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THE FORCE ACTION OF ICE CAKES TO STATIONARY AND FLOATING OBJECTS

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Abstract. *In freezing seas during winter periods between open water and cover by ice, transitional zones are formed from fragments of level ice fields (ice cakes). The quantity and sizes of these fragments decrease as they approach to open water. The ice cakes are drifting due to action of winds and sea currents. During storm periods, being on the stormy surface of the seas, ice cakes are capable of exerting the dynamic loads on stationary and floating objects. At the initial moment of contact of ice floes with various obstacles, significant local pressures are realized on small contact areas, which represent a danger to the integrity of the structures of such obstacles. In the article considered an approach to solving the task of the dynamic impact by fragments of level ice fields on the supporting parts of offshore hydraulic structures that will be function in the conditions of open sea during severe storms in the winter and spring periods.*

Keywords: *ice loads; stationary and floating objects; offshore structures; level ice fields; ice cake, strength characteristics of level ice; storm; parameters of wind waves.*

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СИЛОВА ДІЯ РІВНИХ КРИЖАНИХ ПОЛІВ НА СТАЦІОНАРНІ І ПЛАВАЮЧІ ОБ'ЄКТИ

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Анотація. *Як показують результати натурних спостережень, в замерзаючих морях в зимові періоди між відкритою водою та повністю покритою льодовою кригою, існують перехідні зони з уламків рівних крижаних полів. Кількість та розміри цих уламків зменшуються по мірі їх приближення до чистої водної поверхні. Вони дрейфують під впливом вітрів та течій. В штормові періоди, знаходячись на схвильованій штормовій поверхні морів, такі уламки льоду здібні здійснювати динамічний вплив на стаціонарні та плавучі об'єкти.*

У начальний момент контакту уламків криг з різноманітними перешкодами на малих площах контактів реалізується значний локальній тиск, який представляє загрозу для цілісності таких перешкод. В статті розглянутий підхід до рішення задачі про силовий вплив уламків рівних крижаних полів на опорні частини морських гідротехнічних споруд, які будуть експлуатуватися в умовах відкритого моря в періоди жорстких штормів.

Ключові слова: *льодові навантаження; стаціонарні та плавучі об'єкти; морські гідротехнічні споруди; рівні льодові поля; механічні характеристики льоду; шторм; параметри вітрових хвиль.*

Introduction. In the winter periods, in the freezing seas, on the border between compacted ice edge and ice free water, there are transitional zones, which are drifting fragments of level ice. They differ from level ice their small planned dimensions. The level ices are formatter the detachment of active fast ices from the shores. Active fast ices are form along the perimeter of the islands, on the coasts of peninsulas and continents at negative air temperatures and during an action a winds from the seas to the shores. Under the action of winds from land, active fast ices break away from the coast and drift into the open sea. On ice free water, they are exposed to wind waves. As a result, they are destroyed into separate level ice fields, the initial dimensions of which depend on the bending strength and thickness of the ice, as well as on the parameters of wind waves. Continuing to drift in the open sea, level ice fields increase in thickness under the influence of negative temperatures during the winter period. In the storm periods on the rough surface of the seas, level ice on open water are destroyed on the smaller fragments (ice cake).

In the transitional zones between open water and compacted ice edge the fishing vessels to fish often for various types of seafood. During winter storm periods, they are exposed to the force of drifting fragments of level ices on the surface of the seas and oceans, which drift under the influence of winds and currents. Finely ice cake on the stormy surface of the seas also poses a danger to offshore structures and ships. The ice cakes contribute to the partial damping of the energy of a certain part of the spectrum of irregular storm waves. But on long-period and asymmetric waves, small ice cakes, due to wave orbital velocities and currents, move along the agitated storm surfaces of freezing seas. This phenomenon can be called an ice storm. This phenomenon affects all sea vessels when crossing the transition zones between ice free water and compact floating ice. Encountering with various obstacles in the form of stationary or floating objects, icecfkes floes on a rough storm surface can have a significant dynamic effect on them.

In maritime practice, there are cases where small fishing vessels, finding themselves in such situations, were subjected to impacts from ice cakes, sometimes with the formation of dents and even holes in the sides above the waterline. Particularly dangerous is the case when fishing vessels are towing trawls. In this process, the speed of their movement slows down significantly. For this reason, they cannot maneuver relative to the direction of wave fronts, exposing their sides to the impacts of ice cakes.

Offshore structures and roadstead berths, which operate in conditions of open sea, will also be subject to the force of ice cakes during winter storms. Such influence is typical for all types of coastal protection structures at seas. At the same time, at the initial moment of contact of ice cakes with structures, both global ice load and significant local ice pressure will appear. In the contact zone they will differ from values that are determined in accordance with the recommendation of the standards for various design scenarios. This paper presents a solution to the problem of the determination of ice loads on offshore structures of a vertical profile from ice cakes on a rough sea surface. The norm documents of Ukraine do not contain recommendations for such calculations.

The analysis of methods for calculating ice loads on hydraulic structures. In the regulatory document, which is in force in our country, recommendations for calculating ice loads on stationary structures vertical types in the form of sections or single barriers of various cross sections contain two main design cases. In the first of them, it is assumed that a drifting ice floe, after contact with an obstacle, either stops in front of it (if it is of large length, for example, breakwaters or enclosing structures of sea channels), or continues to drift (if it is a single support, for example, supporting parts of offshore structures, point berths or bridge supports). The second case involves the destruction of an level ice by an obstacle (in front of the wall by crushing, and in front of single obstacles of various shapes – by cutting through drifting level ice). At the same time, the calculation dependencies in the first design case take into account: area of the calculated level ice – A, m2; calculated thickness of the level ice – hd; calculated strength of ice for uniaxial compression – Rc, MPa; estimated drift speed of a flat ice field – V, m/s; obstacle shape coefficient – m; angle of sharpening of the front face of the obstacle (support part) in plan at the level of ice action – γ, deg. (Fig. 1)

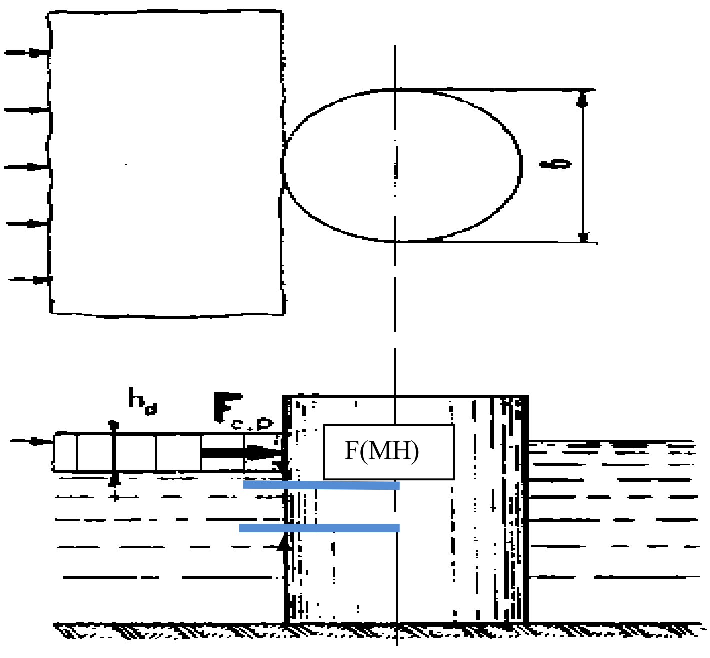

Fig. 1. The action level ice to single obstacle

In the second design case, the diameter of the obstacle or the width of the section of the structure being designed is also taken into account – b, m, but the area of the calculated ice floe – A, m^2 is not taken into account (Fig. 2).

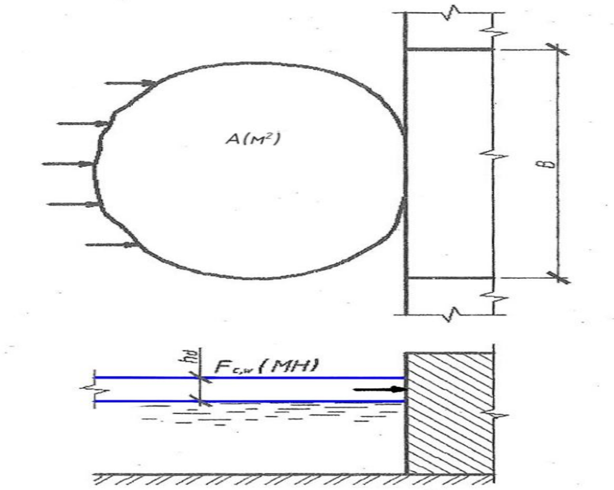

Fig. 2. The action level ice to section of structures

Thus, the calculated dependences of the norms do not contain recommendations for calculating the force impact of ice cakes floating on a stormy surface on vertical offshore hydraulic structures. For this reason, it is not possible to assess their force impact on stationary and floating objects at the design stage. These standards also do not contain recommendations for calculating the local pressure of ice cakes at the initial moment of their contact with obstacles on a rough surface. This circumstance also applies to floating objects on a stormy surface of seas.

The purpose and tasks of the research. The purpose of this work is to develop an approximate method for calculating the force impact of ice cakes drifting on a storm surface of seas on stationary offshore hydraulic structures of a vertical type. The set goal was achieved by solving the following tasks:

- review of methods for calculating ice loads on offshore stationary hydraulic structures for various purposes operating in open sea conditions;
- development of an approximate method for calculating the ice load on stationary and floating objects of a vertical profile from the force impact of ice cakes on the storm surface of the seas.

Materials of the research. To determine the value of the ice load on stationary or floating objects during an ice storm, it is necessary to have information about the parameters of the ice cakes (thickness and area, as well as its mass). In addition, ice loads significantly depends on the calculated parameters of low probability wind waves in the system of design storms, and, accordingly, on the values of the projections of the horizontal component of the orbital velocity. Calculation of such ice loads, as well as local ice pressure on stationary and floating objects, is of definite scientific and practical interest. The scheme of the interaction of ice cakes mass m, t with a vertical stationary obstacle is shown in Figure 3, and with the side of the ship in Fig. 4.

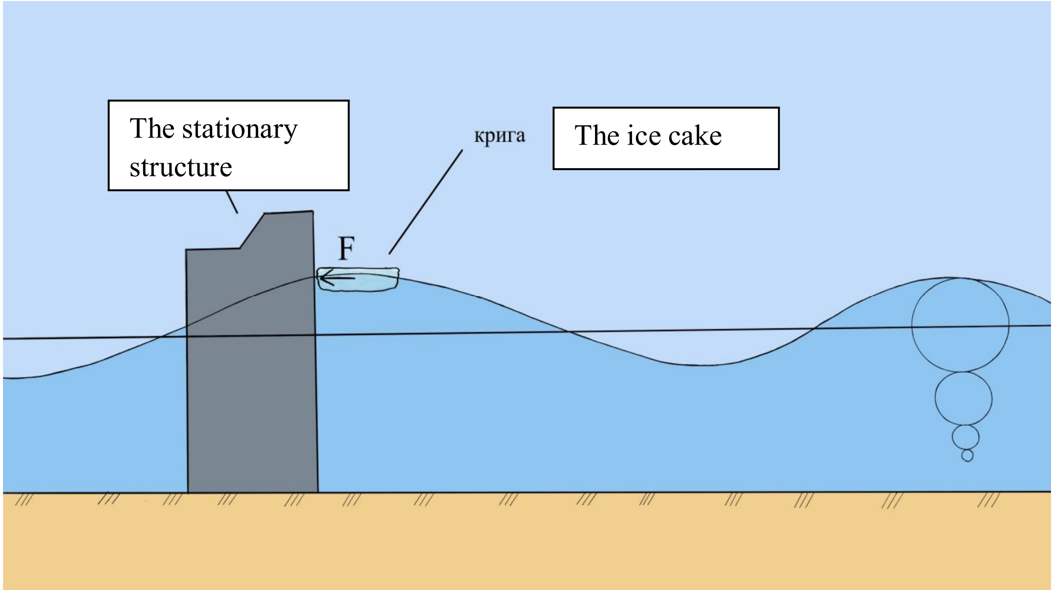

Fig. 3. The force action of ice cake to stationary structure

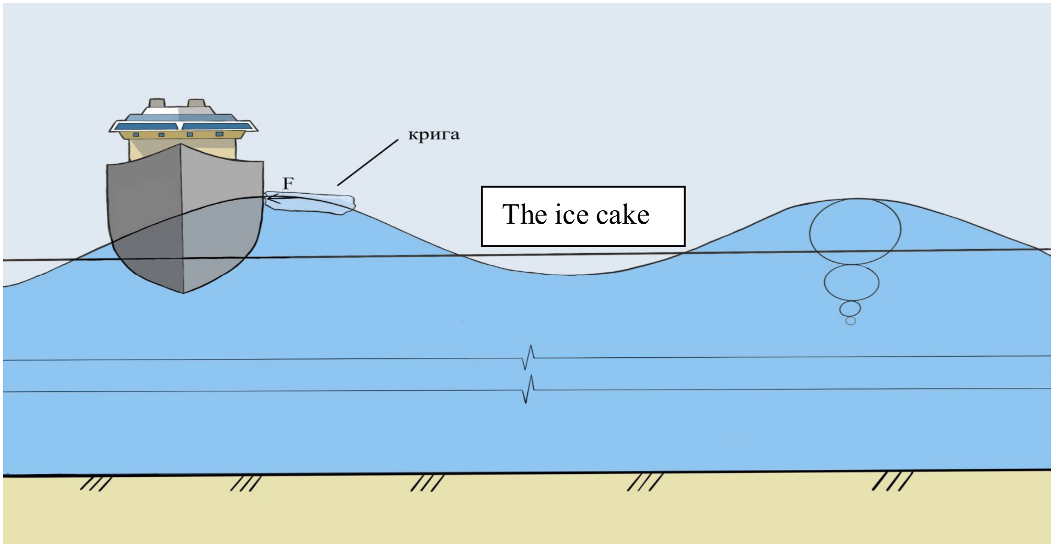

Fig. 4. The force action of ice cake to the side of ship

The assessment of the force impact of fragments of ice cakes, the size of which is significantly less than half the length of the designe wave, during a storm, on floating and stationary objects can be carried out using the well-known Newton's law. Calculation of the horizontal projection of the acceleration of water particles in a wave on the sea surface in deep and shallow water zones can be carried out taking into account the basic principles of the theory of small amplitude waves. According to this theory, the projection of the orbital velocity onto the horizontal *x* axis is determined using the following expression:

$$v_x = \frac{\pi h}{T} \cdot \frac{chk(d + z_0)}{shkd} \cdot cos(kx_0 - \omega t) \qquad (1)$$

where h – wave height, m;
d – water depth, m;
T – wave period, s;
k – wave number;
ω – circular frequency.

The horizontal projection w_x of the acceleration of the movement of particles in a liquid is determined by differentiating expression (1)

$$w_x = \frac{dv_x}{dt} = \frac{\pi h}{T} \omega \frac{chk(d + z_0)}{shkd} sin(kx_0 - \omega t) \qquad (2)$$

The maximum value of the horizontal projection of the acceleration of the movement of water particles in a wave on the water surface at $z_0 = 0$ and $\sin(kx_0 - \omega t) = 1$ is determined from the following expression:

$$w_x = \pi h/T \cdot \omega \cdot chkd/shkd. \qquad (3)$$

This dependence can be transformed taking into account the value of the wave frequency

$$\omega = 2\pi/T : w_x = \pi h/T \cdot 2\pi/T \cdot cthkd \qquad (4)$$

Then

$$w_x = 2\pi^2 h/T^2 \cdot cthkd \qquad (5)$$

A study of the values of the hyperbolic cotangent within limits of practical interest showed its tendency to 1. Thus, as a first approximation, to estimate the ice load F, H from the forceful impact of ice cakes floes during storms on stationary and floating objects, the following expression can be used:

$$F = m \cdot 2\pi^2 h/T^2, \qquad (6)$$

where: m is the mass of the ice cakes, t, moving along the rough surface of the sea, which is determined from its surface area A, m^2 and thickness h_d, m, as well as sea ice density ρ, kg/m^3, which depends on the salinity of the ice and its temperature. Depending on these factors, it fluctuates in different seas from 920 to 953 kg/m^3.

$$m = A \cdot h_d \cdot \rho \tag{7}$$

Ultimately, the value of the force impact of ice cakes floes during stormy periods in the transition zones of freezing seas to stationary and floating objects (see Fig. 3, 4) in a first approximation can be determined using the following expression:

$$F = 2A \cdot h_d \cdot \rho \cdot \pi^2 h/T^2. \tag{8}$$

Using this dependence (8), it is possible to make appropriate calculations at the design stage of stationary objects that will be operated in open sea conditions in unprotected water areas. In addition, this dependence can be used to approximate the force impact of single ice cake floating on the stormy surface of the sea on the sides of ships that are designed for sailing and working in freezing seas.

As for the assessment of the local pressure of ice floes at the moment of contact with an obstacle, it depends on the compressive strength of the ice R_c, MPa and the contact area S, m^2 [1]. At the same time, one should take into account the fact that ice floes on the sea surface experience a temperature difference in thickness. Thus, on their surface the temperature is equal to the air temperature, and the temperature of the lower layer is equal to the temperature of the water in contact with the ice and is approximately $+2^0$C. For this reason, the strength properties of drifting ice floes are also variable, both in thickness and area (strength anisotropy). Under certain conditions of fast ice formation, the uniaxial compressive strength of ice in the near-surface layers may exceed the strength of the lower layer in contact with water. Having such initial data, it is possible to estimate the value of local ice pressure using calculated dependencies obtained from an analysis of the results of experimental studies under natural conditions [2]. They were included in the departmental regulatory document in the form of recommendations.

The results of the research. In this work, calculations were made of the ice load on a stationary object with a vertical front edge under the influence of ice cakes of various areas and thicknesses and various parameters of storm waves. At the same time, the parameters of waves in deep water were varied at $d/\lambda > 0,5$ and a constant density of sea ice $\rho = 0,953 t/m^3$. The results of these calculations are summarized in a table.

As can be seen from the table, even with small areas of ice cakes and wave parameters, the ice loads can be reach dangerous values at which significant local ice pressures are realized. Depending on the area and place of contact of the ice cakes along its thickness, the values of local pressures on obstacles in the form of stationary and floating objects on the water surface, located both in deep water and in shallow water, will also vary. Taking into account the irregular nature of wind waves, in the system of the design storm, the wave parameters of a small percentage of probability will appear with different periods. The most dangerous of them will have a period shorter than the average period of waves in the system of the storm, which is recommended to be taken as calculated in accordance with the requirements of standards when calculating wave loads.

Table

Results of calculations of ice loads on floating and stationary barriers of vertical type depending on the parameters of wind waves and ice cakes on the storm surface of the seas

№	The parameters of waves			The parameters of ice cakes		F, H
	h, m	T, c	λ, m	h_d, m	A, m^2	
1	3,5	5,0	39,0	0.2	2,0	10520
2	3,0	4,0	25,0	0,5	2,0	70000
3	3,0	4,0	25,0	0,8	2,0	50380
4	3,0	5,0	39,0	0,5	2,0	22551
5	3,0	6,0	56,0	0,5	2,0	15660
6	4,0	6,0	56,0	0,3	3,0	18793
7	3,0	5,0	39,0	0,5	3,0	34000
8	3,0	6,0	56,0	0,5	3,0	23490
9	3,0	4,0	25,0	0,5	3,0	52856
10	3,0	5,0	39,0	0,5	3,0	33826
11	4,5	7,0	76,0	0,4	4,0	27615
12	3,0	6,0	56,0	0,5	4,0	31000
13	3,0	4,0	25,0	0,5	4,0	70473
14	4,5	7,0	76,0	0,4	4,0	27615
15	3,0	4,0	25,0	0,5	4,0	70472
16	3,0	5,0	39,0	0,5	4,0	45102
17	5,0	6,0	56,0	0,5	4,0	31321
18	5,0	8,0	100,0	0,5	5,0	36705
19	3,0	4,0	25,0	0,5	5,0	88089
20	3,0	5,0	39,0	0,5	5,0	56377
21	3,0	6,0	56,0	0,5	5,0	39150
22	6,0	9,0	126,0	0,5	6,0	41761
23	3,0	5,0	39,0	0,5	7,0	78928
24	3,0	5,0	39,0	0,5	8,0	90204
25	3,0	5,0	39,0	0,5	9,0	101479
26	3,0	5,0	39,0	0,5	10,0	112754

CONCLUSIONS

1. Current regulatory documents do not contain recommendations for calculating ice loads from ice cakes on stationary and floating objects under the action of storm waves in a system of storms of varying frequency.
2. The development of such recommendations is an important scientific task, which is of practical interest for both marine hydraulic engineers and shipbuilders.

3. When developing calculation dependencies for assessing the ice load on stationary and floating objects, the basic principles of the theory of small amplitude waves were used.

4. The initial data for assessing the significances of the ice loads on stationary and floating obstacles from the actions of ice cakes on the storm surface of the seas are: the parameters of the calculated waves in a system of storms of varying frequency, as well as the sizes of the calculated ice cakes.

5. The significances of local ice pressure at the initial moment of contact of drifting ice cakes with obstacles depends on its area and the strength of the ice for uniaxial compression.

6. Taking into account the irregular nature of sea waves, the greatest value of the ice loads will manifest itself when exposed to waves of low probability with periods shorter than the average wave period in the system of design storm.

7. In the process of designing stationary objects that will be operated in open sea conditions (breakwaters, offshore structures), in accordance with the requirements of current standards, when calculating ice loads for this scenario, it is necessary to consider a severe storm with a repeatability of once in 100 years. In this case, the height of the design wave is taken to be equal to the height of the wave of 1% probability in the system of storm, and its period is taken to be less than the average period of irregular waves.

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