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AN ULTIMATE BEARING CAPACITY OF ICE BEAMS

Shkhinek K.N. [1], Liang Li [1], Zixin Han [1]

[1]St.Petersburg State Polytechnical University, Saint-Petersburg, Russia

ABSTRACT
In the present methods, it is generally believed that the ice load will disapear when flexural tensile stress of the cross section of ice reaches its limits during the process of computing the ice action on the sloping structures. However, during the interaction of the ice and the sloping structures, there will exist the interaction. On the other hand, since the compressive strength of the ice is greater than its tensile strength, the ultimate bearing capacity and action of the ice will change. Therefore, the purpose of this study is to accrately evalute the ultimate bearing capacity of sea ice. The accuracy of the model is validated by simulating the Sodhi experiments of ice sheets using FE software Ansys/Ls-dyna. The variation of stresses on the cross section of ice and the Ice load on the sloping structures is analyzed based on the numerical simulation.

Introduction

The problem of the ultimate bearing capacity of ice beams encountered in many practical problems: the determination of ice loads on sloping hydraulic structures and facilities of the shelf, in the determination of the bearing capacity of the ice cover to traffic, to calculate the landing on the ice, in the determination of the resistance of ice movement of vessels (Ashton, 1986). When interacting with hydro and offshore structures is considered as a floating ice plate or beam. If the sloping front surface structures, the ice in her creeping bent. In the beam (plate), there are two areas - compression and tension. It is often assumed that after reaching the tensile strength tensile stresses (which have much less ice compressive strength (ISO/FDIS 19906, 2010) bar loses its load-carrying capacity (Matskevitch, 1992; Afanasyev, 1968). The tensile strength introduced as determining all Russian and international standards for the calculation of hydraulic structures (ISO/FDIS 19906, 2010; SNiP 2.06.04-89*, 1995; Shkhinek, 1994).

Determination of tensile strength in natural conditions and in the ice tank is based on the method of "keys". (Butyagin,1966) With this method, in the ice, on three sides, cut beams, fastened to the field on the fourth (short) side - the "key." The free end, "key" vertical load is applied. By the force corresponding to the formation of cracks in the tension zone of the beam is determined by the "ultimate bending moment" at the contact with the field. By this point, the marginal tensile stress at which there was a destruction - the ultimate tensile strength. However, this is not entirely accurate. Even in the present case, after the formation of cracks in the tension zone, continues to resist bending moment, formed by compressive stresses in the compressed zone of the beam. This is especially important if a beam bends except there compression (Matskevitch, 1992; Sukhorukov, 1995, 1996, 1997).

Sodhi (1998) conducted experiments with ice beam, separated from the ice field with only two sides and loaded vertical force in the middle (Figure 1). This load is gradually increased.

Recorded load recalculated at the time of stress in the seal and the deflection (deformation) in the center of the beam.

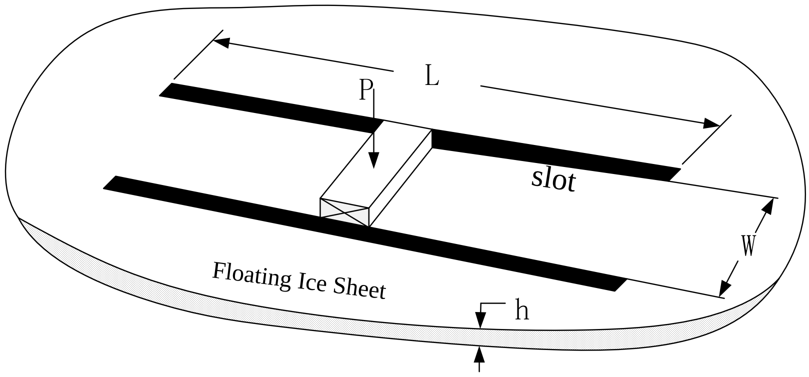


Figure 1. Experimental setup schematic by Sodhi (1998).

Experience has shown that under these conditions after the destruction of the extended area, there are large stresses in the compressed zone, leading to the formation of the plastic hinge (Timoshenko, 1965), and finally cracks (Fig.2). The stress concentration in the areas indicated in Fig leads to the moment resisting bending, and the extra load beam.

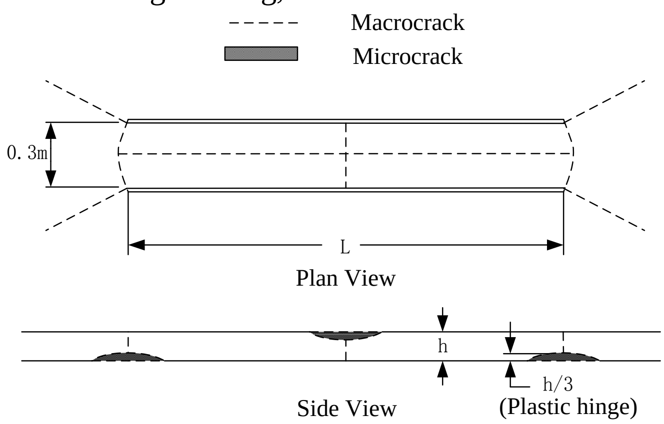


Figure 2. Zones of micro cracked ice in blocks after a fixed-end beam test by Sodhi (1998).

The considered setting simulates to some extent, the situation that arises when moving icebreakers. For hydraulic structures more typical situation is different, ice creeps on the construction and bent. This gives rise to a bending moment and longitudinal force due to a reaction to the impact of ice structures. The presence of this force increases the maximum load-bearing capacity of ice and, accordingly, the load on the structure (Nikitin, 1998, 2002). Thus, we can assume that in the rules adopted by the load on the building makes a mistake in a dangerous direction. It should be noted that the observations in natural conditions, conducted Kärnä (2003), confirmed that after the destruction of ice stretching from bending load on the building continues to grow.
The aim of this study is to determine more accurately the limit bearing capacity of ice to refine loads on structures.

Statement of the problem

We consider the stress field in the floating ice in the water beam. One end of the beam is in contact with a rigid wall (simulated ice field), attached to the other vertical and horizontal force (simulating the stresses on the boundary with the construction). Required to determine the ultimate bearing capacity of the beam and the load on the structure. Ice is considered as elastic - perfectly plastic medium (plasticity of cod (Loset et al., 2010)) in compression and elastic-brittle in tension. Elastic limits in tension and compression are determined by Lavrov (1967), when the tensile strength by stretching at bar - the material is destroyed instantly holding power at this point vanishes.

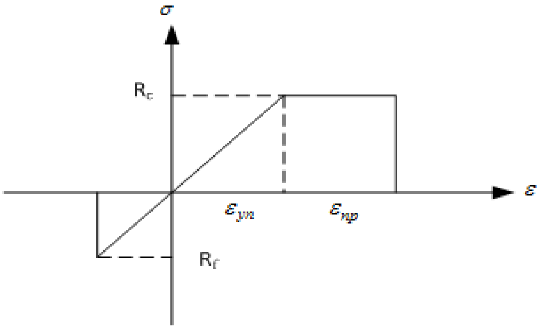


Figure 3. Stress-strain diagram.

Figure taken $\varepsilon, \varepsilon_{yn}, \varepsilon_{np}$ - deformation, elastic deformation limit plastic deformation, respectively; σ - stress (compressive stress of a positive); R_f , R_c -The tensile strength and compression, respectively.

Adopted by the stress-strain diagram is shown in Figure 3. When the limit is reached on the compression, the material goes to a plastic state, which persists until the plastic deformation limit adopted for ice equal to 0.35% (Kim et al, 2000).

Solution method and verify its correctness.

The ice is a polycrystalline material, being both ductile and brittle. Material model * MAT_PLASTICITY_COMPRESSION_TENSION (MAT_124) (Camey et al., 2006; Hallquist et al, 2006) is included in the ANSYS/LS-DYNA to simulate the properties of ice. In the elastic-plastic model as Determines dependence shown (Fig. 3). Upon reaching the elastic limit of the material passes R_c in the plastic stage, and after reaching the limit of plastic deformation in the element - is destroyed. Initial data for the calculation are given in Table 1.

Table 1. Initial data for the calculation

Material Properties for Model	
Density (kg/m^3)	900
Young's Modulus (Pa)	5.0E+9
Poisson's Ratio	0,3
Plastic failure strain %	0.35
Compression strength MPa	2,5
Tensile strength MPa	0.9

Verification results conducted by comparing the calculation results with experiments Sodhi (1998). Considered ice bar, located between the rigid planes (surrounding field). In the central section of the beam load is applied, gradually increasing over time. Figure 4 shows a comparison between calculation and experiment.

The figure shows that both the experiment and calculation have two peaks. The first corresponds to the moment when the tensile stress reaches the tensile strength. There is a rapid destruction of the ice in the tension zone and drop the load. In the compressed zone of deformation of the material goes, first elastic and then plastic. This happens as long as the point of the medium is not reached the limit plastic deformation, then carrying capacity at this point is lost. Value of the maximum load in the experiment and calculation are the same, but the decline after reaching the ultimate strain in the calculation is faster, due to the lack of accurate description of the behavior of the material after fracture. Instantaneous load decline (see Figure 2) after the relevant limits is a crude approximation. Unfortunately, in the literature, this process is almost not considered, and there is not enough sound evidence for its refinement.

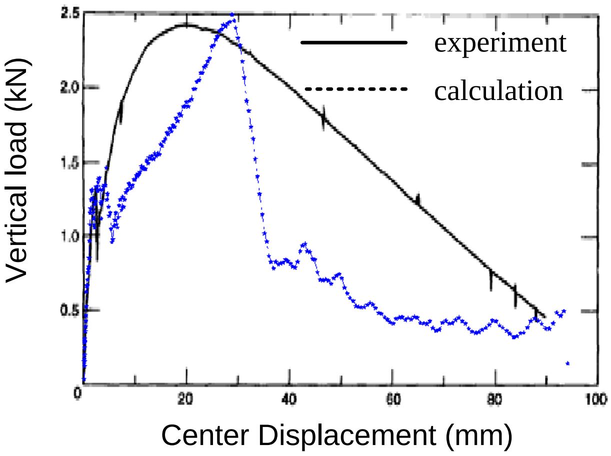


Figure 4. Comparison between calculation and experiment Sodhi (1998).

Figure 5 shows the calculated stress in the median cross section of the beam at different points in time. Compressive stresses taken positive.

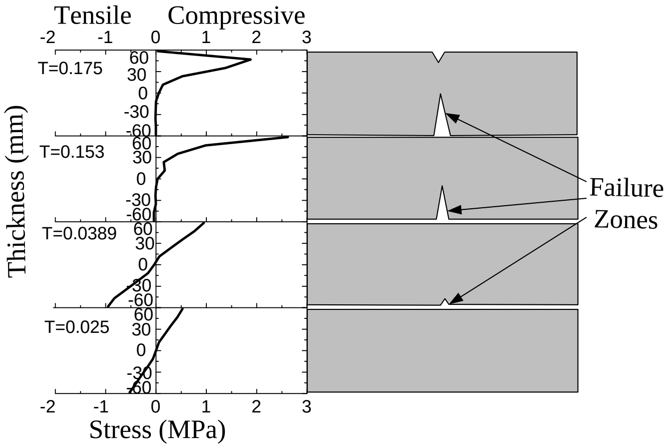


Figure 5. Stress in the median cross section of the beam at different points in time. (Modeling experiment by Sodhi (1998))

Figure 5 shows that initially the tensile and compressive stresses are distributed over the cross section is ant-symmetric (T = 0.025 s and T = 0.0389 s). After time T = 0.0389 to the point corresponding to the free surface of the beam, in the tension zone is achieved by stretching of the ultimate strength. After this destruction spreads the tension zone and at time T = 0.153c destruction spread throughout the tension zone. At this moment of tension in the compressed zone has reached a point of strength in the free surface. In this zone, the plastic flow begins, and then destroyed. Further plastic deformation spreads compressed zone. This is followed by a gradual increase in the stress at the cross-section of plastic flow, when the yield strength, and gradual loss of bearing capacity.

The influence of the properties of ice on the carrying capacity of the ice beam

The above result shows the appropriateness of the numerical calculations of the model. This allows you to use the technique for practical calculations. But should first assess the impact of the properties of ice on the end result. The main parameters of ice affect the carrying capacity, are: compressive strength, tensile strength and ultimate plastic deformation. The results of calculations for various values of tensile strength are shown in Figure 6. All other design parameters ice unchanged. The figure shows that the variation in the strength of ice flexural (tensile) widely affect the value of the first peak load, but in practice has little effect on the ultimate bearing capacity.

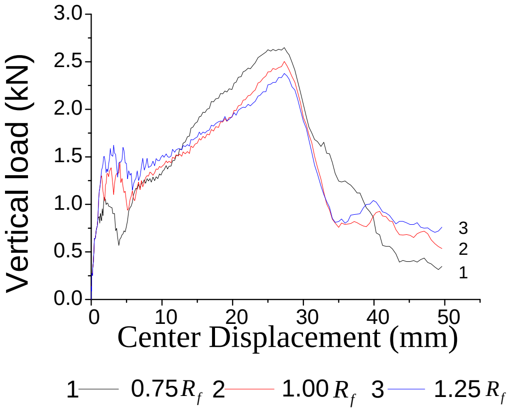
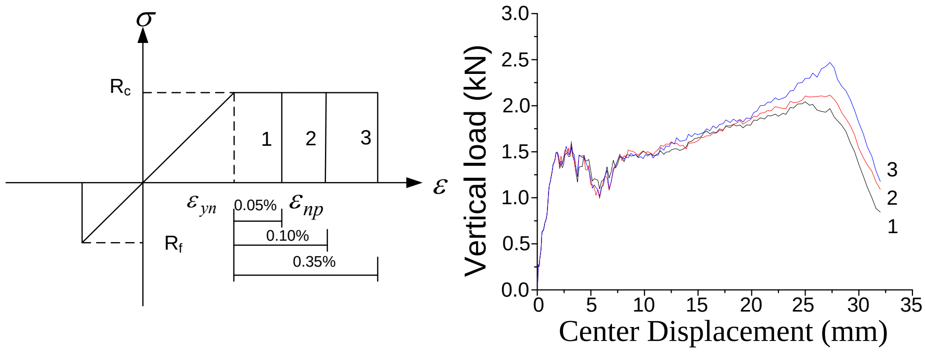
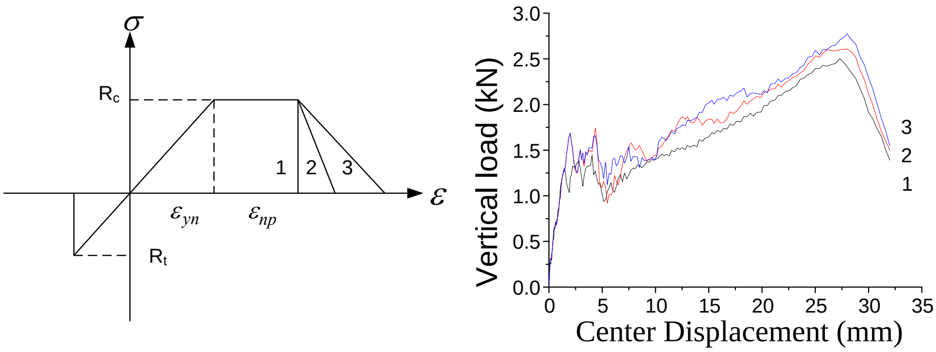


Figure 6. The results of calculations for various values of tensile strength.

Figure 7 shows the change in the carrying capacity for various limiting plastic deformation under otherwise constant parameters. Figure 7-a shows that the limit plastic deformation affects mostly declining load and, apparently, has little effect on the maximum load capacity. Figure 7-b shows that after the compressive strength of the gradient of the stress drop affects the bearing capacity. Thus, the main characteristic of the ice, in the future, the compressive strength.



a. different limit plastic deformation, while the compressive strength is maintained.



b. 1-limit plastic deformation, while the compressive strength is maintained; 2,3 -different limit plastic deformation during the stress drop. 1- ε_{np} =0,35%, 2- ε_{np} =0,50%, 3- ε_{np} =0,80%

Figure 7. The change in the carrying capacity for various limiting plastic deformation.

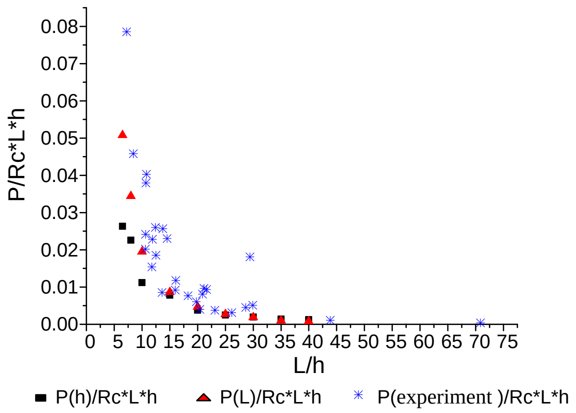


Figure 8. The results of calculations of the dimensionless maximum carrying capacity depending on the ratio of the beam length to its thickness.

P(h) - loads with the constant beam length L and the variable thickness h;
P(L)- loads with the constant thickness h and the variable beam length L;
P(experiment) – loads of experience Sodhi (1998).

Figure 8 shows the results of calculations of the dimensionless maximum carrying capacity depending on the ratio of the beam length to its thickness. Figure shows that the non-dimensional calculation results are consistent with the experimental data Sodhi. It should also be noted that the dimensionless load P / (Rc * L * h) with the growth of the dimensionless length L / h decreases.

Inclined waterworks

Design scheme, usually used in the calculation of ice effect on inclined hydraulic structures is shown in Figure 9. In this case, the ice field must overcome the reaction of structures, friction, impact masses of ice blocks (formed at break before), on the surface structure and force caused by pushing them, the forces of inertia, etc. In the calculations of the ice is generally regarded as a beam on a hydraulic basis under the action of buoyancy forces and pushing the surrounding ice with one hand, and the forces of reaction in the construction and operation of ice on the other. Reaction force is decomposed into vertical and horizontal components. For the given distribution of the beam is determined by the bending moment and stress along the beam with the longitudinal component of the load. It is assumed that in the section where the tensile stress reaches the limit, the beam starts to break down. Usually, as the torque limit used moment occurs when a break free floating beams. The results shown in the previous section show that the presence of longitudinal forces significantly increases the time limit (and load). If in the above case, the longitudinal force is due to the limited capabilities of horizontal expansion of the beam, the circuit shown in Figure 9, it is a result of the impact of the horizontal projection of the reaction structure and blocks of ice on the surface of the structure.

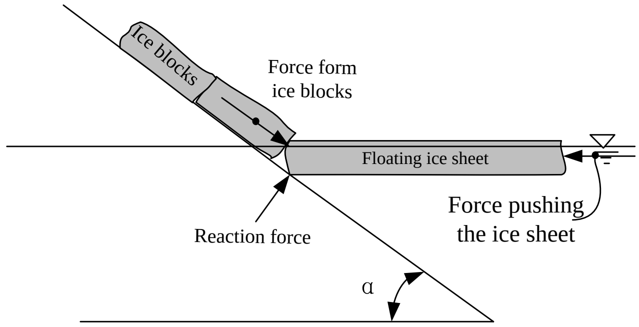


Figure 9. Design scheme for calculation of ice effect on inclined hydraulic structures.

To determine this point, we study the limit bearing capacity of ice cantilever beam. The free end of the beam attached vertical and horizontal loads. Determined by the stress distribution in the beam and the bending moment at which the beam is finally loses load capacity. Solve the following problem: the free end of a floating beam length L and thickness h is applied constant horizontal force F_{hor} and gradually increasing the time the vertical force P (T). Determined by the time when the beam is broken, and finally limiting the bending moment at that time. Baseline data on the properties of ice correspond to those indicated in Table 1.
Figure 10 shows that initially the compressive stresses are uniformly distributed in the cross section (T = 0.120 s). With the increase in the vertical load at 2,150 c in the tension zone reached the limit of flexural strength and a crack. Then the crack grows and at 2,165 c in the compressed zone reached the limit of compressive strength. It should be noted that the area of destruction stretching at this point is almost 75% of the beam.

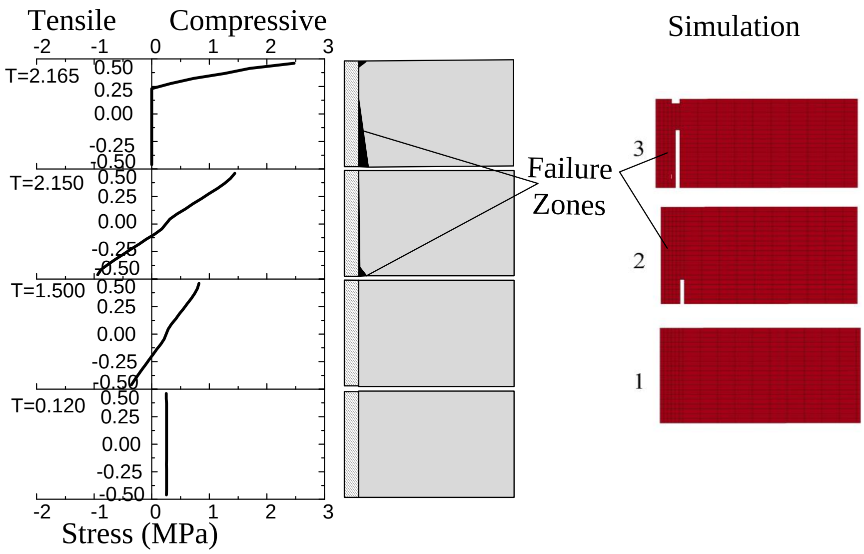


Figure 10. The stress distribution at different times.
(thickness h=0.92m, horizontal force F_{hor}=11.5kN).

In Fig. 11 shows the dependence of the dimensionless parameter M_u / M_e of the ratio L / h. M_e – the maximum bending moment, gotten when the stress at the extreme fiber reached to tensile strength during the elastic work.; M_u - the ultimate moment under the additional effect of longitudinal load. Each curve corresponds to the action of the same vertical force for which found Me and constant longitudinal force F_{hor} = (0,1; 0,2; 0,3) Rc. We see that L / h almost no effect on the dimensionless time limit, and the value of the longitudinal force affects considerably.

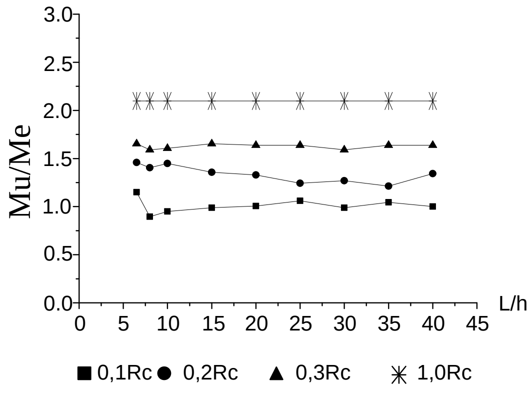


Figure 11. The dependence of the dimensionless parameter M_u / M_e of the ratio L / h.

Figure 12 illustrates in more detail the effect of horizontal load to the limit point. Initially, the presence of this load increases load capacity, but beyond a certain limit is reduced as a result of unnecessarily large longitudinal force of destruction begins in the compressed zone.

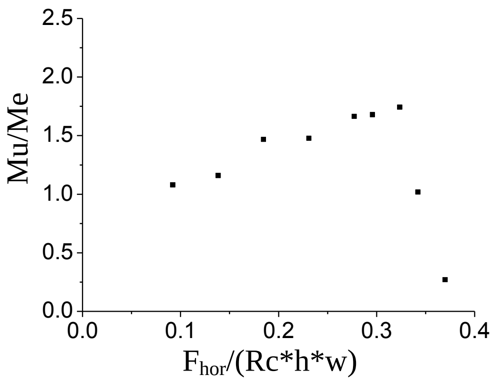


Figure 12. The dependence of the dimensionless parameter M_u / M_e of the ratio F_{hor} /Rc*h*w.

Conclusion

In this article, the ultimate bearing capacity of sea ice in the process of the sea ice and the sloping structures is analyzed using Ansys/Ls-dyna based numerical simulation. The conclusions are as follows:

1. the effect of flexural strength of ice on the ultimate bearing capacity is nelegible;
2. the compressive strength of ice affects the ultimate bearing capacity;
3.the ice load on the sloping structures obviously increases considering the influence on ultim ate bearing capacity in compression zone of cross-section.

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