THE NEW SCHEME OF ICE COVER INTERACTION WITH A SEPARATE STRUCTURE AT TEMPERATURE RISE

A.B. Ivchenko, P.M. Postnikov, V.V. Shushunov, S.P. Vasiliev
State Siberian Transport University, Novosibirsk, Russia

ABSTRACT
In the report the new scheme of interaction when an ice cover is cemented to a shore, and the construction surrounded by an ice cover the shore and from a free edge of an ice between the shore and a free ice deck edge.

INTRODUCTION
Earlier the scheme of interaction when an inflexible structure is included into a rigid, inflexible shore (Figure 1) was considered. In this case the loads on both structure and a shore are identical; structure prevents the opposite side cover ice expanding.

Mechanical properties of ice are described by the rheological model representing cells of Maxwell and Kelvin consequently connected. The model well enough reflects mechanical properties of polycrystalline ice known now. Dependence of mechanical ice characteristics on temperature and some other factors (Ivchenko, 1990, vol.1) is considered.

Figure 1. The scheme of interaction of the structure included in an inflexible shore with an ice covers
1 - structure; 2 - ice loads on structure, q(t); 3 - an ice cover; 4 - an inflexible shore

For this scheme calculated dependence, which makes it possible to estimate stresses in an ice cover and a variable loads in time for structure, q(t), at known temperature of ice cover (Ivchenko, 1990, vol.3) have been made for this scheme. Computer programs to define the values have been made. It is considered as well the scheme when the ice cover is between a stretched
shore to which it is reliably attached, and a separate structure (for example, a bridge support), and the structure adjoining to a deck edge of an ice cover (Figure 2). Ice covers extent in a direction perpendicular to loads is considered unlimited. Arising force influence represents the horizontal loads distributed on contact of ice and a support, applied in a level of an ice cover (Ivchenko, 1998, Ivchenko and Vasiliev, 2004).

Figure 2. The scheme of interaction of with an ice cover of the structure contacting to of an ice cover deck edge, attached to a shore and ice cover:
1 structure; 2 - a free deck edge; 3 - an ice loads; 4 - an ice cover; 5 - an inflexible shore

To define of a variable loads in time \( q_0(t) \) in case of separate structure contacts to an ice cover edge, estimated dependence has been obtained

\[
q_0(t) = K_0 q(t),
\]

where \( q(t) \) – time variable loads on the structure included in an inflexible shore (fig.1), from change of temperature of an elastic-viscous ice cover; \( K_0 \) – the factor considering increase of load on a separate structure, contacting with an ice cover edge (fig. 2) in comparison with loads on the structure included in an inflexible contour.

Figure 3. Dependence of relative loads \( K_0 = q_0(t)/q(t) \) on relative distance \( m = L/b \) for the structure contacting with an ice cover edge

Mechanical properties of ice and change of temperature are considered by size of a loads from an ice cover on a rigid closed loop, \( q(t) \), obtained at the corresponding temperature. From the analytical solution for the considered scheme follows, that \( K_0 \) depends, mainly, on geometric parameters and does not depend on temperature; its dependence on mechanical properties of ice being negligible is small (Ivchenko, 1998, Ivchenko and Vasiliev, 2004). It enables to consider a plate from an elastic material coefficient \( K_0 \), with usage of a finite-element method. When defining an elastic material \( q_0(t) = q_0 \),

-208-
q(t)=q and from dependence (1) it follows, that \( K_0 = q_0/q \). Under this formula experimental dependence of relative loading \( K_0 \) depending on relative distance \( m = L/b \), where \( L \) - distance from a structure to coast, \( b \) - a size of a support has been obtained. The experimental graph \( K_0 = q_0/q \) or \( K_0 = q_0(t)/q(t) \) is presented on fig.3.

**TEXT**

The loads on structure significantly increase in comparison with a load \( q(t) \) on the structure included in an inflexible shore when relative distance \( m \) is increasing. Methods to estimate ice loads worked out while researching schemes, have been included in the current standards.

If the ice cover is attached to a shore and the structure iced in the ice cover, is at offshore distance and from a free ice edge (fig.4). Ice loads on separate structure will be significantly greater, than at the schemes considered earlier.

![Figure 4. The scheme of interaction with an ice covers of the structure surrounded by an ice cover, attached to a shore:](image)

1 structure; 2 - a free of an ice cover edge; 3 - ice loads; 4 - ice cover; 5 - inflexible shore

In this case structure will resist temperature expansion of a greater part of an ice cover, in comparison with earlier considered schemes of interaction (figure1, 2). Accordingly, and loads on it will be significantly greater.

A failure of a railway bridge pier across Sizranski bay of the Saratov water storage occurred under such a pier fracture. At the pier fracture the effort was 6100 kN that corresponds to a distributed load of 660 kN/m and to average stress on contact of ice and a pier 1140 kPa. Tower structure of lock Korichani dam was similarly damaged on river Stupavka in Czechoslovakia (force 1130 kN, a loads of 232 kN/m, average stress 474 kPa), and also some other structures.

Solutions for such a scheme (рис.4) interactions of an ice cover and separate structure interactions are unknown. Our development will determine loads under this rather dangerous scheme.
Let's consider an infinite plane of unit thickness with system of loadings presented in figure 5. We consider, that the plane isotropic and is elastic. The distance change between points C and C'\[\alpha\Delta\theta L,\] where \(\alpha\) - a coefficient of thermal expansion corresponds temperature change of a plane on \(\Delta\theta\). Temperature change of distance CC' is compensated by action of regular distributed and opposite directed equal loadings \(q^*\). These loadings are applied on length \(\langle b\rangle\) lines, passing through points C and C' which are parallel to \(X^*\) and X axes. Equating distance change between the referred points from loading and from temperature we shall estimate the loading \(q^*\).

Figure 5 - System of loads

Let’s calculate distance change between points C and C' from loadings action. Let’s take the known solution of an elastic plane loading by the concentrated force. Calculations give expression for displacements on an axis Y

\[V = \frac{q^*}{4\pi E} \left(1 + v\right) \left[2(1-v)(\psi_2 - \psi_1)Y + (3-v)\left(X + \frac{b}{2}\right)\ln r_2 - \left(X - \frac{b}{2}\right)\ln r_1\right],\]

(2)

here labels

\[r_1^2 = (X - \frac{b}{2})^2 + Y^2, \quad r_2^2 = (X + \frac{b}{2})^2 + Y^2, \quad \psi_1 = \arctg (X - \frac{b}{2}, Y), \quad \psi_2 = \arctg (X + \frac{b}{2}, Y),\]

are accepted.

Let's put in the mentioned formula (2) \(X=0\), and then once we shall accept \(Y=0\), and another - \(Y=2L\). Subtracting the results obtained we shall find distance change between points “C” and “C'”. After obvious simplifications it is found:
ΔCC’ = \(-\frac{q^* (1+ν)}{πE} \left[ 8L(1-ν)arctg\left( \frac{b}{4L} \right) + \frac{b}{2}(3-ν)ln \left( \frac{\sqrt{1+16L^2/b^2}}{4m} \right) \right] \). \hspace{1cm} (3)

Let’s equate value ΔCC’ to value 2αΔθL and considering m=L/b we shall obtain from (3):

\[ q^* = \frac{8αΔθmπE}{(1+ν)(3-ν)ln(1+16m^2)+16m(1-ν)arctg\left( \frac{1}{4m} \right)} \]. \hspace{1cm} (4)

This is the value of the loads acting on separate structure at a temperature rising. Vertical displacements of points of an axis of a symmetry X∗ are equal to null; bring into coincidence combine this axis with a line of an attachment of an ice cover to a shore. Then the distance between separate structure and a bank in the size “b” is equal L, behind structure extent of an ice cover is infinite. Horizontal displacements of points of the axis X∗ are not equal to null, that does not quite correspond to a reality. Because of this and some other assumptions on the separate structure, found on equation (4) it is necessary to consider loads approximated.

In case of, when an ice cover or a plate from elastic material-viscous is surrounded by a rigid closed loop (fig. 1), its full absolute of temperature deformation in time

\[ ΔL(t) = \frac{[1-ν(t)]L}{E(t)}q(t) , \hspace{1cm} (5) \]

where ν(t) - coefficient of full transverse deformation; q(t) - linear in regular intervals a distributed load in case of when the ice cover is limited by an inflexible contour; E(t) - the module of deformation. All the values entering into association (5) - functions of time.

We change in dependence (4) elastic modulus by variable in time the module of deformation; we shall designate by q,t(t) variable in time a load. Absolute deformation of OC piece as function of time, for a plate of infinite extent, according to this will make:

\[ ΔL(t) = \frac{q,t(t)[1+ν(t)]b(3-ν(t))ln(1+16m^2)+16m[1-ν(t)]arctg\left( \frac{1}{4m} \right)]}{8πE(t)} . \hspace{1cm} (6) \]

Equating the right parts of associations (5) and (6), we shall receive expression for average on a line of contact to structure in regular intervals a distributed load from an elastic-viscous ice cover of infinite extent in the form of

\[ q,t(t) = K⋅q(t) , \hspace{1cm} (7) \]
where coefficient
\[
K_+ = \frac{8\pi [1 - v(t)]m}{[1 + v(t)]\beta[3 - v(t)]\ln(1 + 16m^2) + 16m[1 - v(t)]\arctg\left(\frac{1}{4m}\right)}. 
\]

The composition of formula (7) is similar to formula (1). \(K_+\) - the coefficient considering increase of loads on a separate structure, surrounded by the ice cover attached to a shore and having a free deck edge. Coefficients \(K_+\) and \(K_0\) in (7) and (1) - loads on the separate structure, referred to a loads on the structure included in a rigid closed loop.

It follows from (7), as well as from (1), that change of temperature, mechanical properties of ice and its characteristic, are considered at definition \(q(t)\) – a loads on the structure included in an inflexible shore, from change of temperature of an elastic-viscous ice cover.

When solving the problem it is possible to consider factor of a full cross strain \(\nu(t)\) being constant. The relative loading \(K_+\), as well as \(K_0\), depends only on a relation of sizes.

The analysis of the calculated dependence (7) obtained for infinitely big size \(N\) and calculated association (1), obtained for size \(N\) equal to null, consider, as at intermediate values \(N\) (7) where \(K_+\) depends on a ratio of the sizes is being fair. When defining the relative loads \(K_+\) for the separate structure surrounded by an ice cover, as well as for structure on a deck edge of an ice cover, it is possible when defining \(K_+\) to change a plate from a viscous-elastic material a plate from an elastic material. Numerical value of coefficient of full transverse deformation should be accepted as that one of terms ice in of a considered task. The temperature can change even spasmodically, of temperature rise in all cases should be taken identical.

The analytical calculated has allowed to establish character of associations for extreme values \(N=0\) and \(N = \infty\). The similarity of all dependence has been observed. We shall receive numerical values \(K_+\) for intermediate values \(N\) with usage FEA, modeling an ice cover by an elastic plate. This method gives you results at any final values \(N\) that enables to construct graphic for \(K_+\). From (7) full relative loads for separate structure
\[
K_+ = \frac{q_+}{q}. 
\]

We define values \(q_+\) and \(q\) by the finite-element method with usage of computer complex COSMOS/M. The opportunity of ice cover replacement by an elastic plate carrying out the
experiment is proved above.

Let's establish the conditions ensuring exact enough realization of the scheme of interaction, presented on figure 4, at transition to the calculated scheme of the finite-element method which is presented in figure 6.

Figure 6. The calculated scheme of the finite-element method:
1 - a plate, modeling an ice cover; 2 - the separate structure surrounded by an ice cover; 3 - a bank line to which the ice cover is attached; 4 - binding of a lateral deck edge of a plate, in a direction parallel to a bank line.

The ice cover is attached to a bank line and to structure, connections exclude moving along a bank line and in the perpendicular it direction. The symmetry considers half of plate and structure, having changed action of another, symmetric, connections parallel to a bank line.

Checking with usage of a finite-element method has shown that there is no necessity to fix this deck edge from turn. On fig.6 the size B - the considered size of a plate in a direction parallel to a bank line. It is stated, that at $B \geq 2L$ the error of definition of force of interaction is less than 0.5 %.

The practice established, that the result is exact enough when is 9 - 11 the numbers of nodes of a grid of a finite-element method on a line of contact of structure and a plate. Sufficient extent of a plate along the shore and of number on nodes of contact of structure and a plate are ensured in all experiments. Numerical experiment has been conducted at various sizes $b$, $L$, $N$.

When processing data obtained by a finite-element method it is stated, that sizes of a full relative loads $K_+\,$ and its parts $K_N$, depends on a ratio of the sizes, instead of from absolute values of the sizes. (earlier the similar result has been obtained for $K_0$). Graphs of association $K_N/K_0$ from $n=N/L$ at miscellaneous $m=L/b$ are fetched on fig.7. Size $K_N/K_0$ significantly increases at increase in relative distance $n$ from 0 up to 3. The further increase $n$, practically, does not result in increasing $K_N/K_0$ and relative loads $K_+$.

It is possible to present a full relative load...
\[ K_r = K_0 + K_N = K_0 \left(1 + \frac{K_N}{K_0}\right), \]  

(9)

where \( K_0 \) - a part of full relative loads at interaction under the scheme fig.2, when structure contacts a deck edge of an ice cover; \( K_N \) - the additional value of full relative loads caused by a part of an ice cover, having size \( N \) (fig.6). At \( N=0 \) values \( K_r = K_0 \) also can be defined under the graph fig.3.

**CONCLUSION**

At the considered scheme (fig.3) of interaction it is necessary to determine loads on separate structure on (7). The full relative loads entering this \( K_r \) should be found under the formula (9). Value \( K_0 \) is under the schedule fig.3, and relation \( K_N/K_0 \) - on fig.7.

**References**