Draft Translation 347

DEVELOPMENT OF METHODS FOR DETERMINING ICE PRESSURE ON BRIDGE PIERS IN THE USSR

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April 1972

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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DRAFT TRANSLATION 347

ENGLISH TITLE: DEVELOPMENT OF METHODS FOR DETERMINING ICE PRESSURE ON BRIDGE PIERS IN THE USSR

FOREIGN TITLE:

AUTHOR: K.N. Korzhavin

SOURCE: Novosibirskiy Institut Inzhenerov Zheleznodorozhnogo Transporta. Trudy No. 79, Novosibirsk, 1968, p. 3-18.

Translated by U.S. Joint Publications Research Service for U.S. Army Cold Regions Research and Engineering Laboratory, 1972, 16 p.

NOTICE

DEVELOPMENT OF METHODS FOR DETERMINING ICE PRESSURE ON BRIDGE PIERS IN THE USSR

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Introduction

The broad expansion of transport construction in the USSR requires a detailed consideration of the effect of ice on bridge piers both during their erection and also during operation. This is especially important under the climatic conditions existing in the North of the USSR and in Siberia, determining the great thickness and strength of the ice and the heavy spring ice drift, at times occurring tempestuously at high levels, with the formation of ice jams. The dynamic effect of large ice fields sometimes drifting at considerable speed can lead to severe damages and even the destruction of structures. A significant role is also played by an efficient arrangement of the bridge openings into spans. In the case of inadequate spans, it is possible to have the formation of ice jams with very serious consequences.

These questions have long attracted the attention of many researchers both in the USSR and abroad. However, the extent of their development is still inadequate. We have not clarified to a full extent the physical pattern of the phenomena, the mechanical properties of ice during the ice drift, the role played by the friction between the floe and the pier, the form of the pier on the horizontal and profile, and a number of other questions.

As a result of this, the technical specifications and standards which had been in effect until 1959 (TUPM-38, GOST 3440-46, TUPM-47, TUPM-56) often failed to reflect the entire complexity of the phenomenon and in certain instances (e.g. in considering the role of the pier's sloped edge) provided clearly incorrect recommendations.

It seems to us that such a situation was the result of a number of circumstances. The construction of large hydraulic facilities in the USSR, particularly in Siberia, has been launched only in recent years. Bridge piers have been planned with very high strength reserves with large spans and hence cases of damage and destruction of piers have been rare. In addition, one must never overlook the fact that the occurrences of the effect of ice on a structure are quite complex and involve several as yet poorly developed problems in the mechanics of materials' breakdown.

1. Functioning of Bridge Piers During Ice Drift Period

Over the vast territory of the Soviet Union, there are regions differing markedly in their climatic features and hence also in conditions of spring ice drift in the rivers. For instance most of the large Siberian rivers flow northward; owing to this, drifting ice of great thickness and strength can easily form jams. Therefore the highest levels in the year often coincide with the ice drift (or close to its levels), which places the functioning of the structural piers under particularly unfavorable conditions. Since the opening of the large Siberian rivers is often determined by the mechanical effect of a flood wave, the strength of ice during the spring ice-out (debacle) will remain even greater. The area of individual floes attains large dimensions not only during the movements but also in the period of open pack ice. In this way, the spring ice debacle on many Siberian rivers comprises a serious factor requiring a detailed consideration in planning the structures and particularly the individually standing piers. Let us comment that on many large rivers in the European sector of the USSR, the conditions of spring ice breakup are considerably easier.

Field observations of the operation of starlings (ice aprons) on bridge piers and buttresses to hydraulic installations, taking movie films (and photographs) of the ice disintegration process permitted us to clarify the phenomenon's physical pattern [1-3].

At encounter with the ice pack, the pier with a vertical cutting edge "cuts" into the ice for a certain slight distance (about 0.1 - 0.5 m), accompanied by local compression and subsequent breakdown of the ice. The nature of an ice floe's disruption is determined mainly by the reserve of its kinetic energy and also by the form, dimensions and material of the pier's body. As observations in nature have shown, a close contact of the ice pack with a pier is possible only for an ice pack of low strength, not dangerous per se. In case of any strong ice pack, the width of the part of the bridge pier sustaining the ice pressure usually does not exceed 0.5-0.8 of its maximum width.

In the presence of an inclination of the ice-cutting edge toward the horizon, the latter seemingly cuts the ice field from underneath; this promotes a more successful disruption of the ice pack from shearing or most often from bending, reducing the chance of ice congestions' formation.

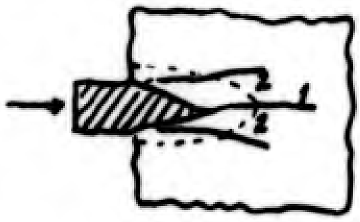

Fig. 1. Nature of Ice's Breakdown by Bridge Pier with Sloped Edge: 1-leading cracks; and 2-ice projections.

Ahead of the cutting edge, two or three leading cracks usually develop, separating the unique ice consoles. The fracture of the consoles usually occurs at a distance from the pier equalling 3-6 ice thicknesses. The width of the strip which is being cut by the pier in the ice pack hardly exceeds the pier's width (Fig. 1). The ice pressure has a periodic nature; it changes through time, fluctuating around a certain average value.

2. Extent to Which Problem Has Been Studied

During the launching of large-scale railroad construction in the USSR, the methods of considering the dynamic ice pressure on structures had hardly been developed. It is typical that in the interesting monograph written by A.N. Komarovskiy [1], having generalized all the domestic (Soviet) and foreign experience in hydraulic construction and bridge building, the technique for calculating the dynamic ice pressure was given only 13 pages out of 314.

A. N. Komarovskiy presents and analyzes various methods for computing (proceeding from the ice's resistance to crushing, based on the theory of pulses, the formulas describing the central impact of two inelastic free bodies, proceeding from the phenomenon of a floe's splitting) and recommends, following N.A. Rynin and A.L. Dubakh, the equation:

$$P = 0.093\ b\ h\ v\ (\ell + v), \qquad (1)$$

obtained from the theorem of pulses, with consideration of the impact of water on the rear edge of the floe, at the arbitrarily assumed time of floe's stopping equalling 1 second (here b, ℓ = width and length of floe, while v = its velocity of travel).

With adequate substantiation, Komarovskiy refutes the method of calculation constructed by analogy with the central impact of free inelastic bodies, proposed as early as 1895 by L.F. Nikolay and recommended later by A.A. Surin.

Let us point out that the incorrect concept of the nature of ice effect on the sloped bridge piers having been differentiated by A.N. Komarovskiy unfortunately then was reflected in the official GOST standards 3440-46 and was utilized extensively in the scientific and training literature.

The requirement for erecting a series of large structures in the North of the USSR and in Siberia called for an immediate solution to the problem of taking the dynamic ice pressure into account. A number of specialists and scientists examined these questions and introduced various recommendations.

A major forward step was the report by Prof. N.M. Shchapov [7], having proposed a proper methodology for determining the pressure of an ice field during its stoppage at a structure. Shchapov's suggestion was then developed further by P.A. Kuznetsov [2], K.N. Korzhavin [4], B.V. Zylev [5] and Ye. V. Platonov [6], having derived convenient calculation formulas which are still in use.

One must also cite the reports by A.I. Gamayunov [7], D.F. Panfilov [7], G.S. Shadrin [8], N.N. Petrunichev [9], V.P. Berdennikov [10], A.S. Ofitserov [7] and other specialists whose studies promoted the solution of the individual aspects of the problem and were used to some extent or other in the preparation of standardizing documents.

With the close participation of the AUSRIH (All-Union Scientific-Research Institute of Hydroengineering) imeni B.Ye. Vedeneyev, in 1946, the USSR Gosstroy approved, as a Union-wide standardizing document, GOST 3440-46, followed by the adoption of standards for considering the ice loads in 1959 (SN 76-59) and finally, in 1966, the Instructions for Determining Ice Loads on River Structures, which were put into effect starting in fall of 1967 (SN 76-66).

On four occasions during these years, the USSR Ministry of Railways reviewed the standards for ice loads given in the Technical Specifications for planning of bridges (TUPM-38, TUPM-47, TUPM-TUPM-56 and SN 200-62), as a rule lowering from year to year the calculated ice pressures.

Several monographs were also published, clarifying in detail the questions of ice effect and among them are the reports by A.N. Komarovskiy [1], P.A. Kuznetsov [2], D.N. Bibikov and N.N. Petrunichev [9], I.M. Konovalov, K.S. Yemel'yanov and P.N. Orlov [11], K.N.

Korzhavin [3] and I.S. Peschanskiy [12]. Specifically, five collections of transactions have been published by the Laboratory of Ice Thermics at the Transport-Power Institute of the USSR Academy of Sciences Siberian Branch, four thematic collections by the All-Union Scientific-Research Institute of Hydroengineering imeni Vedeneyev and five collections of works by the Scientific-Research Institute of Railway Transport, devoted entirely to the questions of ice thermics.

A significant part has been played by the systematically conducted coordinating conferences on ice thermics, having been unique stages in the development of ice-thermal science in the USSR.

Many articles have also been published in the periodical literature, for example: B.V. Zylev, K.N. Korzhavin, I.P. Butyagin, A.I. Gamayunov, D.V. Panfilov, N.M. Shchapov, V.P. Berdennikov, G.S. Shadrin, A.S. Ofitserov and other specialists have written articles; their reports facilitated the solution of a number of major questions in the area of determining the ice loads on structures.

Unfortunately, we must note the extremely varying and not always justified approach to establishing the ice loads as done by certain authors. Some have employed the methods in the theory of elasticity(Gamayunov, Zylev, Panfilov), examining essentially the static effect (on a structure) of an isotropic ice plate of uniform thickness, lying on a resilient base. Moreover, to a considerable extent, there is schematized and simplified the physical pattern of the phenomenon; the elastic constants of ice are not always validly assumed, which must inevitably be reflected in the results.

Others have considered an ice pack as a plastic body; this is not entirely valid for the actual conditions of ice's effect on a structure in the period of springtime ice passage. A third group of authors (Shchapov, Kuznetsov, Korzhavin, Peschanskiy and others) have proceeded from general mechanical concepts, corrected by observations in nature.

It is not surprising that as a result of utilizing such unstandardized methods, the recommended values for the calculated ice loads differ markedly from one another. As has been shown by us and also by G.S. Shadrin and D.F. Panfilov [8], the recommendations in GOST 3440-46 and TUPM-47 were exaggerated by 2-3 times as compared with the actual pressures while the utilization of the suggestions in TUPM-56 led to an unjustifiably low value of ice loads. In connection with this, the appropriate sections of TUPM-56 have been reviewed after 3 years; starting from 1959, new standards (SN 76-59) went into effect (and the proposals in SN 200-62 developed on their base).

Similar situations were most often a result of an insufficiently thorough study of the phenomenon's physical pattern in nature and the employment of calculation systems which at times were far from reality. The authors of many proposals have overlooked the anisotropy of an ice pack (especially significant during the spring ice passage), the formation of leading cracks in the column of the ice pack, the form of piers on the horizontal and even their dimensions, the frictional forces between the bridge piers and the ice fields, and certain other factors. A.I. Gamayunov, B.V. Zylev and D.F. Panfilov in determining the ice loads on inclined ice aprons, for simplifying the problem, excluded from the discussion the horizontal pressure component, largely determining the nature of the occurrence.

In certain reports by V.P. Berdennikov and A.I. Gamayunov, in our opinion an unsubstantiated use has been made of the solutions to the contact problem of the elasticity theory beyond the limits of their applicability; this can not lead to a satisfactory solution to the problem. The investigations of the physico-mechanical properties of ice have obtained a further development in the reports by I.P. Butyagin [13], K.F. Voytkovskiy [14] and other authors [15, 16, 17].

3. Determination of Actual Ice Pressure on Structures

In case of a shortage of natural observations and data on the actual ice pressure during its dynamic effect, we found quite useful the suggestions made by N.N. Davidenkov concerning the installation of ice dynamometers and the B.V. Zylev [5] concepts on the utilization of icebreakers as an analogy. Also of interest are the efforts to determine the actual ice pressure on the Svir' River described by F.I. Bydin and also the researches completed by A.I. Gamayunov on establishing the actual ice pressure against the piers of bridges spanning the Volkhov and Dnieper Rivers [7].

Regrettably, the procedure used by A.I. Gamayunov proved to be too complicated while the equipment employed could not provide the required accuracy. In addition, the studies by Bydin and Gamayunov permitted the obtainment only of isolated results, quite inadequate for making valid conclusions about the actual ice pressure. Therefore of interest is the simple kinematic method, developed in the Scientific-Research Institute for Railway Transport, for finding the actual ice pressure on structural piers.

This method is based on the idea that after coming in contact with a pier, the floe slows down its motion and based on the nature of the decrease in travel speed of the ice field, it is possible to determine also the developing forces of interaction. It permits us to manage without complicated equipment. For the obtainment of data required for the calculation, we initially used movie filming of the process of a large ice floe's breakup, yielding satisfactory results. From 1959-1962, V.K. Morgunov [6] developed new photogrammetric equipment for determining the floe's travel rate and their dimensions; this facilitates the performance of the tasks and increases the precision of the kinematic technique.

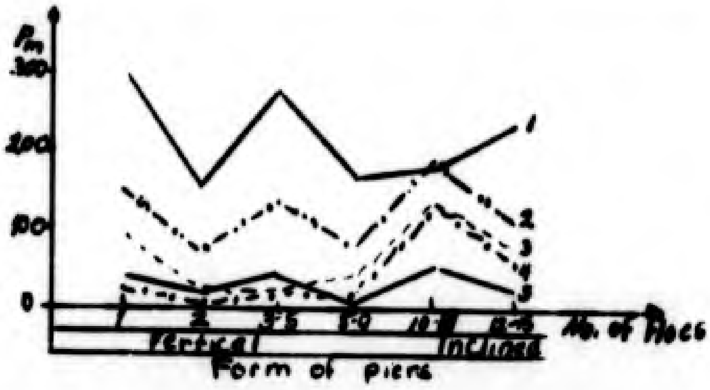

Fig. 2. Comparison of Calculated Ice Loads with Actual Ones: 1-based on GOST 3440-46; 2-based on TUPM-47; 3-based on SN 76-59 and SN 200-62; 4-based on TUPM-56; and 5-actual ice pressure. Key: a) Vertical; b) Inclined; c) Number of floes; and d) Form of piers.

This procedure was utilized by us in more than 40 cases, including at the structures of the Bratsk and Krasnoyarsk HES (Hydroelectric Stations) and on the piers of bridge across the Ob', Tom' and Yenisey Rivers. Figure 2 illustrates the derived data, which allow us to form the following conclusions:

a) the standards in SN 76-59 yielded a value for pressure on the structural piers which was considerably lower than that recommended by GOST 3440-46 and TUPM-47, which favored a reduction in unjustified expenditures;

b) the 1959 standards corrected the erroneous recommendations in TUPM-56 for piers with sloped edges, raising the amount of the calculated pressure;

c) as a rule, the ice loads determined based on SN 76-59 are somewhat higher than those occurring in nature; such a situation should be considered normal, especially since a number of observations have been made of ice fields appreciably weakened by spring thawing processes; and

d) the 1959 standards have expanded the range of factors taken into account in the calculation of ice loads and have dealt more correctly with a number of questions; however, a further improvement was still needed.

4. Evaluating the Role of a Structure's Sloped Edge

As was already indicated above, in the original developments the role of the sloped edge of a bridge pier was incorrectly estimated. The suggestion was made to first determine the ice pressure P on the vertical edge and then to divide it into components on encounter with the ice-cutting edge inclined to the horizon at an angle of β.

It was assumed that the pier is acted on by the vertical component:

$$P_v = P \sin\beta \cos\beta \tag{2}$$

and the horizontal component

$$P_h = P \sin^2 \beta. \tag{3}$$

In reality, there is a significant difference in the actual nature of the ice pack's rupture by the piers with vertical and inclined edges; therefore, the utilization of the same P-value in the computations is not substantiated.

On encounter of the ice field with a pier, a partial compression of the ice edge occurs, with the formation of a gradually increasing force of effect N directed roughly along a perpendicular to the pier's cutting edge.

The pressure force N can be divided into components: a vertical one V and a horizontal one T at any moment, interconnected by the relationship (Fig. 3)

$$V = T \cot\beta. \tag{4}$$

Obviously the horizontal component can lead to the disintegration from crushing while the vertical component can lead to fracture from bending (or, in case of a weak ice sheet, breakup can occur from shearing).

At appreciable inclination angles of the ice-cutting edge to the horizon (β), there occurs first of all the breakup of the floe by bending; at $\beta > 70$-$80°$, it is possible to have breakup from crushing.

The slope of the ice-cutting edge thus promotes the reduction of the horizontal pressure component and, what is most important, facilitates the breakup of the ice pack. The ice-cutting edge forces the broken-off material upward, not creating the effect of local compression. In order to be convinced of this, it suffices to recall the successful operation of icebreakers, climbing onto an ice pack and pressing it down with the ship's weight.

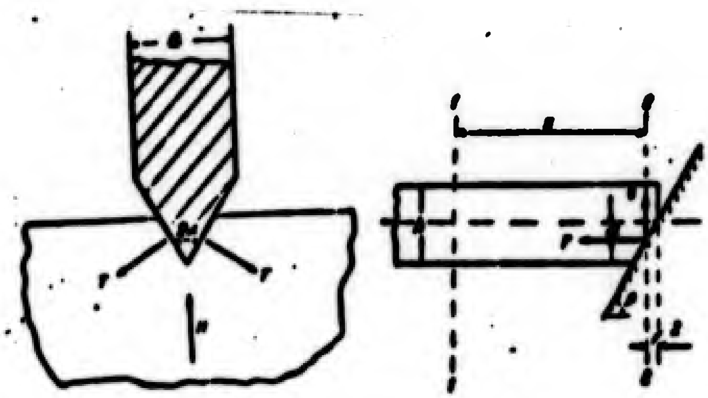

Fig. 3. Diagram Showing Interaction of Floe with Sloped Ice Apron of Bridge Pier.

However, the application of a sloped edge involves an appreciable increase in volume of the structures' body and it is obvious that the use of sloped ice aprons on the bridge piers should be carefully justified in each case. Based on studying the operation of bridge piers, it can be inferred that under the conditions of the USSR European sector, piers with a vertical edge can be used in practically all cases.

Under the conditions of exceptionally heavy ice passage (e.g. in the lower course of the huge Siberian rivers) when there is an actual possibility of contact with large ice fields of great thickness and strength, one should consider a modification of using the piers incorporating the sloped edges at the level of the spring ice breakup.

One should also tie in the question of the choice of piers' type with the spacing of the opening of a bridge or dam into spans. Such attempts were undertaken in the Scientific-Research Institute of Railway Transport as early as 1957 [4]. To avoid the hangup of floes at the piers of a bridge with spans of slight width (and hence with a large number of piers), it is possible to consider a variant with sloped ice aprons.

It goes without saying that the application of edge slope angles to the horizon (β) in the limits ranging from 70-80° and more has no practical sense and should be excluded.

5. Evaluating the Mechanical Properties of Ice During Ice Motion

It is natural that the forces of interaction developing between an ice pack and a structure are closely linked with the ice's mechanical parameters and above all by the limits of its resistance to crushing, bending and shearing.

The Soviet ice specialists have performed extensive work along these lines. Let us note the studies conducted in the AUSRIH (All-Union Scientific-Research Institute for Hydroengineering), AANII, SRIRT*(Scientific-Research Institute for Railway Transport), Transport-Power Engineering Institute of USSR Academy of Sciences (TEI), Permafrostology Institute of USSR Academy of Sciences, the SNIIE (expansion unknown), and other organizations.

The studies conducted both under laboratory and field conditions permitted us to form the following conclusions:

1. By the time of the spring ice passage, the limit of river ice resistance to compression and bending decreases significantly (by 1.5-3 times).

2. The ice's resistance to the pier's penetration is influenced quite significantly by the phenomenon of local compression, capable of increasing the developing forces of interaction by 2-2.5 times.

3. An appreciable (and at times also contradictory) role in assessing the river ice's mechanical properties is played by the rate of deformation.

In the zone of low deformation rates, one notes (S.S. Vyalov et al.) an increase in the strength of ice with an increase in the deformation rate. In the range of high rates (of interest for bridge builders), we observe a decline in ice strength with an increase in deformation rate. This contradiction was solved recently by F.I. Ptukhin; he succeeded in explaining these features in ice behavior under load.

4. In evaluating the ice strength, it should be taken into account that the widely practiced tests of small ice specimens (cubes with a side of 8, 10, 15 cm) permit us to derive only relative values for strength. With an increase in the samples' sizes to 10,000-20,000 cm^2 and with their testing under natural conditions without removal from the water, the ice's resistance to bending decreases.

For practical calculations, R can be determined based on the schematized graph by I.P. Butyagin [13] shown in Fig. 4, in which there are delineated the boundary sectors corresponding to a thickness of ice cover ranging from 30 to 80 cm. The main reason for the decrease in strength with increase in the sample's sizes is ascribable to the presence of cracks and cavities, causing a concentration of stresses and disintegration of the sample.

*Here & elsewhere, SRIRT should read "NIRTE" (Novosibirsk Institute of Railway Transport Engineers)(not: Scientific-Research..)

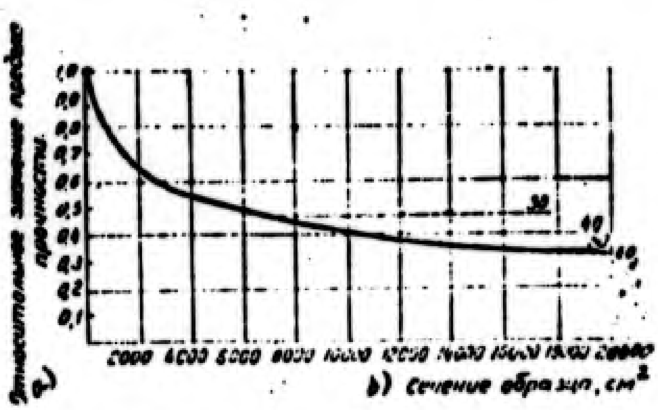

Fig. 4. Calculated Values of Relative Ice Strength at Thickness Ranging from 30-80 cm (After I.P. Butyagin).
Key: a. Relative strength value; and b. Section of sample, cm^2.

5. Strength tests on more than 100 slabs of river ice for bending at temperature close to 0°C showed an average ice strength value of 43 $tons/m^2$ at maximal value of 104 $tons/m^2$. In this context, it was clarified that the ice's resistance to bending is slightly less than its compressive strength; this provides the possibility of undertaking simpler tests for compression.

6. Tests conducted on the strength of three large ice fields at the reservoir of Novosibirskaya HES showed that the strength of the ice pack decreases to 45 $tons/m^2$ at extreme values running from 34 to 54 $tons/m^2$.

The general pattern of disintegration corresponded to B.V. Zylev's solution [5] but the width of the breakup differed significantly (by 1.5-2 times) from the calculated width.

7. Tests (conducted on 73 samples) to determine the resistance of river ice to the penetration of punches having varying shapes indicated the extensive influence of the punch's form (and consequently of the horizontal form of a pier) on the resistance of the ice pack. Therefore one should take into account the effect of a pier's configuration by introducing the form factor m suggested in report [4]. The m-value for the various taper angles of a pier on the horizontal (2α) prove to be about as follows:

2α =	45°	60°	70°	90°	120°
m =	0.60	0.65	0.69	0.73	0.81

As is obvious, the application of more sharply-angled piers is quite desirable.

8. As a result of analyzing the question, we can suggest the calculated values for the strength of river ice (tons/m^2) listed in the table.

Recommended Values for Limit of Ice Strength

Nature of interaction	Rivers of north in European sector of USSR and Siberia			Rivers in central and southern belt of USSR European sector		
	v = 0.5 (m/sec)	v = 1.0 (m/sec)	v = 1.5 (m/sec)	v = 0.5 (m/sec)	v = 1.0 (m/sec)	v = 1.5 (m/sec)
Compression with consideration of local crushing	150	125	110	75	60	50
Bending	100	85	75	50	40	35
Shearing	30 40			20 - 30		

6. Regioning of USSR Territory According to Strength of Spring Ice

The vast territory of the USSR is typified by quite diversified conditions regarding the opening of rivers and the advent of ice passage. While the southern regions in the European and Asiatic parts of the USSR have their main water arteries running from north to south, in the North and in Siberia, the rivers flow mainly from south to north; this situation leaves its imprint on the nature of ice breakup.

The thawing of snow, starting in the river headwaters located farther south, causes a rise in levels and then the ice motion. The flood wave, shifting downstream, on its way encounters ice which is still fairly strong but nevertheless breaks it up; in these cases it is necessary to reckon with the possibility of considerable ice strength.

In addition, the drifting ice masses often form jams, abrupt rises in water level, accompanying the ice passages in many rivers of Siberia.

While GOST 3440-46 failed to provide any instructions on dividing by regions the strength of spring ice over the USSR territory, SN 76-59 and SN 200-62 divide the country into a total of two zones (with a fluctuation in strength by twice); this can not be recognized as satisfactory.

We should therefore consider as a considerable step forward the division, provided by Instructions (SN 76-66) of the USSR territory into six zones, with climatic factors ranging from 0.75 to 2.25.

Undoubtedly an important question concerning the boundaries of the climatic zones and the numerical values for the climatic factor will be refined in the future owing to a more thorough study of the hydrometeorological conditions in individual regions across the country.

7. Certain Additional Suggestions on Allowing for the Dynamic Pressure of Ice, Included in Instructions SN 76-66

In the latest edition of the All-Union Standards for calculating the ice loads on bridge piers (Instructions SN 76-66 of USSR Gosstroy), new proposals are included on computing the dynamic ice pressure under certain special conditions.

Estimating the Effect of a Drifting Ice Field on Structures Located Within the Confines of Reservoirs

During the opening of reservoirs, it is possible to have the interaction of vast ice fields, drifting under the effect of wind and current, with bridge piers, water, water-collecting impoundments and so forth. Such cases could lead to accidents and damages [3].

It is necessary to consider that the piers of structures (e.g. of bridges) can have an appreciable height (up to 50 m) and in such instances, the effect of ice is particularly hazardous.

At the basis of the consideration of the features in the hydrologic regime in reservoirs (weakening of ice strength during the drift period owing to openings (leads) which have formed, possible rates of drift, etc.), a calculation procedure has been suggested which has also been adopted in the Gosstroy Instructions.

It is extremely desirable to undertake observations in nature which would permit us to refine the physical pattern of the phenomenon and improve on the calculation technique.

Evaluating the Effect of Dynamic Pressure of Blocking and Jamming Masses on Structures

The development of this important question has still just begun and involves serious difficulties. We should mention the reports by SHI (State Hydrologic Institute) (Berdennikov), the SRIRT (Korzhavin, Troynin) and the VODGEO (Ofitserov) published recently and permitting us to delineate in broad outlines a calculation setup for the phenomenon and to suggest (as yet quite roughly) the quantitative values for the various parameters.

Experience gained in utilizing the suggestions in SN 76-66 will permit us to introduce in the future the required refinements into this extremely poorly investigated area of calculation.

Conclusion

Although the survey conducted of the development of methods for determining the dynamic pressure of ice on bridge piers in our country is necessarily brief and incomplete, it nevertheless permits us to note that the Soviet ice specialists have made a great contribution to this field of knowledge.

We have studied the physical aspect of the phenomenon; we have indicated the validated calculation procedures; and we have recommended quantitative values for the parameters entering the calculation formulas. We have proposed a technique and we have made dozens of determinations of actual ice pressure on structural piers; in addition, we have improved the official standards for estimating the ice loads.

Several scientific-research organizations have been created, developing successfully the problems of ice studies (at Leningrad, Novosibirsk, Moscow, Alma-Ata, Krasnoyarsk, and Yakutsk); a series of monographs has been published, as well as topical collections and articles. Much work has been performed by the Coordinating Committee on ice thermal studies, which under the leadership of Prof. B.V. Proskuryakov has organized a number of All-Union conferences, has refined the question of terminology (at the suggestion of Prof. Yestifeyev) and has published four collections of conference proceedings.

All these factors have expedited the growth of scientific staffs working in this field, emerging successfully both within the Soviet Union and abroad.

Nevertheless, many questions still remain, requiring a more thorough and broader development. Among them, we might list the following:

a) the collection of data on the actual pressure of ice on structures, which will permit a more valid division of the country's territory by amount of dynamic ice pressure;

b) development of techniques for estimating dynamic ice pressure on bridge piers, with consideration of their deformation;

c) the development of practical procedures for evaluating the forces of interaction developing on blocking and cloggings;

d) improving on the technique for simulating the problem of dynamic pressure of ice on structures. The existing proposals are quite interesting but are inadequate for a reliable extrapolation of the experimental results to field conditions; and

e) a more extensive study of the mechanism involved in the disruption of an ice pack in case of dynamic effects, and a further refinement of the essential physico-mechanical parameters of the ice.

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