lvert a_{1i}\rvert}{L_1}$	Mean pendulum readings x_{2i}	Mean pendulum readings from tests No. 1, 5 and 9	Pendulum deflections $\lvert a_{2i}\rvert = x_i - (7)$	$tg\varphi = \frac{\lvert a_{2i}\rvert}{L_2}$		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1										
2										
3										
4										
5										
6										
7										
8										
9										

4. Calculation of the mean metacentric height GM_{sr} under test conditions:

Table 11

Item	Total heeling moment M_i [tm]	Mean tangent of the heeling angle φ, [rad]	$M_i\, tg_i\varphi$	$tg_i^2\varphi$	$M_i/tg_i\varphi$	$GM_i = \frac{M_i}{D \cdot tg\varphi}$	$\varepsilon_i = GM_i - GM_{sr}$	ε_i^2
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1								
2								
3								
4								
5								
6								
7								
8								
9								
			Σ(4)	Σ(5)				Σ(9)

The mean metacentric height GM_{sr} under test conditions:

$$GM_{sr} = \frac{\Sigma(4)}{\Sigma(5)}\frac{1}{D} = \ldots\ldots\ldots \text{m;}$$

5. The total relative mean square test error, ε, is calculated from the following dependence:

$$\varepsilon = \pm\sqrt{\varepsilon_{GM}^2 + \varepsilon_D^2} = \ldots\ldots\ldots;$$

where:

the relative mean square error ε_{GM} of the initial metacentric height:

$$\varepsilon_{GM} = \frac{1}{GM_{sr}} t_{\alpha n} \sqrt{\frac{\Sigma\left(GM_i - GM_{sr}\right)^2}{n(n-1)}} = \ldots\ldots\ldots;$$

mean square error in determining displacement, ε_D, assuming uniform distribution of error probability density:

$$\varepsilon_D = \frac{\rho \cdot g \cdot F \cdot \Delta T}{D\sqrt{3}} = \ldots\ldots\ldots\ldots;$$

In the above formula ($\varepsilon_D =$), error in draught measurements $\Delta T =$:

$$\Delta T = \ldots\ldots\ldots \text{ m;}$$

waterline area F:

$$F = \ldots\ldots\ldots\ldots\ldots \text{ m}^2;$$

Test absolute error:

$$\Delta GM = \pm\, \varepsilon\, GM_{sr} = \ldots\ldots\ldots \text{ m;}$$

6. Calculation of the effective value of the ship’s metacentric height GM_0 under test conditions.
The correction for the effect of free surfaces of liquids ΔGM_1 on board ship in the course of the test, [m]:

$$\Delta GM_1 = \frac{\Sigma\rho \cdot i}{D} = \ldots\ldots\ldots \text{ m}$$

ρ – liquid density, [t/m^3];
i – moment of inertia of liquid free surface, [m^4];

The effective value of the metacentric height GM_0, [m]:

$$GM_0 = GM_{sr} - \Delta GM + \Delta GM_1 = \text{………} \text{ m}$$

GM_{sr} – mean metacentric height under test conditions, [m];
ΔGM – test absolute error, [m];
ΔGM_1 – correction for metacentric height resulting from free surfaces of liquids on board ship, [m].

7. Calculation of the ship's centre of mass coordinates under test conditions.

   Height of the centre of buoyancy above the base plane, [m]:

$$z_{F\psi} = \text{………} \text{ m}$$

   Transverse metacentric radius, [m]:

$$r_{F\psi} = \text{………} \text{ m}$$

   Ship draught from the base plane at fore perpendicular, [m]:

$$T_d = \text{………} \text{ m}$$

   Ship draught from the base plane at aft perpendicular, [m]:

$$T_r = \text{……….} \text{ m}$$

   Triming angle of the ship, ψ :

$$tg\psi \cong \psi = \frac{T_d - T_r}{L} = \text{………}$$

   Height of the ship's centre of mass (from the base plane), [m]:

$$z_G = z_{F\psi} + (r_{B\psi} - GM_0)\cos\psi = \text{…….m}$$

   Abscissa of the ship's centre of mass (from amidships), [m]:

$$x_G = x_{F\psi} - (r_{B\psi} - GM_0)\sin\psi = \text{…….} \text{ m}$$

8. Calculation of displacement and coordinates of the light ship's centre of mass:

Table 12

Item	Specification	Mass, [t]	Arms, [m]		Moments, [tm]	
			x from amidships or *AP*	*z* from base plane	M_x	M_z
1 2 3	Ship under test conditions Masses to be added Masses to be deducted					
	Σ					

9. Inclining test result

   Displacement, light ship $D =$ ………………… t

   Height of the centre of mass, light ship $z_G =$ …………........ m (from the base plane)

   The abscissa of the centre of mass, light ship $x_G =$……… m (from the midship plane or *AP*)

   Signatures:

   ……………..……….. ……………..……..…. ….………………..…..…. ……..………..……….

3 DETERMINATION OF THE SHIP ROLLING PERIOD

It is recommended that the ship rolling period, T_φ, should be determined during each inclining test.

The basic means of determining the rolling period is recording the ship's roll oscillations using gyroscopic or timing inclinometers. If such devices are not available, stop watches may be used. Not less than 3 stop watches shall be used.

The ship is to be brought to roll by the crew or by suddenly placing a mass on the deck side.

The rolling period (sec) is to be determined as the arithmetic mean of as large number of the ship's oscillations as possible.

When determining the rolling period, it is advisable to put the ship aside from the shore or bring it perpendicularly to the shore in deep water away from other ships.

4 DETERMINATION OF CAPSIZING MOMENT

4.1 Cargo and Fishing Vessels

The capsizing moment M_{kr} taking into account the effect of rolling can be determined using either a curve of dynamic or static stability. When determining the capsizing moment, the following two cases can occur:

.1 The curves of dynamic and static stability are normal or the curve of the static stability is stepped and that of dynamic stability is broken. In this case, the capsizing moment is to be determined as follows:

.1.1 When the curve of dynamic stability is used, first an auxiliary point *A* is to be found on the curve. For this purpose, the amplitude of roll θ_a is to be plotted along the axis of abscissa to the right of the origin of the coordinates; the intersection of the straight line drawn from this point parallel to the axis of ordinates with the curve of dynamic stability gives the auxiliary point *A′* (see Fig. 4.1-1). Then a straight line parallel to the axis of abscissa is to be drawn through point *A′* and segment $\overline{AA'}$ equal to the double amplitude of roll is to be laid off along the line to the left of the auxiliary point *A′*. Point *A* located symmetrically to point *A′* is assumed to be the initial one. From the initial point *A* tangent to the curve of dynamic stability is to be drawn and segment $\overline{AB}$ equal to one radian (57.3°) is to be laid off from *A* on the straight line parallel to the axis of abscissa. From point *B* perpendicular *BE* is to be drawn to intersect with tangent *AC* in point *E*.

Segment $\overline{BE}$ is equal to the capsizing moment if the curve of dynamic stability is plotted to scale of work, and to the arm of the capsizing moment, if the curve of dynamic stability is plotted to scale of arms. In the latter case, to determine the capsizing moment M_{kr} – the value of segment $\overline{BE}$ (in meters) is to be multiplied by ship displacement *D*:

$$M_{kr} = 9.81 D \overline{BE}, \quad [\text{kNm}] \qquad (4.1\text{-}1)$$

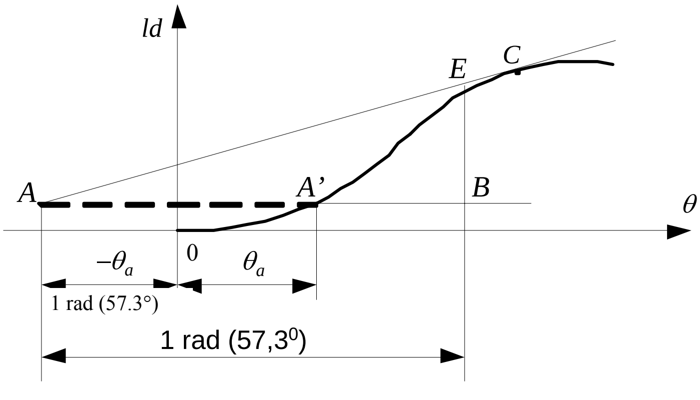

Fig. 4.1-1 Determination of the capsizing moment arm using the curve of dynamic stability

.1.2 When the curve of static stability is used, the capsizing moment can be determined assuming the work of the capsizing and righting moments to be equal and taking into account the effect of rolling. For this purpose, the curve of static stability is to be continued into the region of negative abscissa for a length equal to the amplitude of roll θ_a and straight line *MK* is to be drawn parallel to the axis of abscissa such that the areas S_1 and S_2 (see Fig. 4.1-2) are equal.

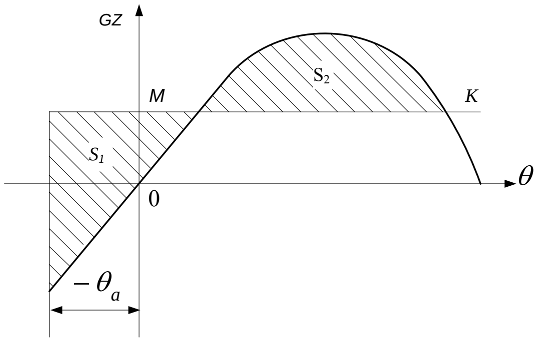

Fig. 4.1-2 Determination of the capsizing moment arm using the curve of static stability

Ordinate $\overline{OM}$ will correspond to the capsizing moment if moments are plotted along the axis of ordinates or to the arm of the capsizing moment if arms of stability are plotted along the axis of ordinates. In the latter case, to determine the capsizing moment, ordinate $\overline{OM}$ (in meters) is to be multiplied by ship displacement *D*:

$$M_{kr} = 9.81 D\overline{OM}\,, \quad [\text{kNm}] \tag{4.1-2}$$

.2 The curves of static and dynamic stability are cut short at the angle of flooding. In this case, the capsizing moment may be determined by one of the methods given below:

.2.1 When the curve of dynamic stability is used, the capsizing moment is to be determined as follows:

Using the method specified in 4.1.1.1, point A is to be found (see Fig. 4.1-3). A tangent to the curve of dynamic stability is to be drawn from point *A*, which is possible only when the angle of heel corresponding to the point of tangency is less than the angle of flooding.

The capsizing moment or its arm is determined by using the tangent, as described in 4.1.1.

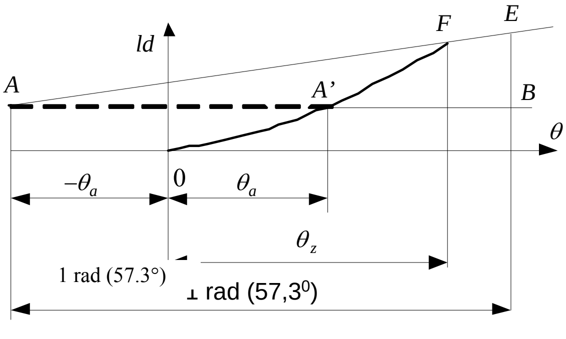

Fig. 4.1-3 Determination of the capsizing moment arm from the curve of dynamic stability taking into account the angle of flooding

If the tangent cannot be drawn, a straight line passing through point *F* of the curve of dynamic stability, corresponding to the angle of flooding, is to be drawn from point *A*. A straight line parallel to the axis of abscissa is to be drawn from point *A* and segment $\overline{AB}$ equal to one radian is to be laid off on this line. From point *B* a perpendicular is to be drawn to intersect with the straight line *AF* in point *E*. Segment $\overline{BE}$ is equal to the desired capsizing moment if work is plotted along the axis of ordinates on the curve of dynamic stability or is equal to the arm of the capsizing moment if arms of dynamic stability are plotted along the axis of ordinates. In the latter case the capsizing moment is determined from formula 4.1-1.

.2.2 When the curve of static stability is used, the capsizing moment for the angle of flooding θ_z is to be determined as follows:

The curve of static stability is to be continued into the negative abscissa region to a length equal to the amplitude of roll $-\theta_a$ (see Fig. 4.1-4) and straight line *MK* is to be drawn parallel to the abscissa axis such that the areas S_1 and S_2 are equal. Ordinate *OM* will correspond to the desired capsizing moment M_{kr} or its arm, depending on the method used for constructing the curve. In the latter case, the capsizing moment is determined from formula 4.1-2.

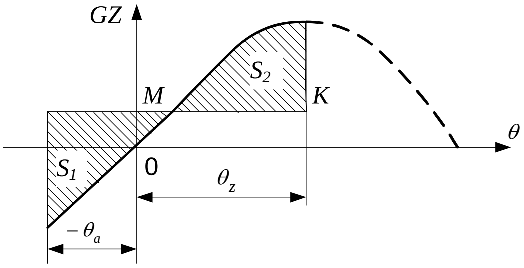

Fig. 4.1-4 Determination of the capsizing moment arm from the curve of static stability taking into account the angle of flooding

4.2 Dredgers

To determine the capsizing moment, a curve of dynamic stability of the ship after spoil discharge is to be plotted. The curve is to be continued into the negative abscissa region. From point *A* corresponding to the minimum on the curve (heeling angle Θ_{BC}) a segment equal to the amplitude of roll Θ_{ap} is to be laid off to the left along the axis of abscissa (see Fig. 4.2-1). The amplitude of roll Θ_{ap} is to be assumed equal to 10° when only the static effect of spoil discharge is taken into account (with the density of spoil in the hopper less than 1.3 t/m^3) and equal to 10° and plus the greatest roll amplitude Θ_{ap} when the dynamic effect of spoil discharge is taken into account. Point *C* corresponding to point *B* is fixed on the curve and tangent *CE* is drawn from this point to the right part of the curve.

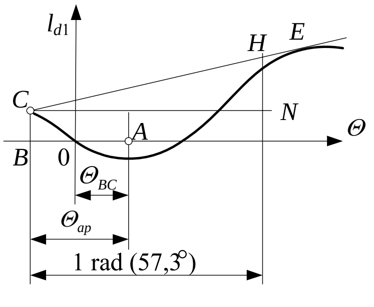

Fig. 4.2-1 Determination of the capsizing moment arm for dredgers

From point *C*, segment $\overline{CN}$ equal to one radian is to be laid off parallel to the axis of abscissa. From point N a perpendicular is to be drawn to intersect with the tangent in point *H*. Segment $\overline{NH}$ is equal to the arm of the capsizing moment.

The capsizing moment is determined from the formula:

$$M_{kr} = 9.81 D \overline{NH}, \quad \text{[kNm]} \qquad (4.2\text{-}1)$$

If the angle of flooding Θ_z proves to be less than the angle of heel corresponding to point *E* on the curve (see Fig. 4.2-1), the secant *CF* is to be drawn from point *C* to the right part of the curve, as shown in Fig. 4.2-2. In this case the arm of the capsizing moment will be determined by segment $\overline{NH}$. If point *F* on the curve (see Fig. 4.2-2) corresponding to the angle of flooding is below point F_1 where the curve intersects the straight line *CN*, the stability of the ship is considered insufficient.

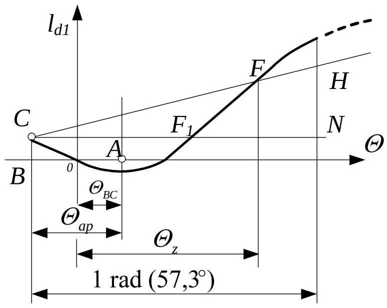

Fig. 4.2-2 Determination of the capsizing moment arm for dredgers, taking into account the angle of flooding Θ_z

If no curve of dynamic stability is available, the minimum capsizing moment may be determined from the curve of static stability (Fig. 4.1-2) as described in 4.1.1, taking into account the initial static heel.

4.3 Floating Cranes

4.3.1 Determination of the capsizing moment and the angle of dynamic heel in working condition at load drop

To determine the capsizing moment and the angle of dynamic heel after load drop, the curve of dynamic stability is to be constructed for the loading condition but without load on hook. If the crane centre of mass after load drop does not coincide with the centreline, the curve is to be constructed with regard to the angle of heel Θ_0' due to unsymmetrical loading (including also unsymmetrical arrangement of cargo on deck). A portion of the curve is to be constructed in the negative angle area. The angle of heel Θ_{dz}' of the floating crane with a load on hook (Fig. 4.3-1), equal to the sum of the amplitude of roll in the working condition Θ_a and the angle of static heel Θ_0 when the load is lifted, decreased by the angle of static heel Θ_s due to wind pressure is to be plotted to the left of the origin of the coordinates (see sub-chapters 4.1.6 and 4.1.8, *Part IV – Stability and Subdivision*). The appropriate point *C* is fixed on the curve.

The curve of the reduced arms is to be plotted to the right of the origin of the coordinates above the curve of static stability, whose ordinates are calculated from the formula:

$$l_{d\lambda} = l_d + \Delta l_\lambda\,, \quad [\mathrm{m}] \tag{4.3.1-1}$$

Δl_λ – correction for damping forces, determined in accordance with 4.3.4.

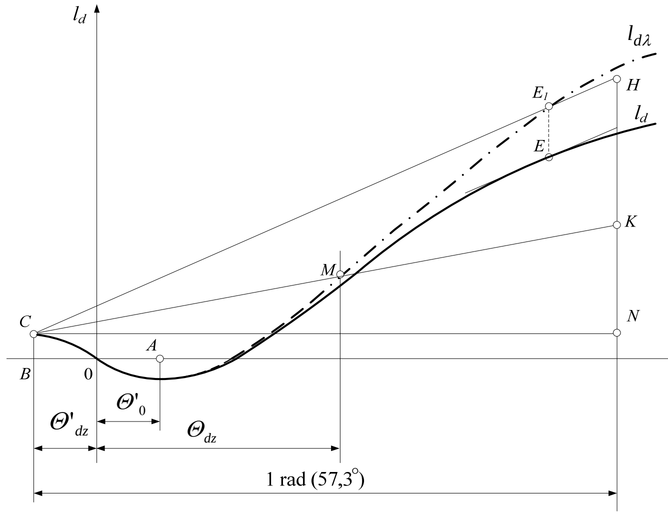

Fig. 4.3-1 Determination of the capsizing moment arm and the angle of dynamic heel after load drop

From point *C* the secant CE_1 is to be drawn such that the point of its intersection with the reduced arm curve E_1 and the point *E*, in which the straight line parallel to the secant touches the curve, lie on the same vertical line. From point *C*, segment $\overline{CN}$ equal to one radian (57.3°) is to be laid off parallel to the axis of abscissa.

From point *N*, a perpendicular is to be drawn to intersect with the secant in point *H*. Segment $\overline{NH}$ is equal to the arm of the capsizing moment taking into account damping, calculated from the formula:

$$M_{d\lambda} = 9.81D\,\overline{NH}\ , \text{[kNm]} \tag{4.3.1-2}$$

From point *N* segment $\overline{NK}$ is to be laid off equal to the arm of the heeling moment, calculated from the formula:

$$\overline{NK} = \frac{M_w}{9.81D}\ , \quad \text{[m]} \tag{4.3.1-3}$$

Points *C* and *K* are to be connected by a straight line, whose point of intersection with the curve of the reduced arm *M* determines the angle of dynamic heel Θ_{dz} at the inclination after load drop.

Stability may be checked without taking into account damping. In such case, the curve of the reduced arm is not constructed and the tangent is drawn to the curve of dynamic stability.
The angle of dynamic heel Θ_{dz} is determined by the point of straight line *CK* intersection with the curve.

4.3.2 Determination of the Capsizing Moment During the Crane Passage

The capsizing moment M_{kr} of the floating crane under the effect of rolling and steady wind may be determined both by the curve of dynamic stability and the curve of static stability; the curve is to also cover negative angles.

4.3.2.1 When using the curve of dynamic stability, the positions of the initial point *A* and point A_1 (Fig. 4.3.2-1) are to be so selected that tangent *AC* is parallel to the tangent A_1K and the difference of the angles of heel corresponding to points *A* and A_1 is equal to the amplitude of roll Θ_a .

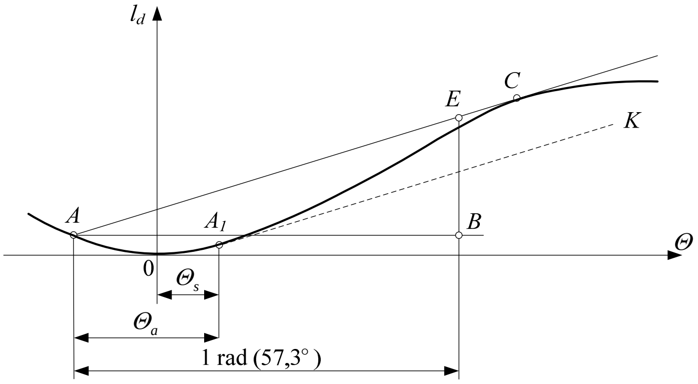

Fig.. 4.3.2-1 Determination of the capsizing moment arm of the floating crane during passage from the curve of dynamic stability

Angle Θ_s so obtained corresponds to the angle of static heel due to limiting wind pressure. The value of Θ_s is determined by equating the areas S_1 and S_2 on static stability curve (see Fig. 4.3.2-2).

Segment $\overline{BE}$ is equal to the capsizing moment if the curve of dynamic stability is plotted to scale of moments or to the arm of the capsizing moment if the curve of dynamic stability is plotted to scale of arms.

In the latter case, the capsizing moment is to be calculated from the formula:

$$M_{kr} = 9.81D\,\overline{BE}\ , \quad \text{[kNm]} \tag{4.3.2-1}$$

4.3.2.2 When the curve of static stability is used, the capsizing moment can be determined assuming the work of the capsizing moment and that of the righting moment to be equal and taking into account the effect of rolling and the static heel due to limiting wind pressure (Fig. 4.3.2-2). For this purpose, the curve of static stability is continued in the region of negative angles for such a portion that the straight line *MK* parallel to the axis of abscissa cuts off the equal shaded areas S_1 and S_2 and the difference of angles corresponding to points A_1 and *A* is equal to the amplitude of roll Θ_a .

Ordinate *OM* will correspond to the capsizing moment if moments are plotted along the axis of ordinate or to the arm of the capsizing moment if arms of stability are plotted along the axis of ordinates.

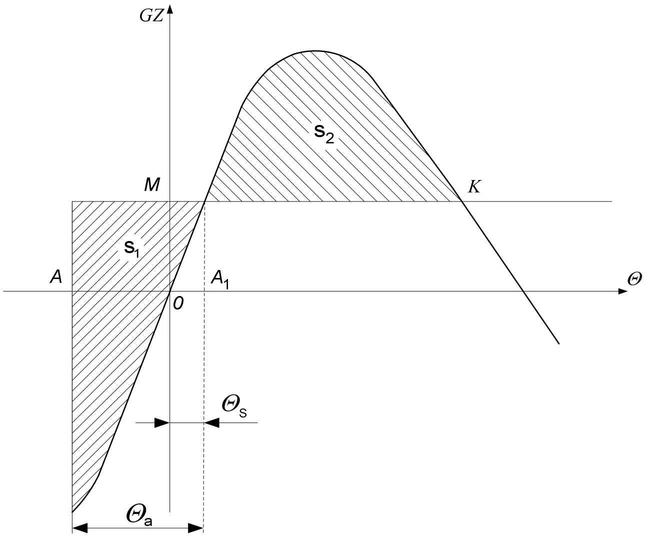

Fig. 4.3.2-2 Determination of the capsizing moment arm of the floating crane during the crane passage from the curve of static stability

4.3.2.3 If the curves of static and dynamic stability are cut short at the angle of flooding, the capsizing moment is to be determined as described in 4.1.2 with regard to static heel and the amplitude of roll in accordance with 4.3.2.1 and 4.3.2.2.

4.3.3 Determination of the Maximum Righting Moment in Non-working Condition

The maximum righting moment is to be determined from the curve of static stability (Fig. 4.3-3) for non-working loading condition with due regard for free surface effect, as well as the initial angle of heel due to the boom turn for floating cranes with slewing cranes.

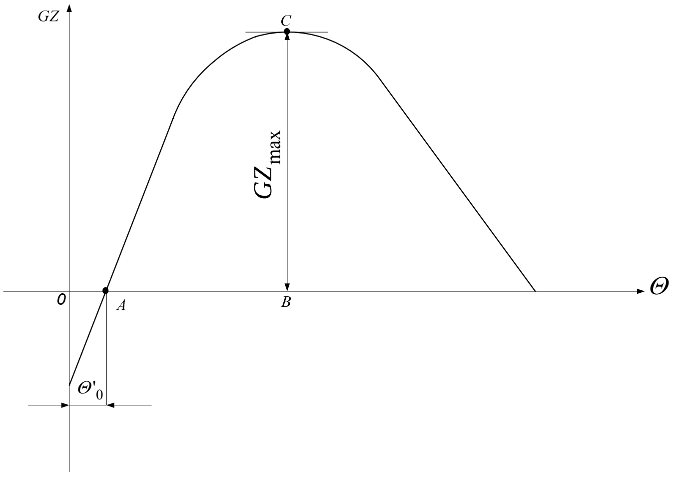

Fig. 4.3-3 Determination of the maximum righting moment arm in non-working condition

Segment $\overline{CB}$ is equal to the maximum righting moment if the curve is plotted to scale of moments and is equal to the arm of the maximum righting moment $GZ_{\max}$ if the curve is plotted to scale of arms. In the latter case, the maximum righting moment is to be calculated from the formula:

$$M_{\max} = 9.81 D \cdot GZ_{\max}\,, \quad [\text{kNm}] \tag{4.3-3}$$

4.3.4 Determination of Correction for Damping Forces

Correction Δl_λ taking into account damping forces is to be calculated from the formula:

$$\Delta l_\lambda = l_\lambda \sqrt{\delta B T}\left(\frac{\Theta_p}{57.3}\right)^2 F_5\,, \quad [\text{m}] \tag{4.3.4-1}$$

Θ_p – deflection angle measured from the angle of the initial heel at load drop, degrees;

l_λ – factor calculated from the formula:

$$l_\lambda = F_0\left(F_1 + \frac{z_G - T}{\sqrt{\delta\, BT}}F_2\right) + \frac{z_G - T}{\sqrt{\delta\, BT}}F_3 + F_4 \tag{4.3.4-2}$$

F_0 – determined from Fig. 4.3.4, depending on characteristics F and the ratio $B/\sqrt{\delta\, BT}$:

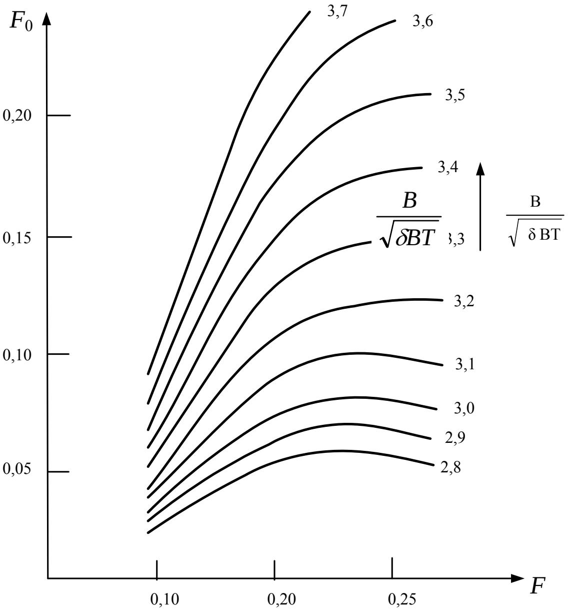

Fig. 4.3.4 Diagram for determining the values of F_0 , depending on characteristics F and the ratio $B/\sqrt{\delta BT}$

F – the value determined from the formula:

$$F = n\frac{\sqrt{GM_0}}{B}\sqrt[4]{\delta\, BT} \tag{4.3.4-3}$$

F_1, F_2, F_3, F_4 – the values taken from Table 4.3.4-1, depending on the ratio $B/\sqrt{\delta\, BT}$:

Table 4.3.4-1
Values F_1, F_2, F_3, F_4

$B/\sqrt{\delta\, BT}$	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7
F_1	1.987	2.087	2.144	2.157	2.138	2.097	2.043	1.982	1.921	1.861
F_2	–3.435	–3.313	–3.097	–2.823	–2.525	–2.230	–1.955	–1.711	–1.497	–1.312
F_3	0.0725	0.0856	0.1007	0.1150	0.1273	0.1357	0.1417	0.1454	0.1474	0.1475
F_4	–0.021	–0.028	–0.037	–0.047	–0.057	–0.067	–0.076	–0.084	–0.091	–0.097

F_5 – the value taken from Table 4.3.4-2, depending on $\dfrac{\Theta_d + \Theta_{dz}'}{\Theta_p}$ ratio

Θ_d – angle at which the deck immerses.

Table 4.3.4-2
Values F_5

$\dfrac{\Theta_d + \Theta_{dz}'}{\Theta_p}$	≥ 1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2
F_5	1	1.053	1.138	1.253	1.374	1.500	1.626	1.747	1.862