Instructions for determining ice loads on river structures

National Research Council of Canada. Division of Building Research

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20337897
Technical Translation (National Research Council of Canada), 1973

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NATIONAL RESEARCH COUNCIL OF CANADA

TECHNICAL TRANSLATION 1663

INSTRUCTIONS FOR DETERMINING ICE LOADS ON RIVER STRUCTURES (SN 76-66)

STATE COMMITTEE OF THE COUNCIL OF MINISTERS (USSR)
FOR CONSTRUCTION (GOSSTROI, USSR)

PUBLISHER
IZDATEL'STVO LITERATURY PO STROITEL'STVU
MOSCOW, 1967, 19P.

TRANSLATED BY

G. BELKOV

THIS IS THE TWO HUNDRED AND TWELFTH OF THE SERIES OF TRANSLATIONS
PREPARED FOR THE DIVISION OF BUILDING RESEARCH

OTTAWA

1973

PREFACE

Because of their corresponding geographical positions, Russia and Canada share similar problems concerning the forces that ice can exert on structures. These problems have received considerable attention from Russian scientists and engineers. Their state of knowledge concerning them has reached the point where it has been possible to formulate quite detailed instructions for the design of structures that must stand up to the action of ice.

Knowledge and experience in Canada has only now reached the point where it is possible to give consideration to the writing of such guidelines. It was thought that it would be useful to have the most recent Russian Code of Practice concerning ice forces available for study and comparison when this task in undertaken. The Division of Building Research of the National Research Council is pleased, therefore, to be able to publish this document in the NRC Technical Translation series. It must be emphasized, however, that the investigations upon which the Russian Code is based are not readily available for evaluation, and so it is not possible to give a judgement as to its validity for Canadian conditions. This document should only be considered as an additional source of experience to be taken into account in the formulation of Canadian guidelines.

The Division of Building Research wishes to express its appreciation to Mr. G. Belkov, Translations Section, National Science Library, for the preparation of this translation, and to Dr. L. W. Gold of this Division who checked the translation.

Ottawa — N. B. Hutcheon

July 1973 — Director

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1663

Title: Instructions for determining ice loads on river structures (SN 76-66)

(Ukazaniya po opredeleniyu ledovykh nagruzok na rechnye sooruzheniya (SN 76-66))

State Committee of the Council of Ministers (USSR) for Construction (Gosstroi, USSR)

(Gosudarstvennyi komitet Soveta Ministrov SSSR po delam stroitel'stva (Gosstroi SSSR))

Publisher: Izdatel'stvo Literatury po Stroitel'stvu. Moscow, 1967. 19p.

Translator: G. Belkov, Translations Section, National Science Library

The "Instructions for Determining Ice Loads on River Structures" (Building Standard 76-66) were formulated by the B. E. Vedeneev All Union Research Institute of Hydrological Engineering, Ministry of Power and Electrification, USSR, in conjunction with the Novosibirsk Engineering Institute for Railroad Transport, Ministry of Communication; VNII VODGEO (All Union Research Institute for Water Supply, Hydrological Engineering Structures and Engineering Hydrogeology) Gosstroi, USSR; and the State Hydrological Institute, Main Administration of the Hydrometeorological Service, Council of Ministers, USSR.

When these "Instructions" come into force on October 1, 1967 they replace the "Technical specifications for determining ice loads on river structures" (SN 76-59).

Editors - E. I. Dyshko (Gosstroi, USSR) and V. I. Sinotin (VNIIG)
(All Union Research Institute for Engineering Hydrology)

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State Committee on Construction Council of Ministers USSR (Gosstroi, USSR)	Building Standards	SN 76-66
	INSTRUCTIONS FOR DETERMINING ICE LOADS ON RIVER STRUCTURES	Replaces SN 76-59

1. TERMS OF REFERENCE

1.1. These Instructions cover the design of hydraulic structures and bridge piers.

Notes: 1. These Instructions also cover the design of structures on lakes and reservoirs.

2. In designing hydraulic structures of Class I magnitude and bridges where there are difficult ice conditions, ice loads determined by the current Instructions should be modified only after detailed field observations and laboratory investigations.

1.2. In designing hydraulic structures on rivers and bridges, the following ice loads must be considered:

a) The dynamic load from impact of individual floating ice floes;

b) Load from ice jams (dynamic);

c) Load due to thermal expansion of a continuous ice cover (static);

d) Load from an ice field due to the action of wind and current (static);

e) Load induced by ice frozen fast to the structure during fluctuations in water level (static);

f) Load resulting from the friction of floating ice against the surface of the structure (dynamic).

Notes: 1. A particular type of ice load need not be taken into consideration if engineering and economic calculations indicate that special measures can be installed to prevent the action of these loads on a structure.

2. In the current Instructions a definition is given for the standard strength limits and load values for ice. The design formulae for determining

Introduced by the Ministry of Power and Electrification, USSR	Confirmed by the State Committee on Construction, Council of Ministers, USSR, 30 December 1966	Instructions come into force 1 October 1967

ice loads take into consideration an assumed overload coefficient of 1.1

3. In designing hydraulic structures by the failure load method the design ice load is taken to be equal to its standard value.

2. DYNAMIC LOADS

Bridge Piers with Vertical Leading Edges

2.1. The load P_1, in tons*, on a pier in the direction of its longitudinal axis resulting from an ice field moving past the pier is determined by the formula

$$P_1 = mAR_p bh, \quad (1)$$

where m is the coefficient for the shape of the pier, taken to be:

a) 0.9 for a semi-circular leading edge;

b) for a triangular leading edge of a pier (regardless of the radius of the leading edge) the value of m depends on the apex angle, 2ε, as shown in Table I.

Note: The value for an angle of 180° is given in the table only for finding the value of m by interpolation when $120^\circ < 2\varepsilon < 180^\circ$;

A is the climatic coefficient taken from Table II;

R_p is the crushing strength of ice, assumed to be (in the absence of experimental data) 75 T/m^2, and at the time of maximum water level at breakup, 45 T/m^2;

b is the width of the bridge pier at the water level occuring at breakup, in meters;

h is the calculated thickness of ice in meters, taken to be 0.8 of the thickest ice during the winter with a probability of 1% of being exceeded (99% confidence level). When there is insufficient original data it is recommended that regional formulae be used for determining h.

* All loads in this Standard have units of metric tons, abbreviated T.

Bridge Piers with Sloping Leading Edges

2.2. The horizontal component of the ice load, $P_{2\gamma}$, in tons, acting on a pier in the direction of its axis is computed by the formula

$$P_{2\gamma} = AR_i h^2 \tan \beta \qquad (2)$$

The vertical component P_{2v}, in tons, is determined by the formula

$$P_{2v} = \frac{P_{2\gamma}}{\tan \beta} \qquad (3)$$

In formulae (2) and (3) R_i, the failure strength of ice in bending in T/m^2, is taken to be 0.5 R_p; β is the angle between the cutting edge of the pier and the horizontal, in degrees.

Note: When the angle of inclination β is greater than 75^o the load $P_{2\gamma}$ should be determined by formula (1).

2.3. If the horizontal load component determined by formula (2) exceeds the load determined by formula (1), the latter is used for calculation.

Vertical Walls

2.4. Load P_3, in tons on vertical walls due to the impact of single ice floes is determined as follows:

a) When the ice floes are moving in a direction close to normal to the face of the structure (ϕ = 80 - 90^o) use the formula

$$P_{3a} = jv_l h\sqrt{\Omega AR_p} \qquad (4)$$

b) When the ice floe is moving at an angle to the face of the structure of $\phi < 80^o$ the normal load component is determined by the formula

$$P_{3b} = jv_l h\sqrt{\Omega AR_p} \sin \phi \qquad (5)$$

The greatest possible load per unit length on a vertical wall of extended structures (dams, dikes, etc.) in T/m acting perpendicular to the face should not be taken as being greater than that determined by the formula

$$P_{3v} = AR_c hk \qquad (6)$$

where R_c is the compressive strength of ice (without taking into consideration local crushing), taken to be 45 T/m^2;

k is a coefficient expressing the irregularity in the contact between the ice surface and structure which is taken to be 0.6 and 0.8 for the initial stage and high water stage of runoff, respectively.

For the notations v_l, Ω and j, see 2.6.

Sloping Surfaces

2.5. The horizontal component of ice load on a sloping surface P_4 in T/m, due to impact of an ice field, is determined by the formula

$$P_4 = AR_ih^2\lambda' \tan \beta \qquad (7)$$

where λ' is a coefficient taken from Table III depending on ice thickness h.

The vertical component of the ice load on a slope P_{4v} is determined by the formula

$$P_{4v} = AR_ih^2\lambda' \qquad (8)$$

The Action of Drifting Ice Floes on Piers in a Reservoir

2.6. The load on a pier P_5, in tons, in a direction along its major axis resulting from collision with a drifting ice floe is determined by formula

$$P_5 = jv_lh\sqrt{\Omega R_p m \tan \varepsilon} \qquad (9)$$

where j, a coefficient having the dimension sec $\cdot$ $T^{\frac{1}{2}}/m^2$, depends on the obstacle the ice floe encounters. For a pier it is 0.43, and for a wall 0.7;

v_l is the calculated velocity of a drifting ice floe in m/sec which, depending on wind velocity, is v_l = 0.02 w m/sec, but not greater than 0.6 m/sec. The calculated wind velocity, w, is based on meteorological data, and when these are deficient it is determined from the area of the ice floe, Ω, using Table IV.

Ω is the calculated area of ice floe in m^2 taken from field observations or by analogy with other structures. The calculated area should not be less than

$$\Omega_{min} = 1.75\ l^2;$$

l is the greatest span of the bridge between piers or the size of the ice discharge opening in meters;

R_p is the crushing strength of ice taken to be 45 T/m^2.

The calculated value of load resulting from a drifting ice floe in a reservoir is taken to be the least of the values calculated by formulae (9) and (1), where the R_p value recommended above, and a climatic factor, A, of 1 are used in formula (1).

2.7. If the direction of movement of the ice floe is different by 10 or more degrees from the direction of the axis of the support, the ice load on the vertical face of the support P_6 is determined by the formula

$$P_6 = P_5 \cos \delta \qquad (10)$$

where δ is the angle between the direction of movement of the ice floe and the axis of the pier.

Dynamic Loads Resulting from Ice Jams

2.8. The load resulting from ice jams (during fall and winter) acting against a pier in a direction parallel to its longitudinal axis is determined by the formula

$$P_7 = m \tau_p b h_3, \qquad (11)$$

where m is a coefficient depending on the shape of the pier, given in Table I.

b is the width of the pier in meters;

τ_p is the failure strength of the ice mass taken to be 12 T/m^2 (in shear);

h_3 is the estimated thickness of the ice mass based on an analysis of the ice-thermal regime of that portion of the river, but not greater than 0.8 of the average depth of water during the ice jamming period.

2.9. The influence of ice jams on structures (during spring breakup) is estimated by analyzing field observations of the ice conditions at the proposed site. It is recommended that the structure be designed so as to avoid the possibility of an ice jam forming at the structure (increasing the span of bridges, the size of ice removal openings, etc.).

Friction Effects of Ice Floes on the Surface of Structures

2.10. The maximum longitudinal load P_8 in T/m resulting from the movement of an ice floe along a vertical structure is determined by the formula

$$P_8 = P_{3v} f \qquad (12)$$

where P_{3v} is the maximum possible ice load perpendicular to the front of the structure, determined by formula (6);

f is the coefficient of ice friction against the surface of a structure, for concrete taken to be 0.11.

Note: In designing structures special measures should be developed to decrease the friction of ice against structures (providing a smooth surface, increasing the strength of the surface layer of concrete, providing smooth facings on concrete surfaces, etc).

3. STATIC LOADS

Loads Generated During Thermal Expansion of a Continuous Ice Cover

Vertical walls

3.1. The static load P_t, in T/m, per unit of length of contact between the ice and a structure resulting from thermal expansion of the ice cover is determined by the formula

$$P_{\tau} = (R_0 h + 2 \alpha h \vartheta \mu \varphi) s, \qquad (13)$$

where R_0 is the elastic limit of ice taken to be 5 T/m^2;

h is the thickness of the ice cover in m taken to be equal to the maximum thickness of ice with a probability of 1% of being exceeded;

α is the coefficient of linear expansion of ice equal to $5.5 \cdot 10^{-5} \frac{1}{^{\circ}C}$;

ϑ is the rate of increase in air temperature in degrees per hour during a time period of τ in hours. During regular observations carried out four times a day the highest value of ϑ for any six-hour period of the day is taken;

μ is the coefficient of ice viscosity in $T \cdot hr/m^2$ determined as follows:

a) for $t \geq -20^{\circ}C$ use formula

$$\mu = (3,3 - 0,28t + 0,083t^2)\,10^4; \qquad (14)$$

b) when $t < -20^{\circ}C$ use the formula

$$\mu = (3,3 - 1,85\,t)\,10^4; \qquad (15)$$

t is the ice temperature in $^{\circ}C$ determined by the formula

$$t = \theta\eta_0 + \frac{\vartheta\tau}{2}\psi; \qquad (16)$$

θ is the initial air temperature in $^{\circ}C$ from which the temperature begins to increase;

η_0 relative thickness of the ice cover taking into consideration the influence of snow and determined by the formula

$$\eta_0 = \frac{h}{h_n} = \frac{h}{h + h_c\sqrt{\frac{a}{a_c}} + \frac{\lambda}{\alpha_b}}; \qquad (17)$$

h_{π} is the reduced thickness of ice cover;

h_c is the least thickness of ice cover in m, corresponding to the period of calculation and determined by direct observations of the ice cover for the given section of the river.

When there are no direct observations snow cover is not taken into account;

a is the thermal diffusivity of ice equal to $0.0041\ m^2/hr$;

α_c is the thermal diffusivity of snow equal to $0.002\ m^2/hr$;

λ is the thermal conductivity of ice equal to $2\ kcal/m \cdot hr \cdot degree$;

α_b is the coefficient of heat transfer from air to the snow-ice surface in $kcal/m^2 \cdot hr$, equal to:

a) in the presence of snow, $20\sqrt{w + 0.3}$;

b) in the absence of snow, $5\sqrt{w + 0.3}$;

w is the mean peak velocity of wind in m/sec corresponding to the period of the largest calculated value of the rate of increase of air temperature ϑ;

ψ, ϕ are coefficients whose values are determined from Figures 1 and 2 respectively depending on the value of $C = \frac{a\tau}{h_{\pi}^2}$ and $\eta_0 = \frac{h}{h_{\pi}}$;

s is the coefficient depending on the extent of ice cover determined from Table V.

Bridge Piers

3.2. The static load P_o, in tons, on a pier when an ice-free area is maintained in the spans between them is determined by the formula

$$P_o = \left(1 + \frac{l}{3b}\right) b P_T, \qquad (18)$$

where l is the width of span in m;

b is the width of support in m;

P_T is the static load determined by equation (13).

Loads Resulting from Pile-up of an Ice Field

3.3. The horizontal load P_H, in tons, resulting from a wind and water driven pile-up of an ice field against a structure is determined by the formula

$$P_H = (p_1 + p_2 + p_3 + p_4)\,\Omega, \qquad (19)$$

where p_1 is the force caused by current drag on the lower surface of the ice field per unit area, in T/m^2;

p_2 is the force of hydrodynamic pressure on the edge of the ice field caused by flow, per unit edge surface area, in T/m^2;

p_3 is the horizontal component of the force of gravity on the ice field where there is a slope of the free flow surface, per unit surface area of the ice field, in T/m^2;

p_4 is the force resulting from the air drag against the upper surface of the ice field, per unit surface area, in T/m^2;

Ω is the estimated area of the ice field in m^2.

The values of p_1, p_2, p_3, p_4 in T/m^2 are taken to be:

$$p_1 = k_1 v^2; \qquad (20)$$

$$p_2 = k_2 \frac{h}{L} v^2; \qquad (21)$$

$$p_3 = k_3 hi; \qquad (22)$$

$$p_4 = k_4 w^2, \qquad (23)$$

where k_1 is a coefficient having the dimensions of $T \cdot sec^2/m^4$ and taken to be $5 \cdot 10^{-4}$ for a continuous ice field and $20 \cdot 10^{-4}$ for ice jams;

k_2 is a coefficient having the dimension of $T \cdot sec^2/m^4$ and taken to be $5 \cdot 10^{-2}$;

k_3 is a coefficient having the dimension of T/m^3 taken to be 0.92;

k_4 is a coefficient having the dimension of $T \cdot sec^2/m^4$ and taken to be $2 \cdot 10^{-6}$;

v is the flow rate of water under the ice in m/sec during the periods of ice accummulation, with a probability of 1% of being exceeded;

w is the velocity of wind in m/sec during the period of breakup with a probability of 1% of being exceeded;

h is the thickness of an ice field in m taken from section 2.1.;

L is the mean length of ice field in the the direction of the flow taken from field observations but not to exceed three times the width, in meters;

i is the water surface slope.

Loads Resulting from an Ice Jam

3.4. The load P_z, in tons, against a structure during the accummulation of ice (perpendicular to the ice front) is determined by the formula

$$P_z = L_z B(p_1 + p_2 + p_3 + p_4) \qquad (24)$$

where L_z is the length of the ice jam from which pressure is transmitted against the structure, taken to be $1\frac{1}{2}$ times the width of the river at the structure, in meters;

B is the length of the structure in meters;

p_1, p_2, p_3, p_4 are pressure components determined from section 3.3. In making these calculations the thickness of the ice jam is taken from section 2.8; in computing the rate of flow consideration is given to constriction of the river bed by the ice jam of the given thickness; the slopes at the location where the ice jam is formed are determined from observations or by analogy with other situations.

3.5. The load exerted by an ice jam on unit length of structure parallel to the direction of flow (as well as against the shores) P_b, in T/m, is determined by the formula

$$P_b = \xi L_z(p_1 + p_2 + p_3 + p_4) \qquad (25)$$

where ξ is the coefficient of lateral pressure taken from Table VI.

The Effect of an Ice Cover Frozen Fast to a Structure

Slopes and walls

3.6. A bending moment may be generated on a structure or on individual parts of it when an ice cover frozen to it moves vertically due to variations in water level. This moment M_x in ton-m, acting in the vertical plane perpendicular to the face of the structure is determined by the formula

$$M_x = \frac{Bh_k^2}{6} \cdot \frac{R_{d.t.}\ R_{d.c.}}{R_{d.t.} + R_{d.c.}} (1 + 2k_E) \qquad (26)$$

where B is the calculated length of the face of the structure or individual parts of it at the water line, in meters;

h_k is the calculated thickness of the ice cover in meters, taken to be equal to the thickness of the crystalline layer established by observation for the given case; for preliminary calculations of the thickness of the crystalline layer it can be assumed to be within the limits of h_k = 0.8 to 0.9 h, where h, the thickness of the ice cover beyond the shore-influenced zone, is taken to be equal to the thickness of the ice, with a 1% probability of being exceeded, for the period during which the water level fluctuates;

$R_{d.t}$, $R_{d.c}$ are the design stress of crystalline ice in T/m^2 in tension and compression respectively, determined with the time-dependent ice stress coefficient $k_p \leqq 0.85$ by formulae (27) and (28); if the value of $k_p > 0.85$, then the design stress is taken to be $R_{t.t.}$ and $R_{t.c.}$

k_p is the time-dependent ice stress coefficient associated with relaxation under tension or compression.

$k_p = \frac{R_p}{R_t} = \exp(-\tau/n)$ (notation given in section 3.7);

$R_{t.t}$, $R_{t.c}$ are the yield strength of crystalline ice in tension and compression taken either from Table VII or from experimental data, in T/m^2;

k_E is the coefficient of modulus of elasticity taken as 1 when $k_p \leqq 0.85$ and 2 when $k_p > 0.85$.

3.7. Design values of the time-dependent stress associated with relaxation during deformation of ice are calculated by the formulae

$$R_{d.t} = R_{t.t} \exp(-\tau/n) \quad (27)$$

$$R_{d.c} = R_{t.c} \exp(-\tau/n) \quad (28)$$

where τ is the time in hours during which there is deformation of the ice cover due to rise or fall in water level by an amount equal to the thickness of the ice;

n is a parameter characterizing the rate of relaxation; $n = \frac{\mu}{E} 10^3$;

μ is a coefficient representing the viscosity of ice as determined in section 3.1 for an ice temperature corresponding to the temperature of the upper part of the ice cover, in $T \cdot hr/m^2$;

E is the modulus of elasticity of the ice which in the absence of experimental data is taken to be $4 \cdot 10^5$ T/m^2.

Notes: 1. The temperature of the upper part of the ice cover used in denoting the design yield point of ice and in computing the viscosity coefficient is taken to be the mean temperature of the lower, diurnal, below-freezing air temperatures during the period when the water level changes. For the above case the insulating effect of snow is ignored. The influence of snow on ice temperature, according to section 3.1, is considered in regions where there is a stable snow cover during the period when there are changes in water level.

2. During deformation of the ice cover caused by an increase in water level the temperature of the upper part of the ice is considered to be within the range of 0 to $-2^{\circ}C$.

3. The temperature of the lower part of the ice cover is in all cases considered to be $0^{\circ}C$.

4. In calculations for the spring low-water period before melting starts, the thickness of the ice cover, h, and the mean below-freezing diurnal air temperatures are obtained from the mean annual values for the period of 30 days before the beginning of continuous melting of the ice.

Piles and Pile Clusters

3.8 The vertical load P_c, in T, which is transmitted by an adhering ice cover to individual piles and pile clusters when the water level increases is determined by the formula

$$P_c = \frac{k_c h^2}{\ln \frac{50h}{d}}, \qquad (29)$$

where k_c is taken to be 300 T/m^2;

- h the thickness of the ice cover, is taken to be the maximum thickness of ice with a 1% probability of being exceeded, in meters;
- d is the diameter of the pile or piles cluster in meters; with a rectangular cluster with sides x and y the value of d is taken to be $\sqrt{xy}$.

Notes: 1. Formula (29) is applicable when there is a continuous ice cover.

2. Here we consider individual piles and pile clusters surrounded by a continuous ice cover extending over a radius of not less than 20 h.

3. Formula (29) may be applied for a pile cluster in which the distance between individual piles is not more than 1 m.

Table I

Value of coefficient m

2ε	45°	60°	75°	90°	120°	180°
m	0,54	0,59	0,64	0,69	0,77	1

Table II

Climatic coefficient A

No. of region	Boundaries of region	Climatic coefficient A	Notes
1	South of the line Talin - Minsk - Khar'kov - Astrakhan - Nukus - Alma-Ata	0.75	1. For regions No. 2-5 the lower boundary is also the boundary of the foregoing region. 2. The climatic coefficient can be based on field observations of conditions at spring breakup, but for breakup with negative air temperatures (< 0°C) it must not be less than 2.
2	South of the line Vyborg - Smolensk - Kamyshin - Aktyubinsk - Balkhash	1	
3	South of the line Arkhangel'sk - Kirov - Ufa - Kustanai Karaganda - Ust'-Kamenogorsk	1.25	
4	South of the line Vorkuta - Khanty - Mansiisk - Krasnoyarsk - Ulan-Ude - Nikolaevsk-na-Amure	1.75	
5	South of the line Dikson - Noril'sk - Vodaibo - Okhotsk	2	
6	North of the line Dikson - Noril'sk Vodaibo - Okhotsk	2.25	

Table III

Value of the coefficient λ'

h in m	0,4	0,5	0,6—0,7	0,8—0,9	1—1,3
γ' in m^{-1}	0,08	0,07	0,06	0,05	0,04

Table IV

Calculated wind velocity

$\Omega \cdot 10^{-3}$ in m^2	10	40	250	1000
w in m/sec	34	31	27	24

Table V

Value of coefficient s

L in m	up to 50	51—75	76—100	101—150	more than 150
s	1	0,9	0,8	0,7	0,6

Table VI

Value of coefficient ξ

Computation Cases	ξ
Compression when there is a trend towards a limiting stress state for gently sloping sandy shores	0.7
The same for rocky shores and vertical walls of structures....	0.9

Table VII

Yield strength of crystalline ice when the force is acting perpendicular to the axis of the crystals

Ice temperature in ^{o}C	Yield strength of ice (rounded figures) T/m^2	
	Tension $R_{t.t}$	Compression $R_{t.c}$
	Upper part of ice cover	
From 0 to -2	70	180
From -3 to -10	80	250
From -11 to -20	110	280
	Lower part of ice cover	
From 0 to -2	50	120

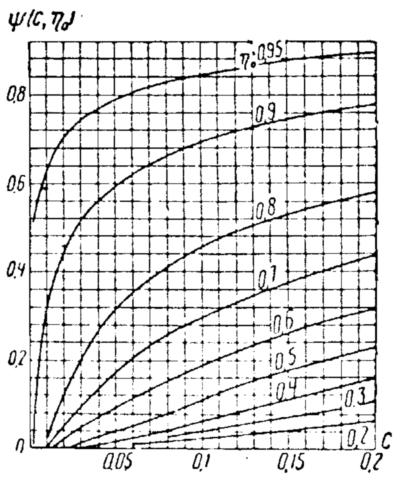

Fig. 1

Graph for determining ψ

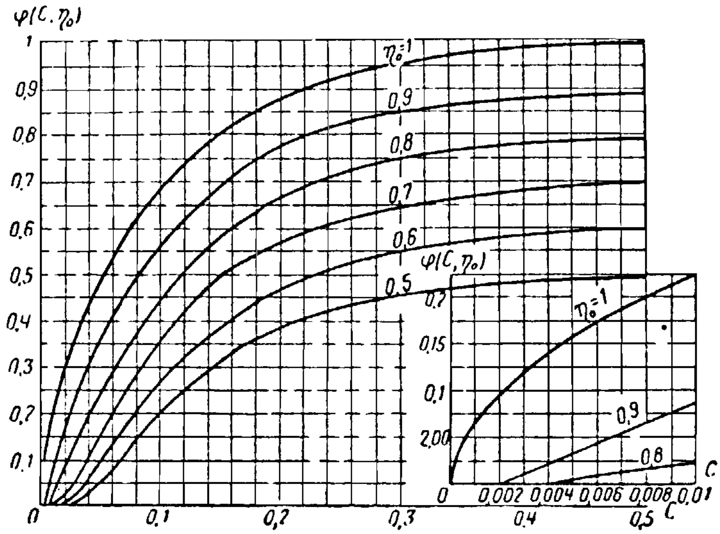

Fig. 2

Graph for determining ϕ