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Experimental Researching of the Specific Energy Mechanical Fracture of Ice by Method of Uniaxial Compression of Samples

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ABSTRACT

Long known for the method of determining the specific energy breaking the ice using falling hard body on the surface of the ice (DBT method). Earlier studies have shown that in such experiments the ice is destroyed by layers, and a specific energy mechanical fracture of ice is fairly stable. It have the expressed commitment of the temperature dependence of ice and not dependent on mass and velocity. But the fracture process in the ice array is different from the development such fracture processes in the edge of ice field limited thickness. There are also difficulties in integrating energy spent on fracturing only the amount of ice that is counted as a result of the experience. It is known that the ice sheet dissected by vertical radial cracks and horizontal cracks her cleavage on the trapeze-shaped and wedge-shaped blocks. But such blocks not separated from ice array in far from contact area, as large branches from a tree trunk. This process is fundamentally different from the testing process of samples on uniaxial compression, as well as from the testing interaction process of rigid sphere in half-space of ice. The objective of the laboratory's experiments is to improve the method of determining the specific energy of mechanical destruction of ice. In this study for testing not adopted prismatic shape of ice samples, but research trapeze-shaped forms of beams like at the edge of the ice field. In the lab are simulated the deformation and destruction of edges sea ice blocks-samples that have such special forms, like the destruction of the trapeze-shaped and wedge-shaped ice blocks on contact with the surface of the interacted structure leg into edge ice cover in nature.

KEY WORDS: Ice; Fracture; Compression test; Specific energy fracture.

INTRODUCTION

Many studies are known, where basic goal of contemporary authors in the field of research the mechanics of interaction of drifting ice formations with feet of drilling platforms is to create a mathematical model of the phenomenon that would adequately describe the process of the formation of cyclic ice load on the structure. Not a stationary process of breaking the ice on contact drifting ice field and structure can lead to dangerous vibrations and potentially dangerous dynamic loads on offshore structures. Extreme resonant oscillations of the platforms fundaments of can cause not only violations of the regular functioning of the object, but also significantly reduce the reliability of the facility and its durability, causing fatigue fracture in Foundation design elements of the platform or its equipment.

The solution of these tasks has a close link with the mechanism of breaking the ice, as a way to transfer the kinetic energy of the ice field into energy of elastic displacement of structures and energy spent on ice fracture. Therefore, on the way to the development of mathematical descriptions one or other the fracture mechanism for ice, there was a need to examine patterns of the laws of inception and development of all physical phenomena, which together constitute the process of breaking the ice. In this connection, on first plan standing the tasks of research problems of physics and mechanics of breaking the ice, as the materially medium, which creating a pressure on structure. Such a model has not yet been established, it would require to take into account the phenomenological features of destruction of sea ice is as a mechanism for converting the kinetic energy of the ice field into energy elastic deviations structures and energy spent on fracture of ice.

Sea ice is a very complex material that consists of separate various shape and size crystals, inclusive of brine areas, air impurities and mechanical fractions. The mechanical properties of ice depend upon its composition, physical state and temperature. The ice fracture is a complex, integrated process, and describe any changes occurring destruction from reaching limits stresses and deformations stretching, longitudinal and transverse shear for a compressed volume portion of the ice using power strength criterion is impossible. But you can take into account the energy costs for the development of all fracture processes specific volume of ice, using the energetical concept of fracture.

It was assumed that the critical state of stress volume of ice is a condition of the limit equilibrium the total elastic surface energy of cracking in this volume and input external energy. In the Griffith's concept the development the fracture crack for one-dimensional problem as the failure criteria is adopted threshold values the specific surface energy G_c, which "propagating a crack", the corresponding critical value velocity of release of elastic energy stored in the body. A similar approach was developed by Kheisin et al. (1966), Khrapaty & Tsuprik (1976a). They offered to take as the fracture criterion in a tensile single amount of ice in this case the criterion of $\boldsymbol{\varepsilon_{cr}}$ – as a moment of the beginning increase and merge of all types of cracks formed in this volume from of the many defects in the crystal lattice, long cells with brine, inclusions and defects on the borders of the crystals. Therefore during the investigation of sea ice strength, the integral strength properties shall be mentioned inclusive of structural strength (links between its components) and fresh ice crystal lattice strength.

Khrapaty & Tsuprik (1976a) proposed $\boldsymbol{\varepsilon_{cr}}$ as a criterion for calculation of ice loads on structures. In this time a mathematical model that describes the implementing of this process was developed by Tsuprik (1978, 2012). Determination of $\boldsymbol{\varepsilon_{cr}}$ as the fracture criteria was considered as a necessary and sufficient condition for beginning the process of fracture in a unit volume of ice. The execution of this requirement follows from the conservation equations and boundary condition (in relation to the equations of the theory of elasticity) when deciding on the ultimate energy balance of the array with the micro-cracks and defects. With this in mind, and based on the hypothesis above, the decision of model regarding this criterion, written in such form

$$\Delta U/\delta W \geq \varepsilon_{cr}, \qquad (1)$$

where ΔU is changing the energy of the body due to elastic volume change on δW.

The verification of the ice fracture model with using the value of $\boldsymbol{\varepsilon_{cr}}$ by use comparisons of calculated and DBT spheres with masses from 70 to 300 kg was carried out and gave a good convergence (Khrapaty & Tsuprik, 1976b).

In the work of Afanasyev et al. (1978) in materials international symposium IAHR was published the first dependence of values $\boldsymbol{\varepsilon_{cr}}$ versus temperature of the ice received according to results of a large number of DBT experiments on the sea ice of the Amur Bay, Sea of Japan. The authors proposed to consider this value as the strength characteristic of ice for calculation of ice load. Ayer (1978) noted that ice is a very brittle material with low destruction energy and to calculate the sharp changes of load through use in calculations of the force criterion is very difficult. Therefore, Ayer (1978) concluded that the unit volume of ice in contact zone is correlated with the energy of its destruction. Sodhi & Morris (1984) held a large number of laboratory experiments on the interaction of ice with models structure in ice pool where also determine the value $\boldsymbol{\varepsilon_{cr}}$ and they also noted that "*the concept of specific energy may be useful in estimating the ice forces during impact of ice floes* *on structures…".* Vershinin et al. (2006) offered his version of the calculation method of ice load from impacting the ice at the structures using "specific crushing energy of ice" based on the energy balance equation. The consumption of kinetic energy of ice floe at ice-structure interaction can be expressed as the sum of energy consumption for ice destruction in a volume of formed area (Bekker et al., 2016). In this case the energy for ice volume destruction, i.e. the specific energy of destruction ε_{cr}, shall be considered as a calculation unit of sea ice strength. Therefore, as we believe, this criterion must be defined in the integrated fracture process of ice in the array of ice field or by test of the large specimens, if use in the test such specimens the condition that identical with condition fracture of the edge facets of ice field.

The purpose of this investigation is a complex task for verification of hypothesis that the volume of elastic energy being released due to the brittle failure of ice volume ε_{cr}, is a constant value for this material. The verification of this hypothesis provides the application of energy criterion for identification of ice load calculation values, i.e. an actual ice pressure acting upon the structure. The achievement of this complex purpose is possible subject to the development of method for experimental identification of the specific index of energy consumption of ice floe against the mechanical destruction of ice due to the interaction with structure support, i.e. the specific energy of mechanical ice fracture ε_{cr}.

DEVELOPMENT OF ICE FRACTURE PROCESSES ON CONTACT WITH ICE COVER

The change of global load per time acting upon the structure is of an accidental character. Furthermore, according to the observations by different scientists, variation of contact force values depends on the following parameters of ice field penetration by the structural support: velocity of ice filed and its thickness; physical parameters of ice; dimensional parameters of support, etc. The combination of these factors has defined ice destruction process: spalling of free surface of cold ice subject to high velocity of loading due to significant variation of contact forces values; crushing of "warm" ice subject to relatively low velocity of loading due to smooth changing of load. Accounting for experimental research of ice penetration of many authors (Peyton, 1966; Afanasyev et al., 1974; Hirayama et al., 1975; Croasdale, et al., 1975, 1977; Schwarz, 1975; Saeki et al., 1976; Maattanen,1978; Khrapaty & Tsuprik, 1979; Frederking et al., 1999) we concluded that the contact force have high changeability due to the differences of mechanical ice destruction.

The study of ice destruction mechanisms in large-scale tests with natural ice in the Amur Bay (Khrapaty & Tsuprik, 1979) have shown that the edge of ice field under local loading was destructed by development of the vertical and horizontal cracks at the contact area (Fig. 1). Such picture of the edge destruction were studied by many authors in that years, e.g. Schwarz (1970,1975), Croasdale (1970, 1975), Tryde P. (1974), Hyrayama et al. (1975), Kivisild H.R. and Iyer S.H. (1976), Saeki et al. (1976, 1977), Nevel et al., (1977), Michel and Toussaint (1977), Kry (1980), Taylor (1981), Ojima et al. (1985), Yamashita M. et al. (1985) and others.

All researchers have noted the same picture of the destruction, depending on the thickness of the ice, temperature and velocity of the load. Researchers noted that in addition to the development of the initial radial cracks and full crushing ice throughout its height, in front of the structural support is formed by a limited volume of the heavily compressed ice in the form of a prism, inside which the ice crushed. In addition, in front of the surface of structural support occurs: the crushing and crumbling of ice; the crumbly products of ice extrude the outside; spalling of wedge-shaped wreckages; shifting all products of ice fracture of towards the upper and lower surfaces of the ice cover; the periodic repeat all these processes.

Later studies of Palmer et al. (1983), Sodhi & Morris (1984), Sanderson (1988), Joensuu et al. (1988), Daley (1991), Muhonen (1992), Kujala (1994), Gagnon (1994), Kärnä et al. (1999) and others show that the primary role in breaking down the edges of the ice cover in front of the structural support play a crack of different nature. Further investigations by different scientists were dedicated to the mechanics of destruction of the central block by the structural support (Fig. 1), after the initial fracture of upper and lower surface of the field limited by two radial vertical cracks in front of the support with central angle φ. Several scientists have focused their research projects on theoretical and experimental investigation of block destruction mechanisms, inclusive of Gagnon et al. (2006), Kärnä (2006), Jordaan and Frederking (2006), Vershinin & Truskov (2010), Taylor & Jordaan (2011), Karulin et al. (2014) and other researchers.

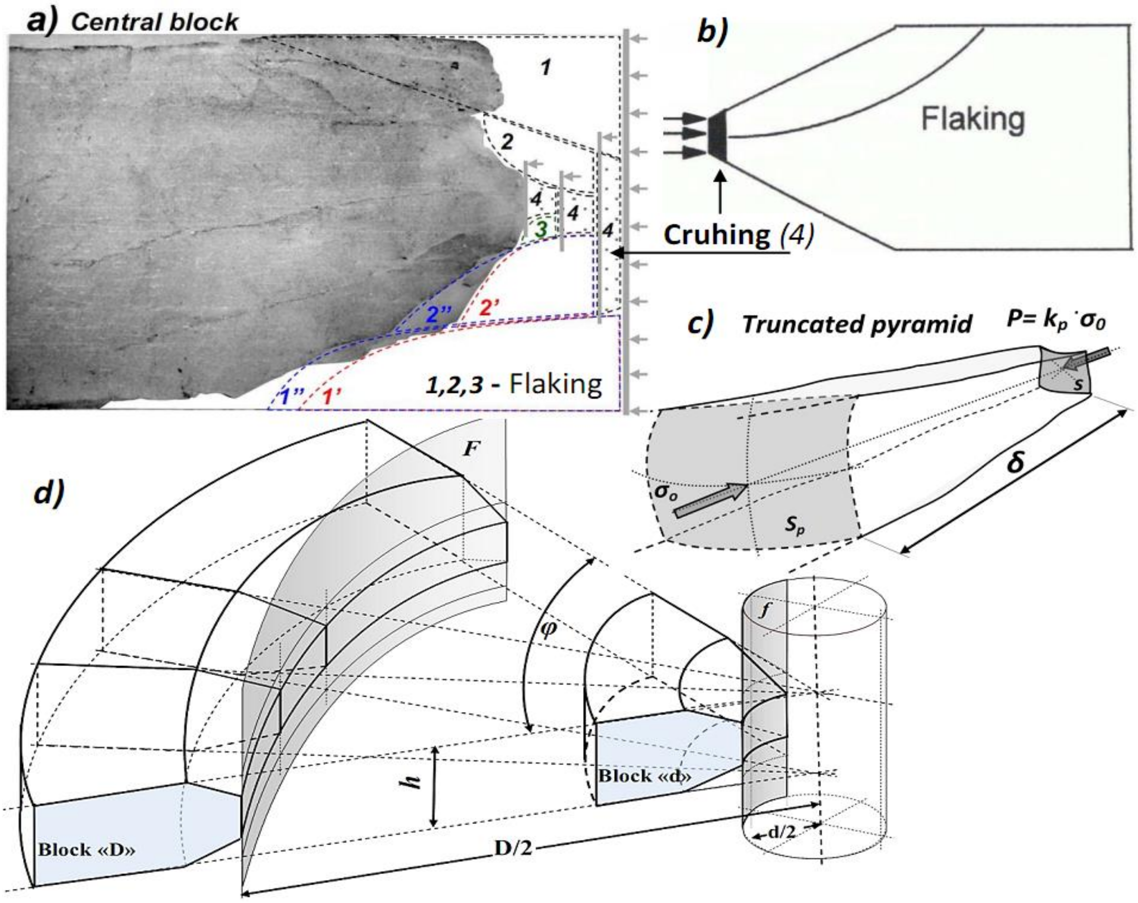

Figure 1. The theoretical and experimental investigation of ice field edge fracture mechanisms: a) - the picture of natural ice edge fracture as per Khrapaty & Tsuprik, (1979), b) - the failure process central V-area of field as per Kujala (1994); c) - scheme of destructed element within Tsuprik, (2012); d) - the hypothesis of field destruction by cracks in front of large (***F***) and small (***f***) supports and the form of central ice block

In compliance with Fig. 3, the central block of edge area of ice field is divided by the system of radial and horizontal cracks into separate trapezoidal and V-shaped elements due to the interaction with hard surface of the support. It can be supposed that the global ice load upon the structural elements consists of local loads providing the destruction of separate elements of the central block. This destruction process was studied in laboratory conditions by Joensuu & Riska (1988), Gagnon (1994) (Fig. 2) and results are close to ones of Khrapaty & Tsuprik (1979) (Fig. 1).

Large-scale and significant investigations of ice block destruction processes featured with V-shaped central block of the ice field were performed by Habib et al., 2014). Fig. 3, a, b show the results of series of experiments of specific energy consumptions. But the authors of this work had the other goal in it study. Fig. 3, c, d show the results of Storheim et al. (2015) of impact ice-ship and ice-structure. Unfortunately, there is no measurement data on ice destruction volume W_{cr} due to the contact (Fig. 3, a, c). Therefore, it is not possible to correlate the energy consumption on to destructed of ice volume U_{cr} (Fig. 3, b, d) for calculation the specific energy mechanical fracture of ice εcr. Besides, the external holder provides the high level of compression that increases the ice floe resistance level against cracks formation. It is obvious that most energy is used for compression of ice subject to closed volume. In reality the volume of destruction can be much higher.

As a result of investigations specified herein, it can be concluded that there is a large theoretical experience and high number of different experiments. Subject to the complex investigation, it provides the basis for distinct and clear sequence of ice brittle destruction process development due to the contact with hard support. So, it is important to describe the typical development of ice destruction per time.

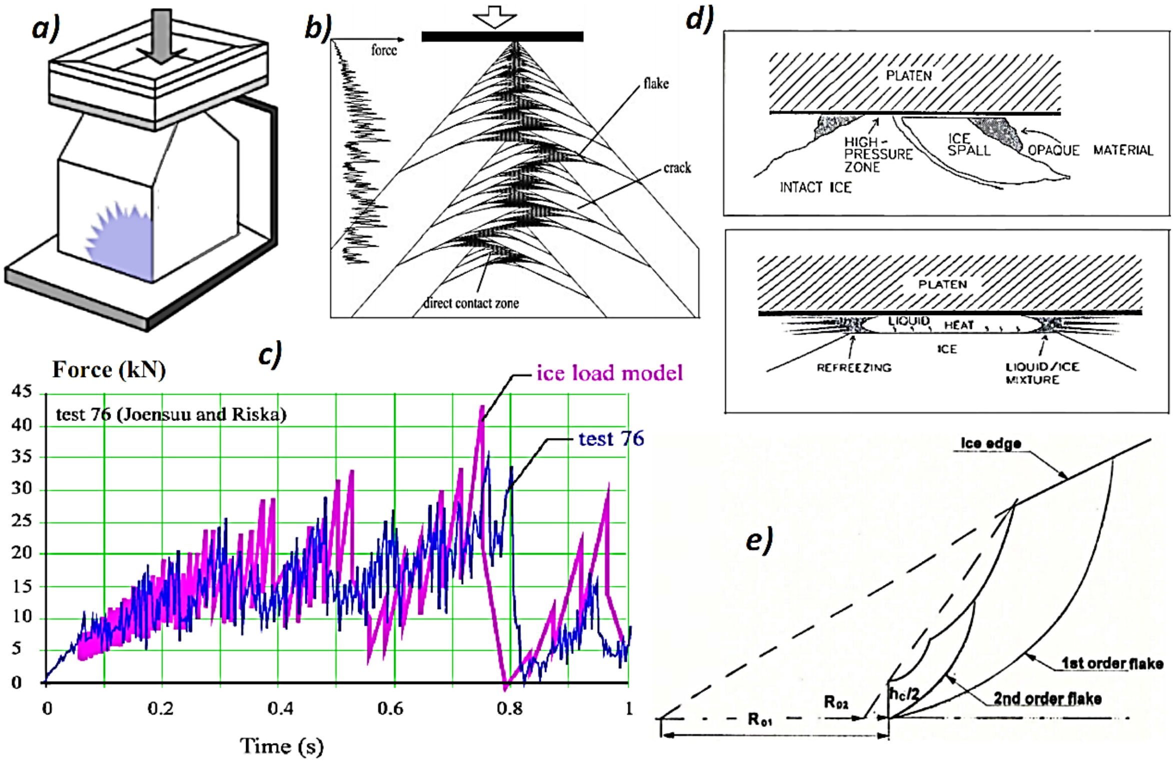

Figure 2. Failure of central block of ice sheet: a) load records (Joensuu et al., 1988); b) model of unsymmetrical fracture (Daley, 1991); c) comparison of contact force of model Daley versus "test 76" of Joensuu et al., 1988); d) destruction of cone (Gagnon, 1994); e) calculation scheme of ice volumes (Kujala, 1994)

ENERGY TRANSFER MECHANISM FROM ICE FIELD TO STRUCTURE

This section of article provides the integrated description of brittle destruction of ice within the central V- shape area of ice floe. Several details herein are especially emphasized as this description is intended for verification of experimental identification method selection related to the numerical parameters of specific energy of ice destruction, i.e. these details are of a high importance. It is wildly known that the process of ice destruction due to the contact of ice and support surface has cycled character. Each cycle of load variation acting upon the structure consists of repeated stages with complex process. Let's consider one cycle of ice destruction process consisting of three basic stages and different independent continuous processes.

The first stage of typical cycle is featured with accumulation of elastic strain within the ice field. The exceeding of definite tension limit at the contact area provides the initial fracture of the upper and lower surface of field resulting in vertical radial cracks. At this an active zone of compaction can be defined within the ice massive (central V- shaped area). As a result of several contact processes the kinetic energy of ice field is transferred into the elastic energy of ice massive. The size of active area depends as follows: support diameter; thickness of ice field and its velocity; ice temperature and its structure.

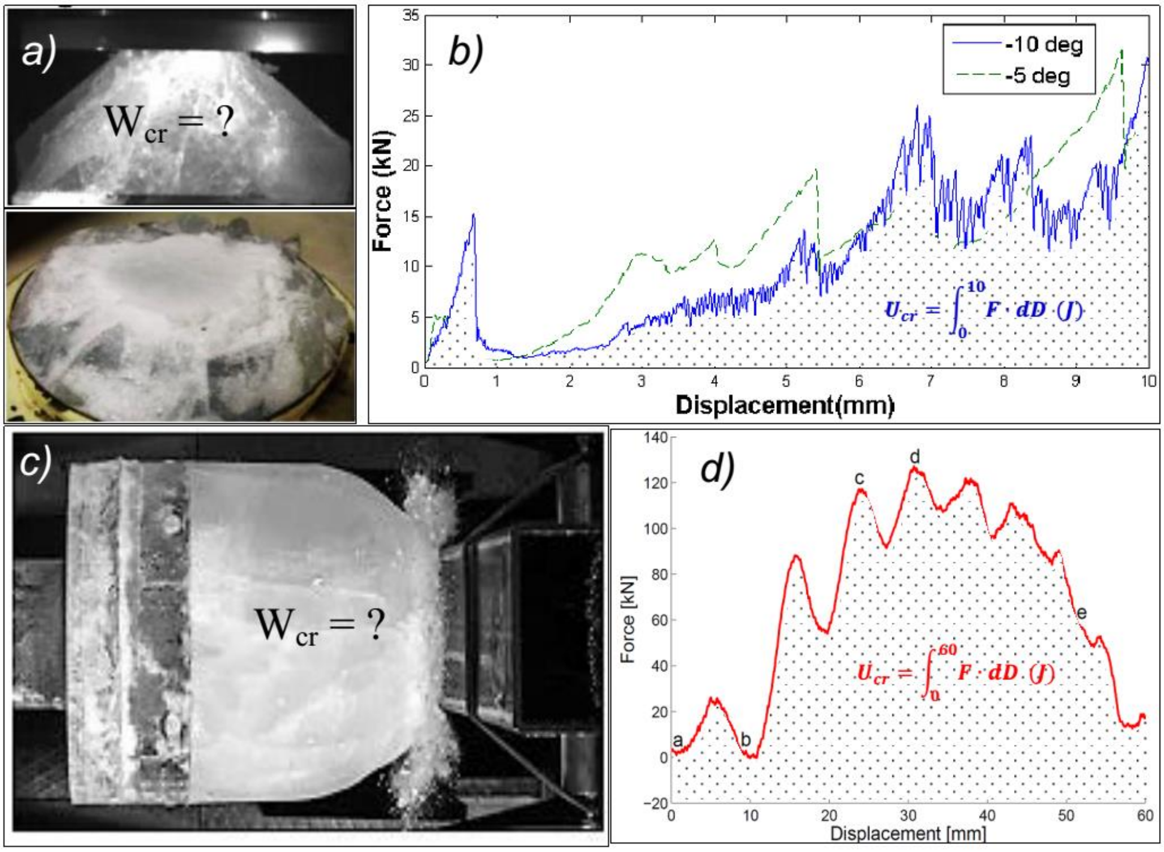

Figure 3. The cone ice sample destruction and the result of destruction:
a, b) pictures and force-deformation curve as per Habib et al. (2014) for low velocity (0.1 mm/s);
c, d) pictures and force-deformation curve (Storheim et al., 2015) for impact (8.0 m/s)

Then the horizontal crack appears at the centre of strained volume of ice field. This crack is developed in both sides. As a result, two plates act with the same scheme of tension accumulation and get fractured into smaller pieces, i.e. field is fractured into secondary pieces. Some previously formed cracks continue developing into ice massive due to energy transfer to its upper sections; the other cracks get stopped due to gaps or other cracks; several new cracks are formed at the points of maximum tension concentration within the crystals border or foreign inclusions. Considering the volume feature of this event, it shall be noted that cracks are developed within all radial areas. The volume of non-destructed ice is located between cracks. These ice blocks are featured with extended shape due to compacted volume of ice destruction products subject to the previous cycle of destruction. Therefore, V- shaped and trapezoidal ice blocks are formed within the local contact zone of ice field. These blocks are extended into ice massive by the ends located against the contact surface (Fig. 1).

The second stage of destruction is featured with strained volumes of contact zone of large ice blocks, appeared from ice massive. The complex process is developed with these blocks: a part of ice kinetic energy is accumulated in the form of elastic energy providing the significant change due to small side and internal fractures inclusive of multiple radial cracks within active areas of single large ice blocks. The "layers of initial fracture" will be accidentally destructed along different blocks forming the edge of ice field, crashing the most rigid areas of ice (high pressure zones – HPZ, Fig. 2, d). At the same time, ice destruction products (small blocks, crystals and ice fractures) are pressed out of the large blocks contact areas. At this, accidental new rigid areas (HPZ) appear. The contact force is higher in comparison with the other sections of contact area. These sections are destructed and replaced with new sections that are subject to further destruction.

Intermediate processes of layer-by-layer destruction are featured with accumulation of elastic energy by the trapezoidal blocks due to increase of their contact areas. The diagram of contact pressure is equalized. The area of block compaction appears subject to standard cracking that subdivides the block into two pieces. Certain energy is released via enlarged master cracks forming continuously extended large blocks.

The third stage is an avalanched type development of large side fractures and significant decrease of blocks cross section at the contact area. Increase of contact pressure provides development of layer-by-layer destruction of edge contact areas. The process of field edge destruction will continue till the moment when the velocity of energy transfer to ice massive via destruction surface is less than the total velocity of energy dissipation within the ice field due to formation of multiple cracks, crashing of blocks, etc. The process of cycle destruction of ice and load transfer upon structure will continue until the kinetic energy is less than energy for destruction of ice. This logical description of sea ice destruction subject to penetration with solid body is based on the results of theoretical and experimental studies, considered in this article (Fig. 1-3). This conceptual description of ice destruction mechanism was considered as a basis for development of method for identification of specific energy of fractured ice due to dynamic loading of **large samples** using test equipment with constant velocity of loading plate Displacement.

SPECIFIC ENERGY MECHANICAL FRACTURE OF ICE AND COMPRESSION OF LARGE SAMPLES OF NON-PRISMATIC SHAPE

In this work, the new non-tested method of ε_{cr} value investigation was applied. The method of trapezoidal or V- shape ice sample loading is featured with dynamic compression by testing machine plate that moves with actual velocity of the ice field. This method of physical modelling considers both physical and phenomenological particulars of ice - inclusive of all process parameters due to destruction and solid ice surface impact. The prototype of this method can be considered a similar method that was applied in Sodhi & Morris (1984) to identify specific energy fracture of the modeled ice in the ice basin.

The purpose of this suggested method is its possible application for identification of specific energy of ice destruction $\boldsymbol{\varepsilon_{cr}}$ under the laboratory conditions similar to ice field central section destruction conditions. This purpose can be achieved by compliance of dimensional and kinematic similarity of ice destruction process under natural and laboratory conditions. It can be obtained via establishment of the dynamic multi-cycled loading of trapezoidal shape ice block sample formed under the natural conditions between vertical and horizontal cracks at the middle of ice field (see Fig. 1). Another requirement was the approximation of sample size to ice block size under field conditions.

In order to obtain the kinematic conformity of testing conditions against the real ice destruction conditions, velocity of press plate shall be equal to ice field Displacement velocity under the natural conditions related to investigation of ice strength parameter. Compliance of the above-mentioned experimental conditions shall provide high accuracy of obtained data, necessary for structures design under freezing seas shelf conditions.

So, the suggested method provide the definition of specific energy of mechanical ice destruction $\boldsymbol{\varepsilon_{cr}}$ as per the velocity of its loading corresponding to ice field drift velocity and related to realization of multi-cycle destruction of ice sample section, as the sum of specific integral consumption of energy for shear and compressed deformation used for displacement of ice destruction products out of the contact area and displacement of fractures

$$\boldsymbol{\varepsilon_{cr}^{o} = U_{cr}/W_{cr} \cdot \rho} \qquad (2)$$

where $\boldsymbol{\varepsilon_{cr}^{o}}$ is specific energy of mechanical destruction of ice, defined as per the dynamic destruction of samples; $\boldsymbol{\rho}$ – ice density.

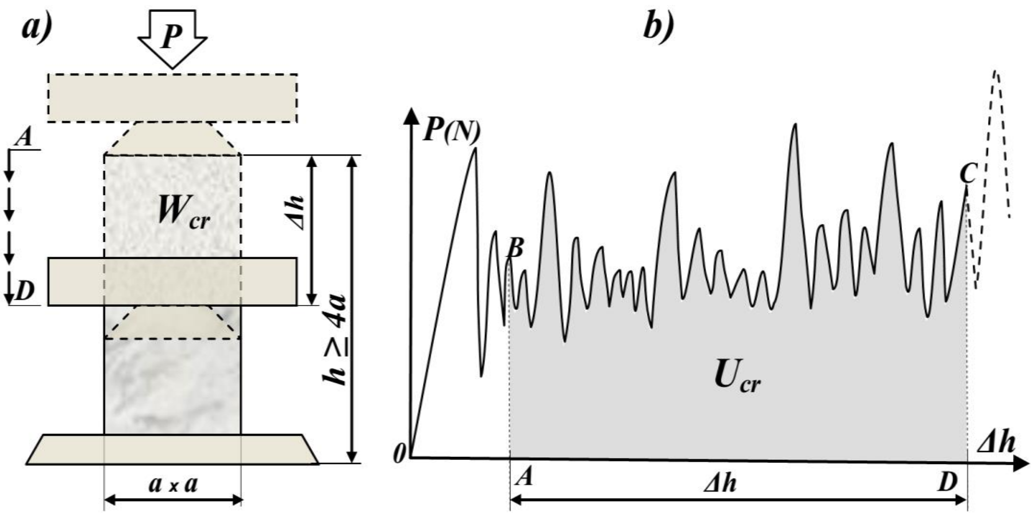

Figure 4. Calculation scheme of specific destruction energy and force-deformation diagram: a) scheme of "high" ice sample; b) scheme for calculation specific energy required to fracture ice

Thus, the main difference of the suggested method from the standard method is the establishment of conditions for the beginning of continuous destruction of ice sample upper area. Normally it is achieved by application of samples with shape truncated pyramid or cone shape (Fig. 5). It is the first and basic condition for multi-cycle ice destruction. The area of upper basis of sample located on movable press support shall be less than area of bottom foundation area.

The second condition is preparation of relatively high sample that is essential to establish conditions for long-term process of ice destruction. There are two basic reasons for ice destruction: firstly, the most tensile condition inside sample occurs at its upper section, as its upper surface area is larger than its lower surface area. Secondly, due to significant height of the sample against its foundation, high tensile area of sample surface in contact with upper and lower surface shall provide no areas of high tensile within the central area of sample.

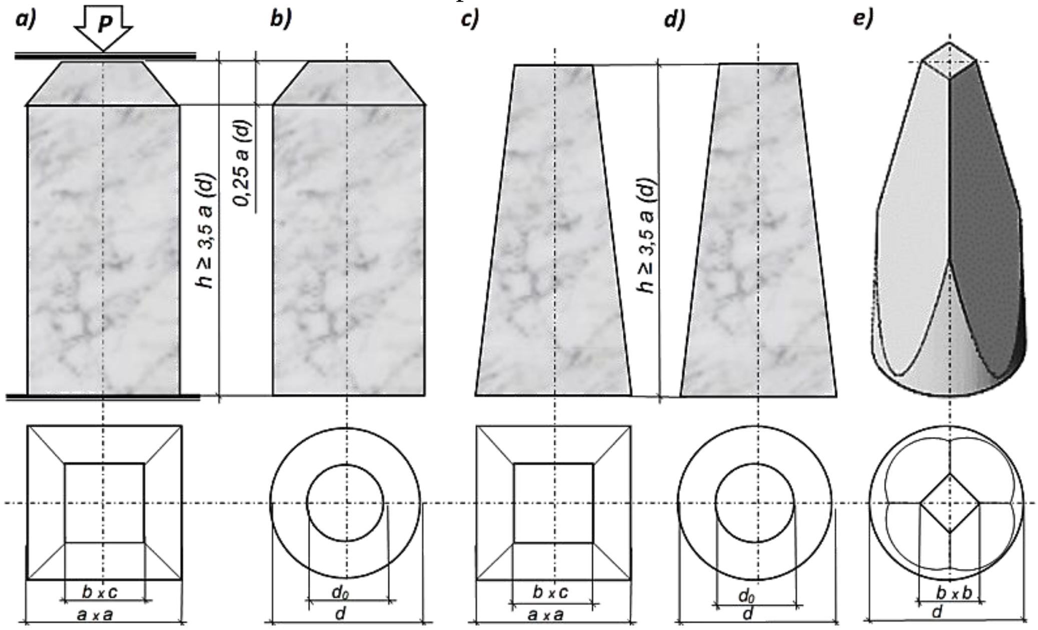

Figure 5. Shape and size of samples used in experiments

Considering these conditions subject to selection of sample size and shape, inclusive of press plate Displacement velocity shall provide the achievement of specified purpose, i.e. the dynamic multi-cycle process of ice sample loading. In this case, the specific energy of destruction becomes the *integral feature* inclusive of crack formation of ice massive, ice fracture energy at the surface of ice field and the compression energy of ice central block, inclusive of energy for displacement of ice fractures within the contact area of ice and structure.

EXPERIMENTAL RESULTS

The suggested method has been realized in compliance with the procedure of maximum ice strength identification as per the standard samples investigation method for uniaxial compression. Some samples of artificial fresh ice and nature sea ice were tested for a method adjustment. The significant preliminary results were obtained presented here, but studding all events of fracture ice process and values of parameter $\boldsymbol{\varepsilon^{o}_{cr}}$ dependences from different factors, are continuing.

1. Force-Displacement diagram of ice sample testing by new method (Fig. 6) is similar to presented earlier (Peyton, 1966; Afanasyev et al., 1971; Croasdale, 1975; Hyrayama et al., 1975; Schwarz, 1975; Maattanen, 1978; Yue et al., 1998; Frederking et al., 1999; Kärnä, et al., 2003, 2006; Jordaan et al., 2006; Karulin et al., 2014).

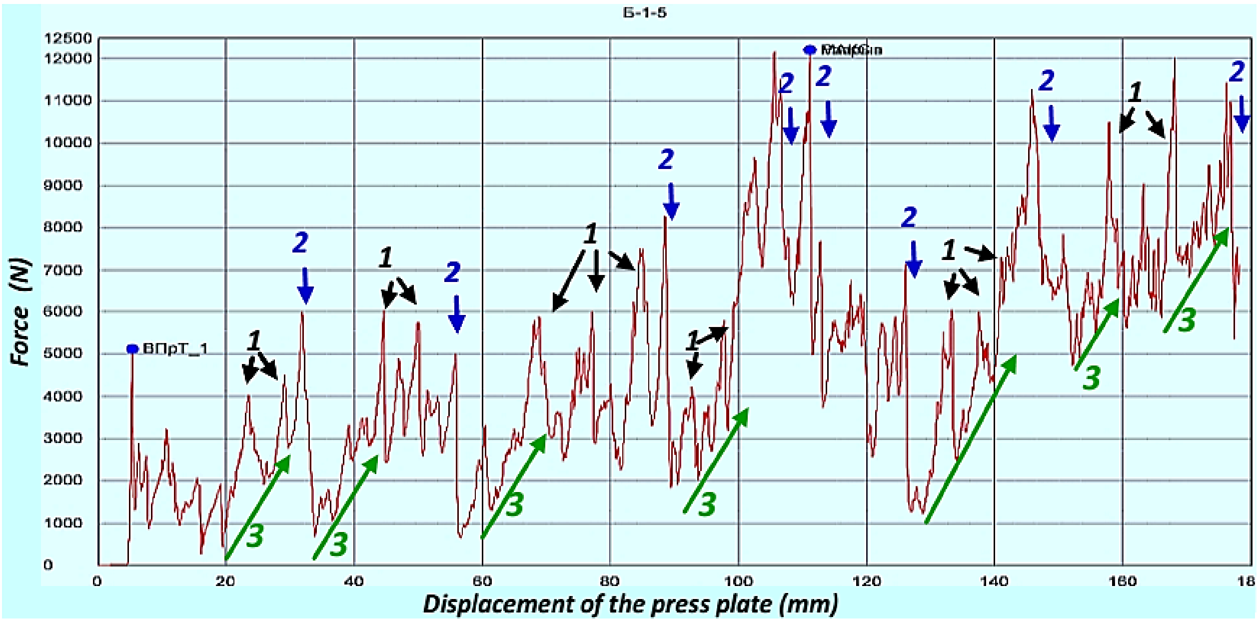

Figure 6. The Force-Displacement curve destruction of sample showed cyclical process where occurring: 1 - the fracture ice in alternating of high pressure zones (HPZ); 2 - spalls of side edges and 3 – ejection of the crushed ice layer and the shards of ice out

2. The process of continuous destruction of sample upper surface under the compression show accidentally repeated deformations of side sections at the contact area of sample and surface of moving plate, i.e. the middle area of its working contact is compressed and ice destruction products are moved out of the contact area (Fig. 7). The process of destruction is accompanied with expansion of side surface and occurrence of pulsating sizzle sound. The wreckages from spalls of ice have curve surface (Fig. 7).

3. As the moving press plate approaches to the lower immovable plate to the distance equal to vertical size of cubic sample, the remained section of sample is crushed with one of the standard types of cubic ice sample destruction: longitudinal vertical cracks 1-2 or displacement of side cones.

According to testing results of some samples with different temperature (no less than -5^{0}C however) subject to change of loading velocity, the authors have concluded that the experimental purpose was achieved: the observed destruction of sample is similar to real parameters of ice field and structural support interaction due to destruction type and parameters of this event. The obtained experimental curves of Force-Deformation (Fig. 6) was processed in order to obtain the total value work of elastic deformations of ice that spent on destruction of ice on fixed sample height as per selected method.

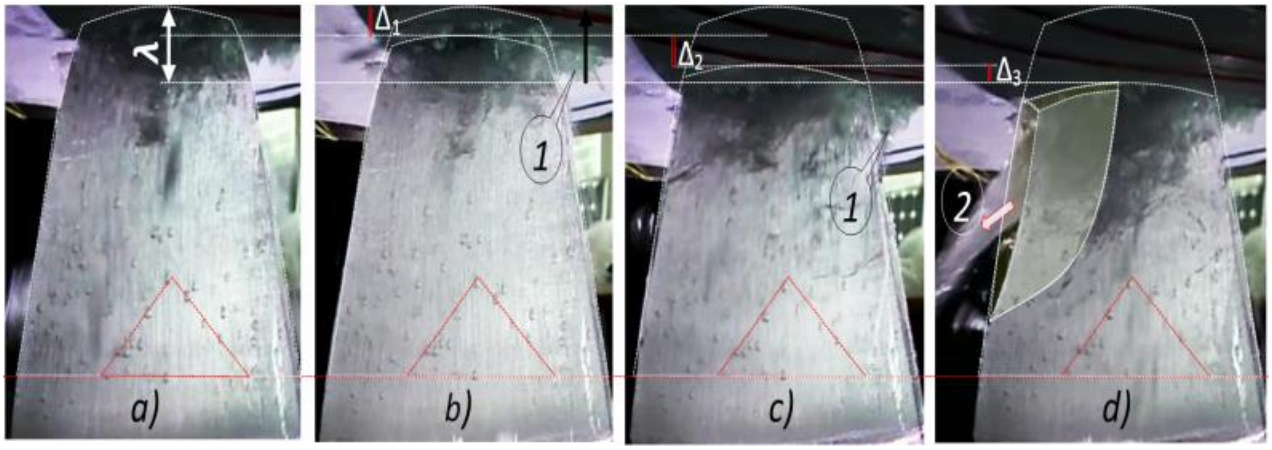

Figure 7. Stages of process ice fracture: a) formed layer of crushing with λ depth; a, b) process of compression of crushed ice and displacement products of ice fracture (1) out of the contact area; c, d) rigid contact and spalling (2) of side edges of ice block

This work is equal to released energy of elastic deformation of ice, U_{cr} per the fractured volume W_{cr}. It was calculated via the height of destructed area Δh of sample using trapezium method. Dependency of the specific energy of mechanical fracture of ice has been obtained. This dependency has been obtained during ice samples testing under the dynamic multi-cycle load from temperature (Fig. 8), but not dependence from velocity of press plate and from time testing of specimen (Fig. 9, a). When increasing the velocity of interaction Indenter with ice, as is well known, the contact force decreases. This phenomenon can be seen and for crushing process of samples in the graph in Fig. 9, b.

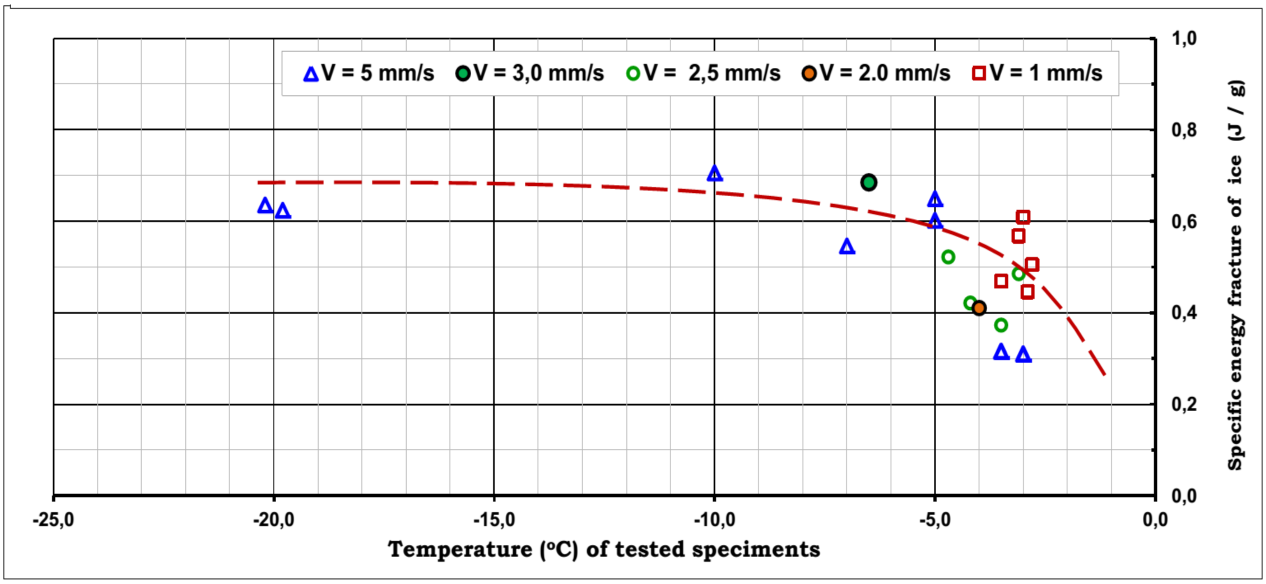

Figure 8. Dependency of specific energy of mechanical fracture of ice ε^{o}_{cr} from temperature

The obtained dependency ε^{o}_{cr} from temperature is identical by the nature of the curve with such dependency for this magnitude obtained by DBT. However its numerical values are less than obtained data related to drop ball test more than 10 times (Tsuprik, 2012, 2013). It is said that in the DBT method virtually impossible to properly account for all energy loss, which is not spent on local failure of ice. Given the importance of this physical magnitude as the energetical of ice strength criterion this study gives justification for spending in further very careful review these two methods.

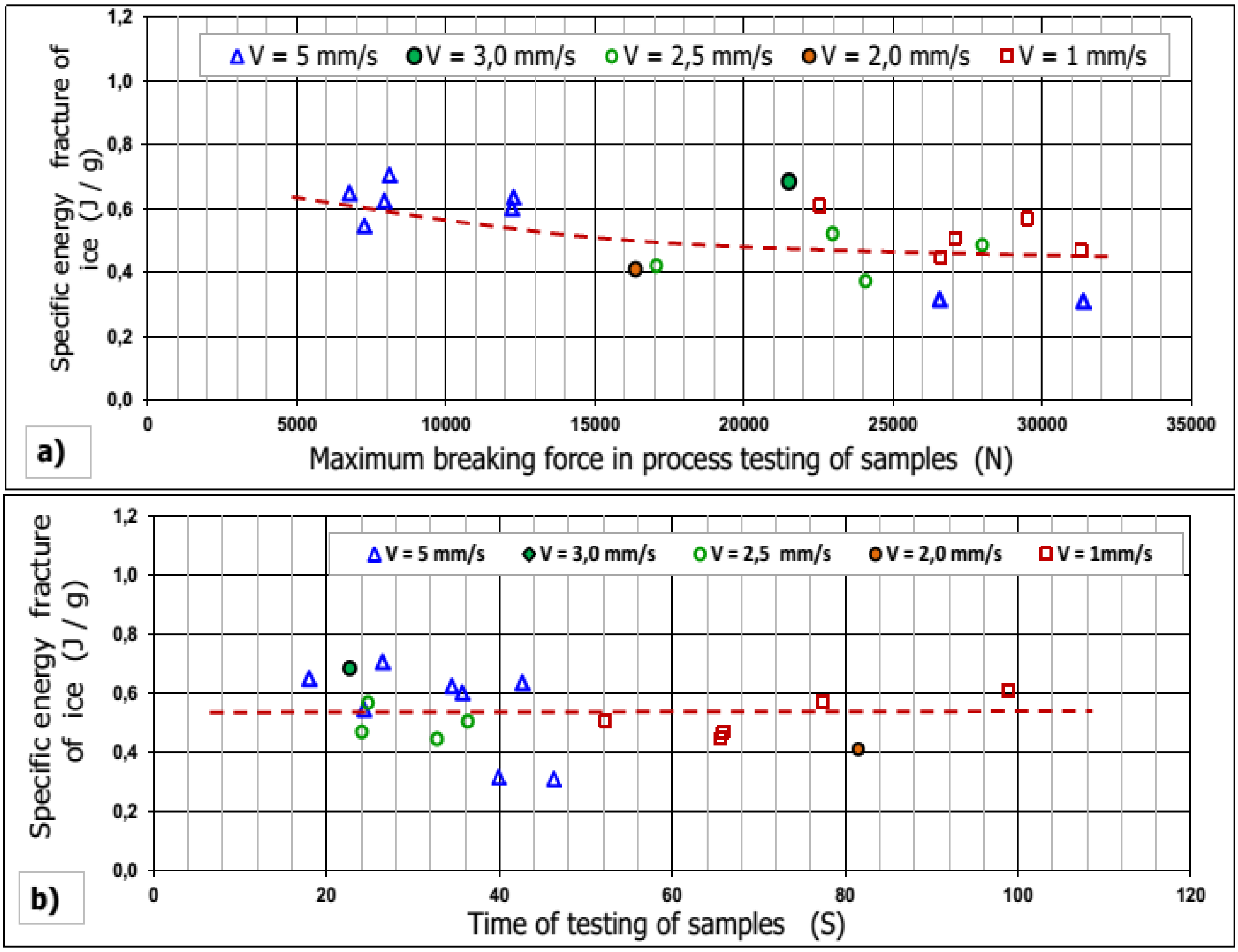

Figure 9. Dependency of specific energy of mechanical fracture of ice $\boldsymbol{\varepsilon^{o}_{cr}}$:
a) - from contact force; b) - from speed of press plate and from testing time of specimens

CONCLUSIONS

The objective of this laboratory experiments is the approbation of the testing method uniaxial compression of high ice samples to determine the specific energy of mechanical fracture of ice. This new method of determining the specific energy of mechanical destruction of ice considered as an alternative method of Drop Test Boll (DBT). In this study adopted a samples form of trapezoidal and wedge-shaped beams such like as the fracture edges of blocks in contact zone with the surface of penetration into the ice cover of the leg of structure as in nature.

During testing of samples by of dynamic loading conditions were obtained different mechanisms breaking the ice depending on its temperature and speed the movement of plates press. The increase of the speed of interaction plate with ice leads to decreases of contact force, this phenomenon corresponds the processes that occur naturally in interoperating ice with real constructions. This results are fully supported by the results of studies by other authors.

The performed investigation of energy criterion of ice destruction provides the simplicity of its experimental identification, independence from experiment conditions, stability of values and flexibility. The specific energy of mechanical fracture of ice $\boldsymbol{\varepsilon^{o}_{cr}}$ does not depend from speed of moving press plates and from testing time of sample.

These all facts provide the possibility of method development for the calculation of ice load acting upon the structure on the basis of application of the specific energy of mechanical fracture of ice $\boldsymbol{\varepsilon^{o}_{cr}}$ as an alternative to the existing method.

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