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CALCULATION OF BROKEN ICE RESISTANCE BASED ON MODEL TESTING

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Experimental investigation of ice resistance was started in the 1940's and was related primarily to icebreakers. Methods of model representation for ship motions in broken and solid ice were developed by Professor Nogrid, References [1], [2], and [3]. Ship motions in broken ice are considered to be an ideal environment with main parameters (thickness of the ice, percentage of broken ice to open water in the broken channel, width of the channel, and the form of the ice blocks) constant. The second assumption is that the ship does not break the ice blocks. Considering the parts of ship resistance as independent, we can give the general resistance as the sum of water resistance (R_B) and resistance due only to ice ($R_{Л.Ч}$). This second part of resistance might be determined from model testing using the formula:

$$R_{Л.Ч} = R_T - R_B$$

where R_T is the total resistance.

To obtain the resistance of the actual ship from model testing results, we use the Froude criterion with equal relative speeds and geometrical similarity of ice conditions, References [1], [2], and [4].

Here we can use the following expressions:

$$\left.\begin{aligned} R_{Л.Ч_1} &= R_{ЛЧ_2} \cdot \ell^3 \\ R_{ЛЧ_1} &= K_{ЛЧ} \cdot D_1 \\ v_1 &= v_2 \sqrt{\ell} \\ \tau_1 &= \tau_2 \cdot \ell \\ t_1 &= t_2 \ell \\ B_{K_1} &= B_{K_2} \ell \\ Б &= Б_2 \end{aligned}\right\} \qquad (1)$$

where the index (1) is related to the ship and the index (2) is related to the model. ℓ is a scale factor, $R_{Л.Ч}$ V, L, B and D are correspondingly ice resistance, ship speed, length, beam, and displacement. σ, Z, t, and B_K are correspondingly ice cover, relative ice block length, ice thickness, and channel width. Relative ice block length can be determined as

$$z = \sqrt{f} \tag{2}$$

where f is the area of the ice block (m^2).

$K_{Л.Ч.}$ - coefficient of ice resistance; $K_{Л.Ч.} = R_{Л.Ч.}/D$

$$\frac{R_{ЛЧ_1}}{D_1} = \frac{R_{ЛЧ_2}}{D_2}, \quad \text{т.е.} \quad K_{ЛЧ_1} = K_{ЛЧ_2} = K_{ЛЧ}. \tag{3}$$

A series of model tests were performed at LSI model basin from 1950-1955 including models of icebreakers "Sibiz," "Ezmack," and models of cargo ships (see Table 1).

Tabl. 1

Ship	Scale ℓ	D kg.	L M.	B M.	T M	L/B	B/T	δ	γ_H
„Lena"	1:50	87,4	2,43	0,37	0,15	6,58	2.47	0,647	0,770
„Ermack"	1:50	65.2	1,86	0,435	0,152	4.30	2.83	0,532	0,715
„Sibir"	1:40	140.8	2,46	0,558	0,208	4.40	2,68	0,50	0,660
„Sibir"	1:60	41,7	1,64	0,372	0,138	4.46	2.68	0,50	0,660

Model tests were conducted in open water and in broken ice. The results of the broken ice test are given in Table 2.

Tabl. 2

	model	„Lena" 1:50	„Ermak" 1:50	„Sibiz" 1:40	„Sibir" 1:60
1	Bк/B	14.8 ; 8 ; 4.	12.7 ; 7.5 4.3 ; 2,3	10,0 ; 7,0 4,0 ; 2,0	10,8 ; 6 ; 3
2	Sea	8	8	6	6
3	t M.	0,016	0,016	0,019	0,019
4	$z=\sqrt{f}$	0,12	0,08	0,12	0,12

All models were made from wax with scale factors for icebreaker "Sibiz" of 1:40 and 1:60, and for icebreaker "Ezmack" and the cargo ship of 1:50. The artificial ice was made of paraffin with specific density 0.85 gm/cm^3 and ice blocks were hexagonal in plain view.

The main purpose of the evaluation of the experimental results was to establish the relationships between ice resistance, width of channel, and parameters of the ice.

The mode data were collected as a function of:

$$R_{Λ.Ч.} = f\left(\frac{v}{\sqrt{gL}}\right)$$

for the different B_k/B ratios shown in Figures 1 and 2. Figures 3 and 4 show the relation of the broken ice resistance coefficient $K_{Λ.Ч} = \frac{R_{Λ.Ч}}{D}$ as a function of $\frac{v}{\sqrt{gL}}$ for different values of B_k/B for the model cargo ship and the icebreaker "Sibiz."

According to References [1], [2], and [4], these figures can be used to determine the ice resistance of icebreakers and cargo ships using formula (3). If ice parameters t/D 1/3, 2/D 1/3 and percent ice cover in the channel differ from parameters given in figures, the data can be corrected using graphs in Figure 5. Figure 6 gives a comparison of ice resistance for the icebreakers "Sibiz" and "Captain Bllousov" calculated by this method to the data obtained by full scale (5) for 7-9 numeral of ice coverage and B_k/B ratios equal to 12.

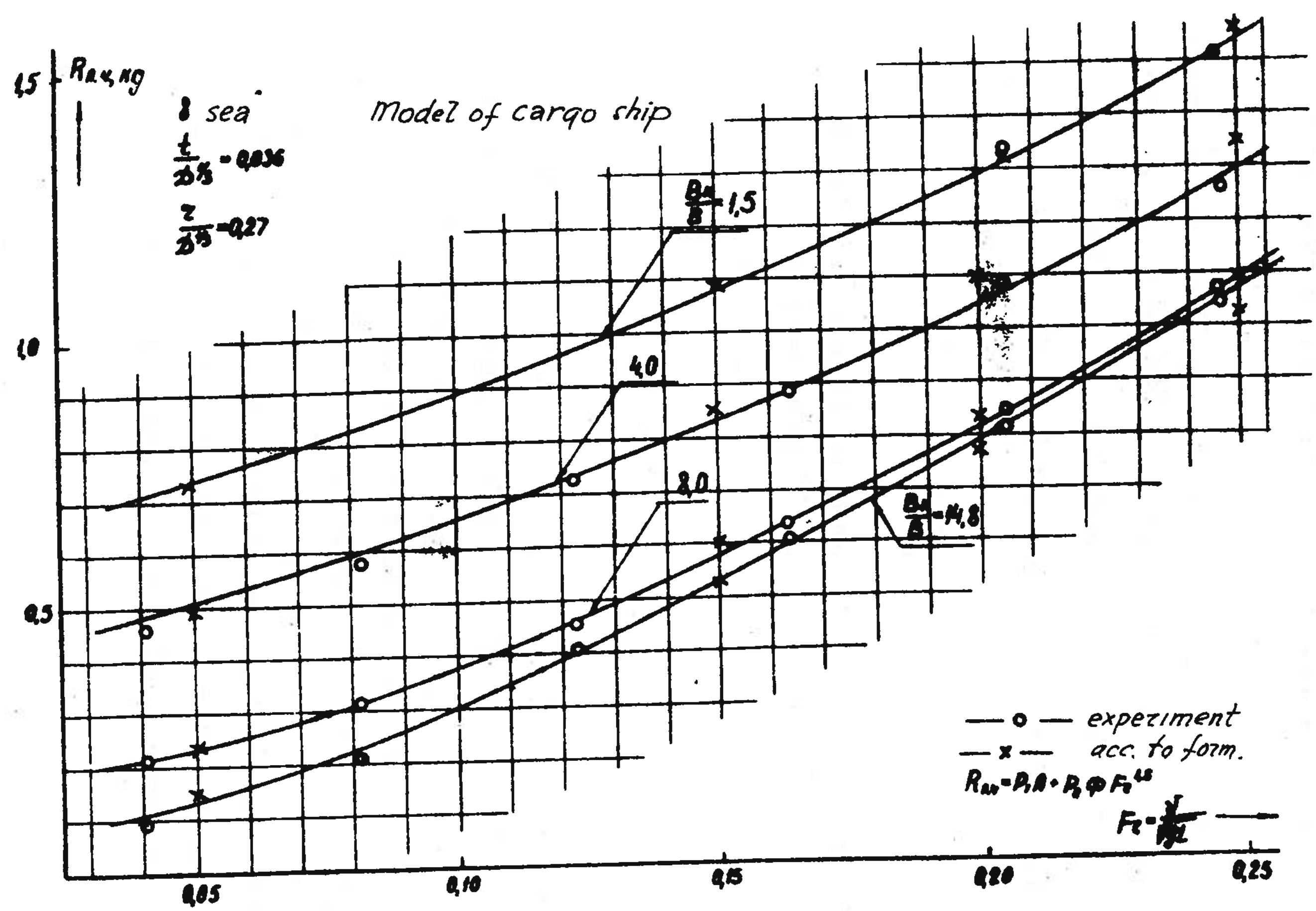
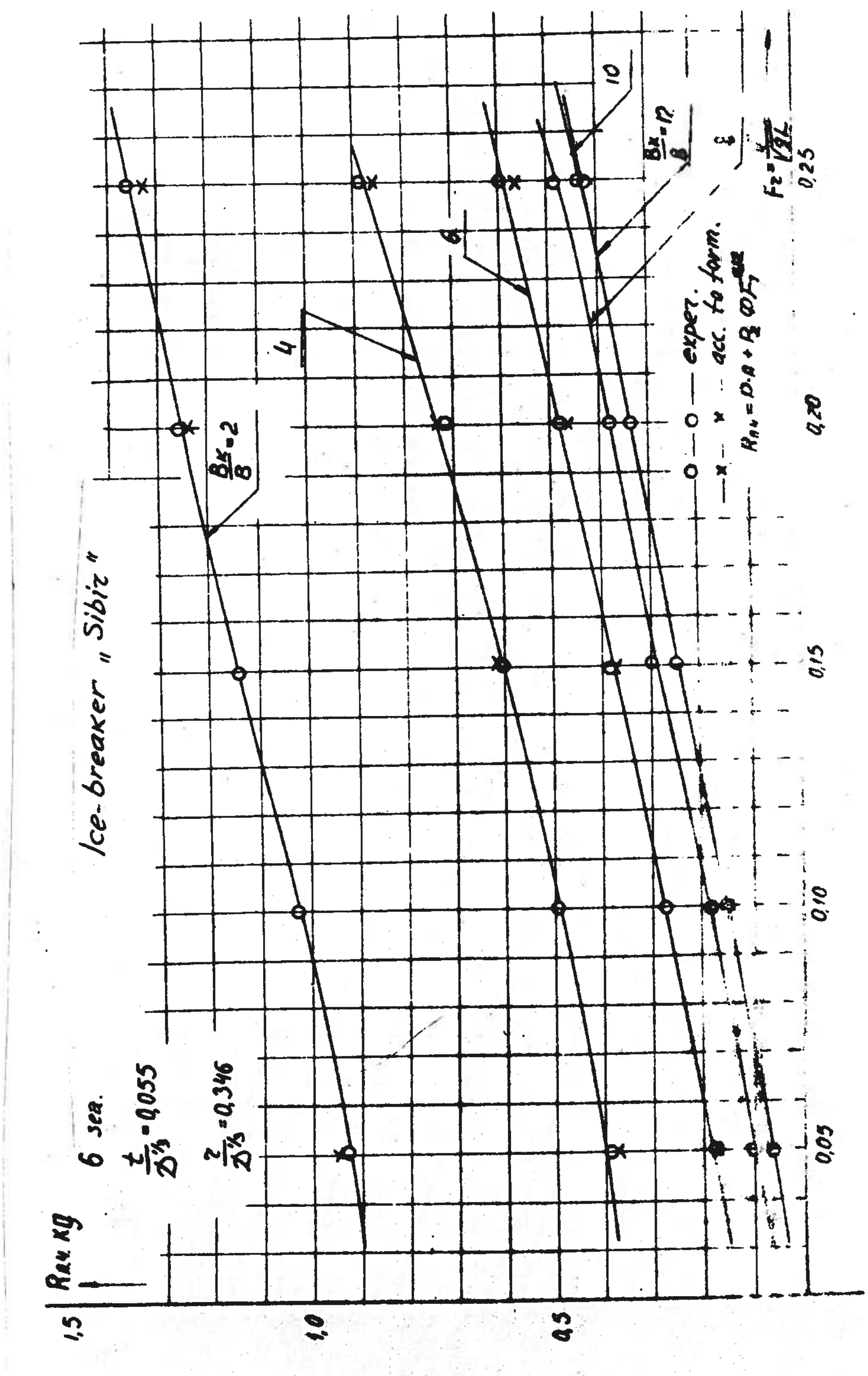
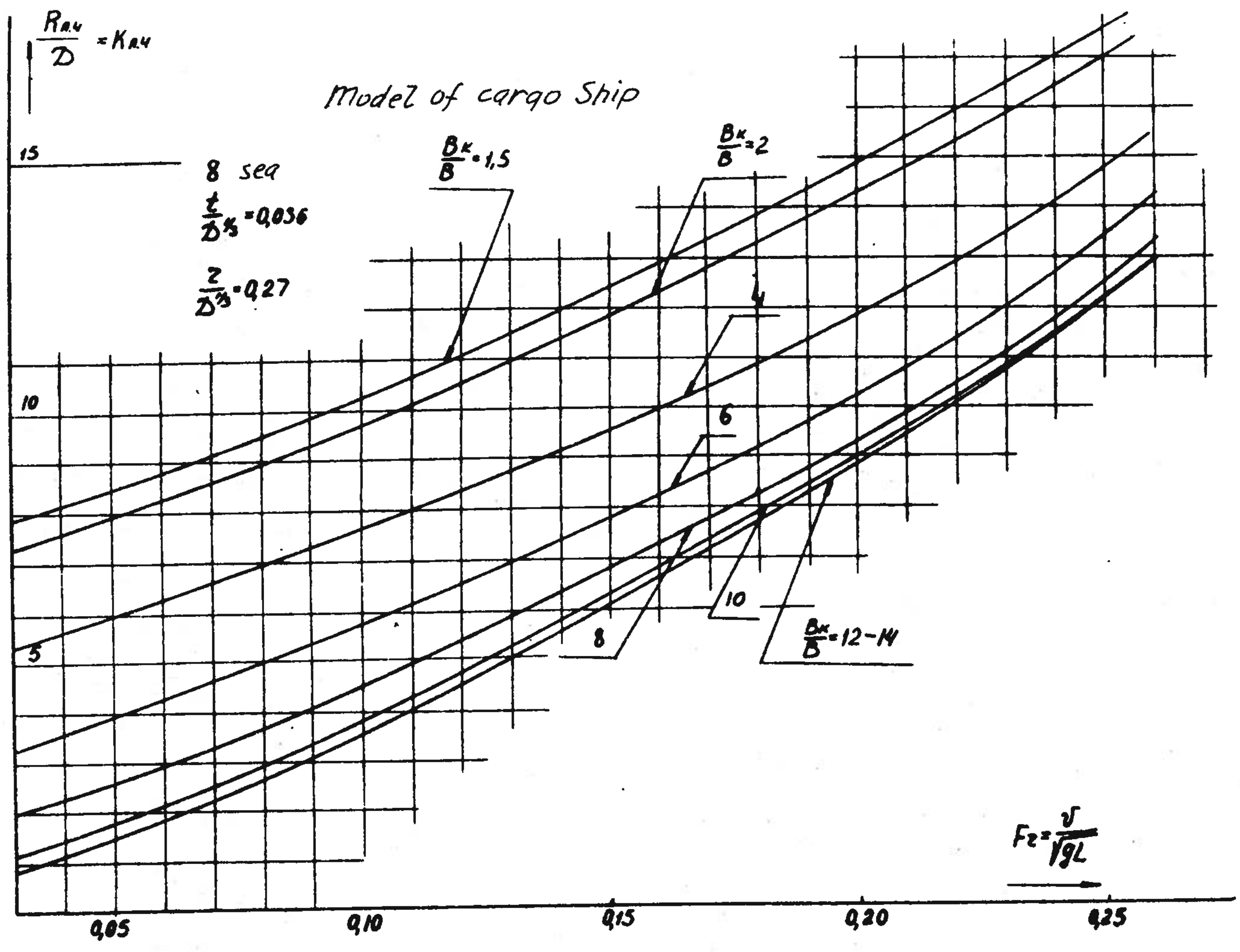

Model of cargo ship
8 sea
1,5
1,0
0,5
0,05
0,10
0,15
0,20
0,25
1,5
4,0
8,0
14,8
— o — experiment
— x — acc. to form.

Figure 1



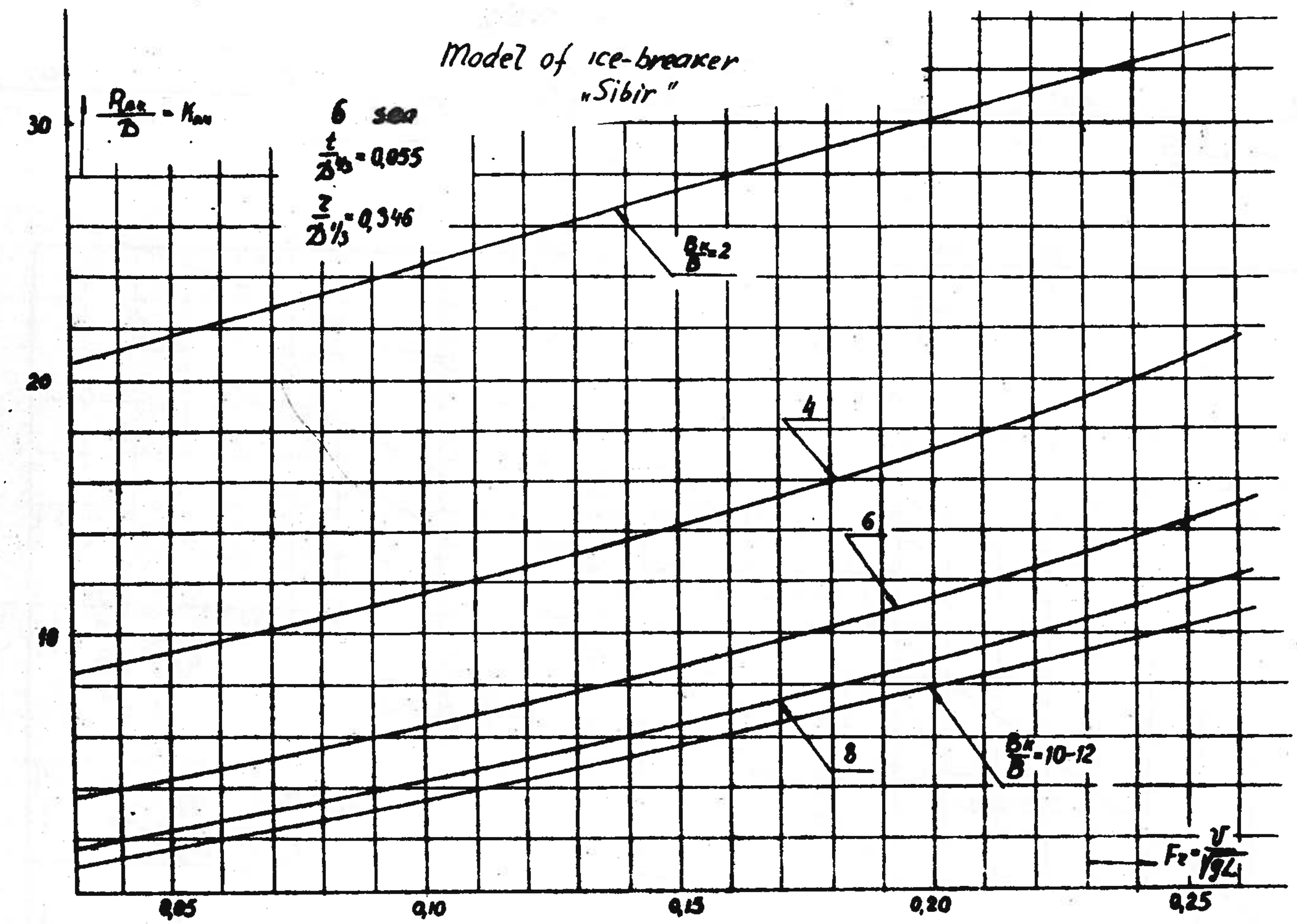
Ice-breaker „Sibiz"
6 sea.
Rau kg
1,5
1,0
0,5
0,05
0,10
0,15
0,20
0,25
4
6
10
exper.
acc. to form.

Figure 2



$\frac{R_{RЧ}}{D} = K_{RЧ}$
Model of cargo Ship
8 sea
$\frac{t}{D^{1/3}} = 0,036$
$\frac{z}{D^{1/3}} = 0,27$
$\frac{B_K}{B} = 1,5$
$\frac{B_K}{B} = 2$
4
6
8
10
$\frac{B_K}{B} = 12-14$
15
10
5
0,05
0,10
0,15
0,20
0,25
$F_z = \frac{v}{\sqrt{gL}}$

Figure 3



Model of ice-breaker
„Sibir"
6 sea
t/D^1/3 = 0,055
z/D^1/3 = 0,346
R_ak/D = K_ak
Bk/B = 2
4
6
8
Bk/B = 10-12
Fr = v/√gL
30
20
10
0,05
0,10
0,15
0,20
0,25

Figure 4

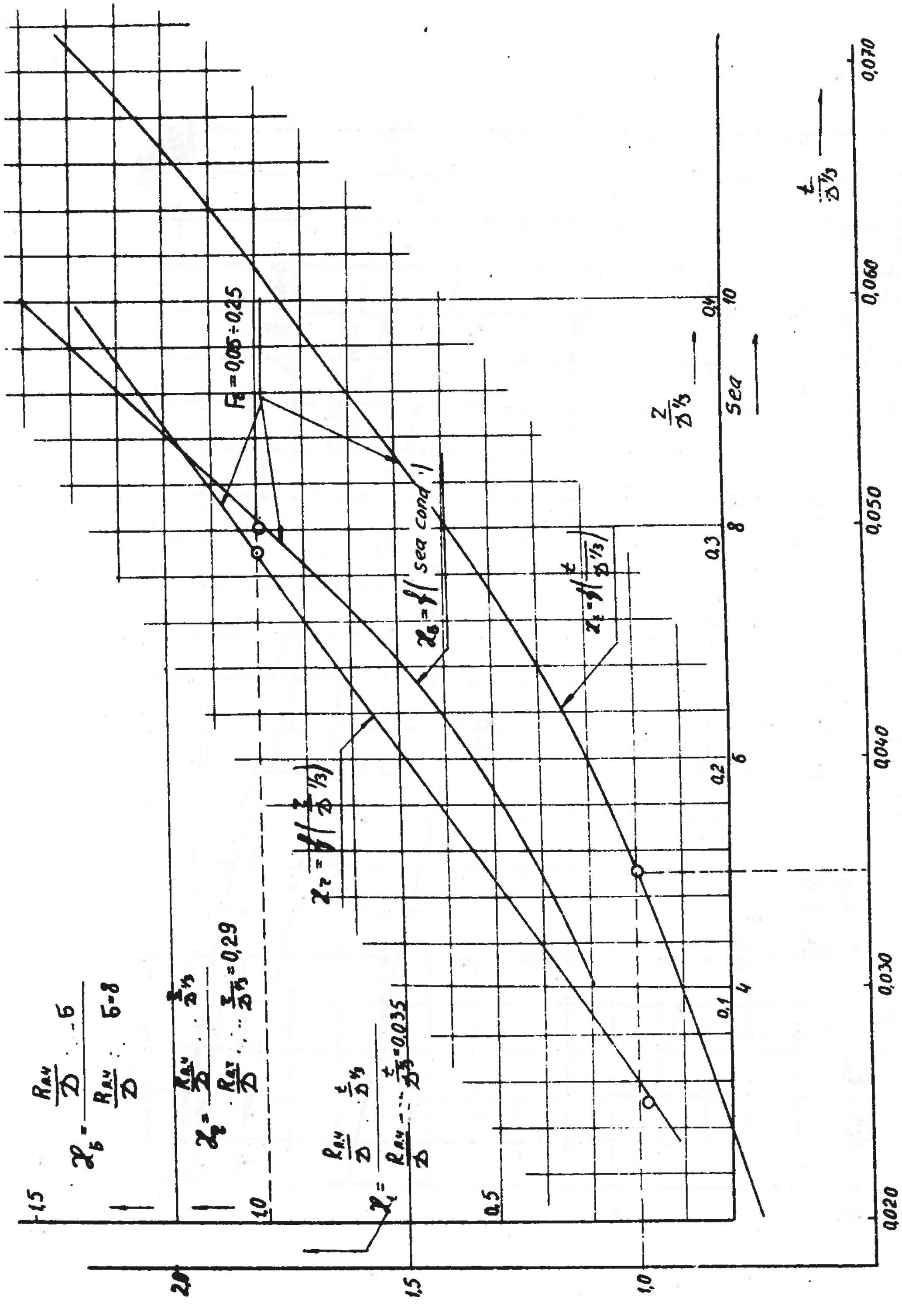


Figure 5

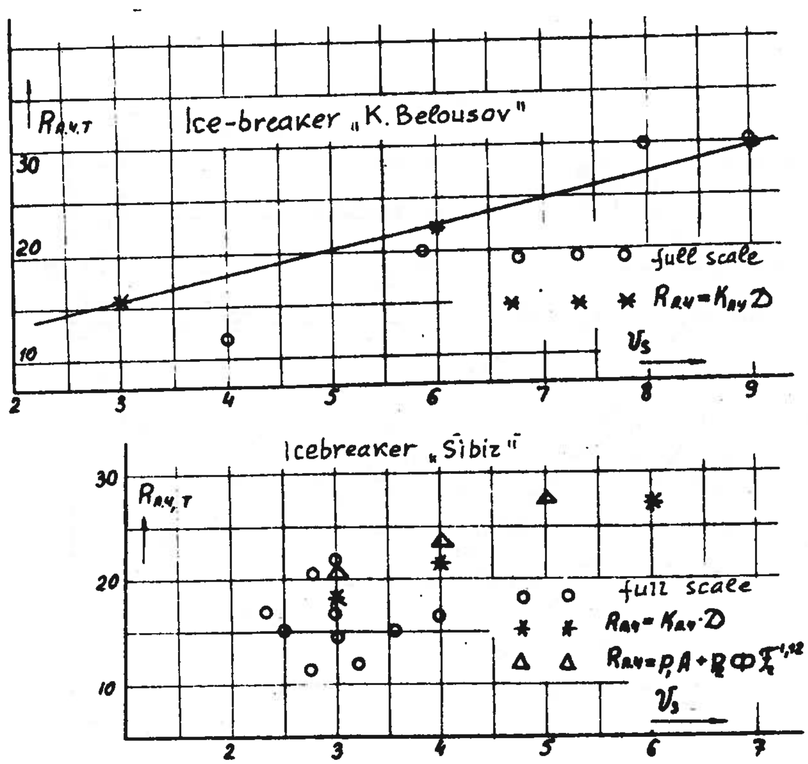


Figure 6

For ice resistance we can recommend an empirical formula which was developed according to (3, 5, 6) and described by these tests.

$$R_{\Lambda Ч.} = p_1 \cdot A + p_2 \cdot \Phi \cdot \mathcal{F}_{\tau}^{n} . \qquad (4)$$

where parameters A and Φ are given by:

$$A = \frac{1}{4} B^2 \sqrt{\tau t}\, \gamma_\Lambda \left(1 + 2 \frac{\ell}{B} f_T \alpha_H\right)$$
$$\Phi = \tau t \gamma_\Lambda B \left[f_T + tg\,\alpha_0 \left(\alpha_H + \frac{\ell}{B} tg\,\alpha_0\right)\right] \qquad (5)$$

where again:

γ_Λ = density of ice (kg/cm^3)

f_T = ice to steel friction coefficient

α_H = prismatic fore-body coefficient

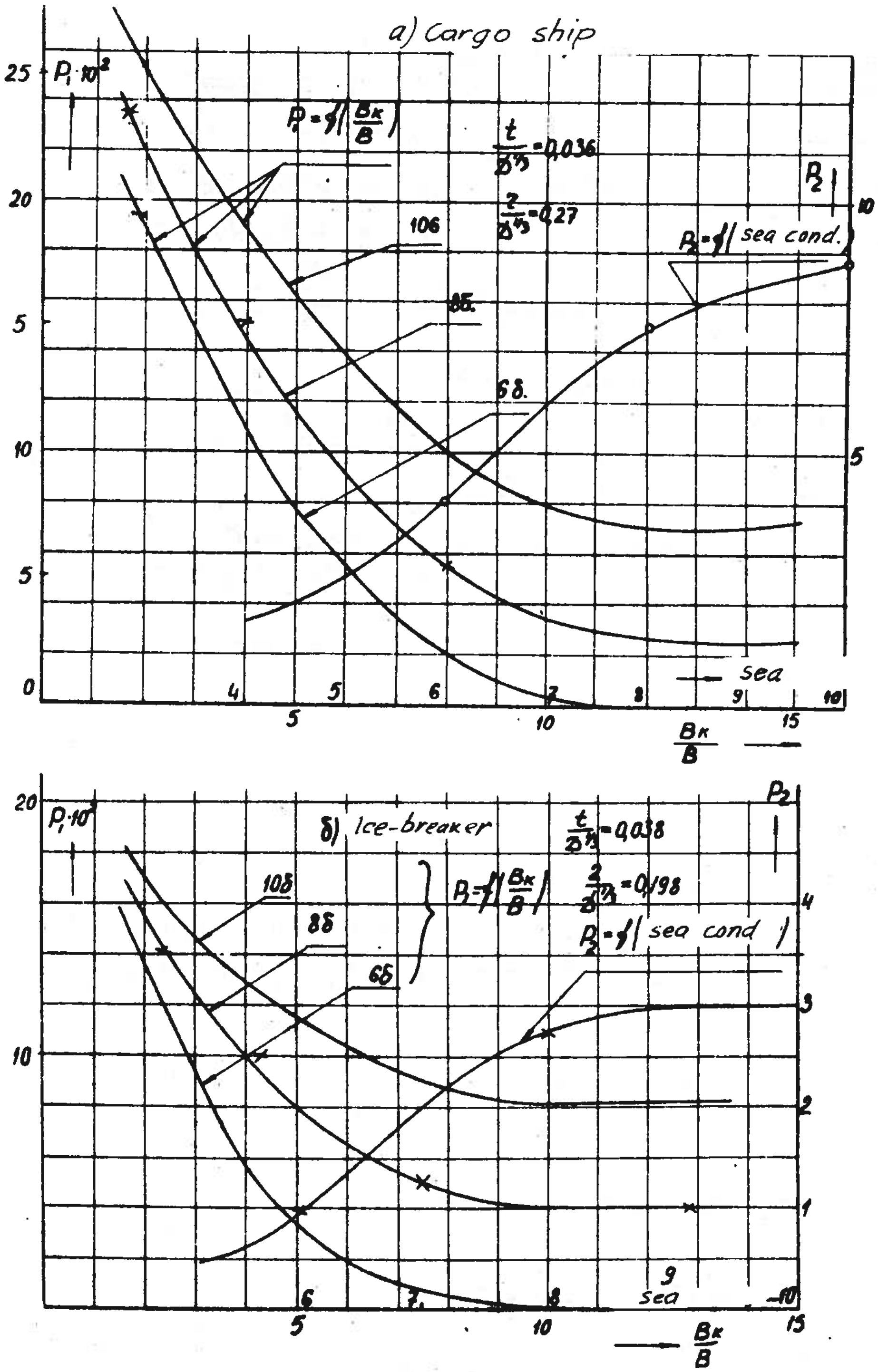

a) Cargo ship
P1·10²
P1 = f(Bк/B)
t/D^1/3 = 0,036
z/D^1/3 = 0,27
P2
P2 = f(sea cond.)
10б
8б.
6б.
sea
Bк/B
б) Ice-breaker
P1·10²
10б
8б
6б
P1 = f(Bк/B)
t/D^1/3 = 0,038
z/D^1/3 = 0,198
P2 = f(sea cond)
P2
sea
Bк/B

Figure 7

α_o = waterline entrance angle

P_1 & P_2 = numerical coefficient

f_2 = - Froude number

n = powering coefficient

(n = 1.12 for icebreakers)

(n = 1.5 for ice strengthened cargo ships)

Coefficients P_1 & P_2 are given by Figure 7 and Figures 1, 2 and 6 give results of calculation for these ships.

CONCLUSIONS

This method of predicting resistance of ships in broken ice provides adequate information for most calculations. The method of calculation and model test results have been verified in full scale test to produce results within acceptable error.

REFERENCES

[1] L. M. Noged, "Criterior of Similarity for Modeling of Ice Resistance Tests," Proceeding of Academy of Science of USSR, 1951

[2] L. M. Noged, "Modeling of Ship Motisus in Solid and Broken Ice," Proceedings of Leningrad Shipbuilding Institute, Vol. 28, 1959

[3] L. M. Noged, "Ship Resistance Calculations from Model Tests," Proceedings of Leningrad Shipbuilding Institute, Vol. 29, 1959

[4] A. V. Bronnikov, "Investigation of Ship Resistance in Broken Ice," Proceeding of Leningrad Shipbuilding Institute, Vol. 27, 1959

[5] A. J. Busuev, "Calculation of Ship Resistance in Small Blocks of Broken Ice," Merchant Fleet, No. 8, 1961

[6] A. J. Reblin, "Ship Resistance in Broken Ice, Method of Calculation," PHD Thesis, Leningrad Shipbuilding Institute, 1963

[7] O. V. Dubrovin, "Model Basin Study of Ship Motions in Broken Ice," Proceedings of Arctic and Anarctic Institute, 1950