

Mathematical Modeling of Ice Loads on Ship Hull in View of Their Stochastic Nature: Method Development & Solution Implementation

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ABSTRACT

This article is of a conceptual nature and deals through the example of ice loads with the consideration of general issues related to researching the external environmental effects on marine infrastructure facilities under presence and influence of random components. Fundamentals of method for modeling the stochastic ice loads on ship hull based on combination of probabilistic and simulation approaches and developed under direct participation of authors are outlined. The detailed stepwise algorithm to implement the appropriate modeling process and its flow chart are submitted. Key aspects of processing, representing and assessing the output data of probabilistic simulation of ice loads acting on ship hull are noted. Certain results of modeling the random values of design ice load parameters are provided and interpreted applied to the real ice-going ship operating in the ice conditions of specified navigation water area and season. Practically significant problems within which it is expedient to use the developed solution are formulated. The conclusion is drawn that the introduction of probabilistic simulation concept, together with the application of direct calculation methods, to assess and forecast the ice loads on ship hull will ultimately contribute to a considerable decrease in the damageability level and increase in the safety level for marine transport when operating in ice.

KEY WORDS: Probabilistic Simulation; Ice Load; Ship Hull; Statistical Test; Theoretical Distribution.

INTRODUCTION

The use of principles and tools of probabilistic simulation with regard to the ice loads acting on ship hull makes it possible to set and to solve a number of practically significant problems, including the following:

- estimating the regulatory exceedance probability for design ice loads on ice strengthened ship hull structures factored in their actual technical state;

- developing the new hull structures of ice-going ships under specified exceedance probability for design ice loads;
- assuring the strength balance for different ships related to the same ice class (or, more exactly, having the same category of ice strengthening for hull) or for different hull structures of the same ice-going ship taking into consideration the variability of ice loads;
- forecasting the damageability characteristics and reliability indices for hull structures during the ship operation in the multifarious ice conditions;
- substantiating the correspondence between ice class (category of ice strengthening for hull) assigned to the ship and actual conditions of its navigation in ice.

Furthermore, solving the problem on probabilistic simulation of ice loads acting on ship hull will allow to account their stochastic nature when developing the specialized on-board documentation and software according to the ice strength requirements. The given on-board facilities are directly used by navigators to ascertain the parameters of safe ship operation in the ice conditions (primarily, this is about the ship speed in ice). Thus, Likhomanov, et al. (1998) suggest the probabilistic approach to the development of ship's ice passport, and Appolonov, et al. (2014) review the methodological basics of on-board computer system for forecasting the extreme ice loads and allowable modes of ship navigation in ice proceeding from the presence and influence of random components. The application of results of modeling the stochastic ice loads on ship hull appears also an innovative and prospective direction in order to build the probabilistic model for ice damageability of ships (Appolonov, 2016) and to manage the risks during the ship operation in the ice conditions within the framework of formal safety assessment (FSA) concept (Ehlers, et al., 2014). Finally, Kujala, et al. (2019) emphasize the crucial role of estimating the stochastic ice loads arising from the ship-to-ice mechanical interaction as well as of analyzing the stochastic responses of hull structures induced by loads action in the risk-based design of ice-going ships (RBSD).

DEVELOPMENT OF METHOD FOR MODELING THE STOCHASTIC ICE LOADS ON SHIP HULL

To model the stochastic ice loads acting on ship hull under its dynamic (impact) interaction with the ice cover and being of local character, a method combining the probabilistic and simulation approaches has been developed at the Ship Structure and Technical Operation Department of the Saint Petersburg State Marine Technical University under direct participation of authors of this paper. The proposed solution is based on multiple targeted computer experimentation that implements the well-known and widely accepted method of statistical tests (the Monte-Carlo method) and involves the standard (in particular, linear congruous) pseudorandom number generators and inverse transformation algorithms to reproduce the input random components. The appropriate theoretical background as well as the introduced assumptions and restrictions and calculation dependences of modeling method under consideration were in detail outlined by Tryaskin, et al. (2012).

The design values of ice load parameters are determined for each combination of influencing random components in an analytical way with the use of direct calculation methods. The given methods are based on physical models of mechanical interaction between ship hull and external environment, including the ice cover, and directly take into account the specifics and details of a concrete interaction process. Therefore, they are deemed the most universal, and appear in certain cases the only acceptable. For today, when using the software tools distinguished by a considerable speed and memory amount, the practical implementation of theoretically developed methods usually does not cause any technical difficulties. It should be noted that the contemporary worldwide trends in improving the requirements of regulatory

documentation indicate an increase in the significance and priority namely for direct calculation methods when solving the problems related to assessing and forecasting the external environmental effects of any nature on marine infrastructure facilities (Yakimov, 2012).

The direct calculation method accepted for consideration deals with the mechanical interaction between two impacting bodies that are translationally moving ship and motionless ice cover. It is based on postulates of classical impact theory (assuming the instantaneous impact), fundamental conservation laws for linear momentum and for angular momentum, principle of least action and differential equations for motion of physical system. The ice loads acting on ship hull under its impact interaction with the ice cover are determined as a result of solving the general differential equation for ship motion in the normal direction at the impact point:

$$M_{12}^{red} \cdot w \frac{dw}{d\zeta} + \int_F p dF = 0 \text{ under initial condition } w_0 = w_{\zeta=0} = v_0^{red}, \quad (1)$$

where M_{12}^{red} is a mass of ship-ice system reduced to the impact direction; ζ is a depth of ship side penetration into the ice being the inelastic crushing strain of ice cover edge proper; w is a speed of ship side penetration into the ice in the impact direction; v_0^{red} is a speed of ship motion reduced to the impact direction at the initial moment of interaction with the ice cover; p is a contact pressure and F is an area of contact zone.

To set the contact pressure, the hydrodynamic model of solid body impact against the ice is used in its traditional (Kurdyumov & Kheysin, 1976) and modified (Appolonov, et al., 2011) definitions. The given model is based on solving the problem concerning the extrusion of relatively thin interlayer having the finely dispersed structure and both viscous and plastic properties from the contact zone during the solid body penetration into the ice. To describe the medium motion, a set of Hencky non-linear differential equations for viscoplastic body is applied which is reduced after linearization to a simplified set of Reynolds differential equations defining the quasi-static out squeezing of thin layer of viscous liquid (neglecting the interlayer plasticity) between two surfaces that are surface of penetrating solid body and surface of non-failed ice bulk. In the general case, the solution for contact pressure could be obtained as follows:

$$p = \sigma_c \cdot \left[\frac{n+3}{n} \cdot \frac{\mu_1 \cdot w}{\sigma_c \cdot l} \cdot \frac{b^2}{l^2} \cdot \bar{\varphi} \left(\frac{x}{b}, \frac{y}{b} \right) \right]^{\frac{n}{n+3}}, \quad (2)$$

where σ_c is a compression strength for ice; μ_1 is a coefficient of internal friction in the interlayer; w is a speed of solid body penetration into the ice in the impact direction; b is a typical linear dimension (i.e. a height) of contact zone; l is a typical thickness of interlayer; $\bar{\varphi} \left(\frac{x}{b}, \frac{y}{b} \right)$ is a solution of Poisson equation $\nabla^2 \bar{\varphi} \left(\frac{x}{b}, \frac{y}{b} \right) = -1$ for contact zone under zero boundary conditions on contour represented in the dimensionless form and $n > 0$ is a numerical factor characterizing the properties of failure surface, namely its rigidity or compliance.

In the equation (1), the integration of contact pressures should be performed not over the full, but over the effective area of contact zone. When impacting the inclined flat ship side against the ice cover edge, the contact zone has a form of segment considerably extended lengthwise, and the extrusion of crushed ice from the contact zone during the impact predominantly occurs in the vertical direction, i.e. across the contact zone. Consequently, in the case of one-dimensional ice extrusion, the contact pressures are integrated over the effective height of contact zone:

$$b_{eff} = b/\alpha < b. \quad (3)$$

Within the traditional definition of hydrodynamic impact model, the dimensionless factor α

takes into account the existence of ice chips that are formed at the edges of contact zone owing to the unrestricted increase in the tangential stresses when approaching its boundary. Within the modified definition of hydrodynamic impact model, the given factor acts as an empirical peakedness parameter that reflects the actual pronounced peak-like character of distribution for contact pressures ascertained by experimental way. In any case, within the framework of modeling method under consideration, the factor α is assumed to be a random variable uniformly distributed in the appropriate range of values.

CONSTRUCTION OF ALGORITHM TO IMPLEMENT THE PROCESS FOR MODELING THE STOCHASTIC ICE LOADS ON SHIP HULL

According to the developed solution, in the general case, the process for modeling the stochastic ice loads on ship hull could be represented as a sequence of the following steps:

- preparing the initial information about the ship;
- preparing the initial information about the water area and season of ship navigation in ice;
- analyzing the ship hull form in the areas of ice loads action;
- analyzing the ship performance in open water;
- generating the separate flows of random numbers uniformly distributed in the range $(0, 1)$;
- dividing the entire route of ship navigation in ice into the separate short-length sections characterized by homogeneous hydrometeorological and ice conditions;
- determining (i.e. estimating in the first approximation) the total number of impact impulses corresponding to the total number of realizations for random values of ice load parameters within the entire route of ship navigation in ice and within its separate sections;
- modeling the random values of parameters of hydrometeorological conditions, including the ambient air temperature, wind speed, sea water salinity and density, within the set ranges;
- modeling the random values of parameters of ice conditions, including the ice cover thickness, its typical linear size, concentration, hummocking, disturbing, snow-covering and nip intensity, based on data of initial tables or bar charts of partial (frequency) distribution;
- modeling the random values of physical characteristics of ice cover, including the ice temperature, salinity, density and porosity, specific volume of main ice components (pure ice, brine, solid salts and gas), etc.;
- modeling the random values of mechanical characteristics of ice cover, including the flexural, shearing, compression and crushing ice strength, dynamic ice strength by crushing, Young modulus and Poisson ratio for ice, coefficients of steel-ice friction, etc.;
- modeling the random geometric form of ice cover edge in the contact zone (rounded or angular) and the random values of characteristics of ice cover edge (rounded radius or included angle);
- analyzing the load-bearing capacity of ice cover by flexure, including factored in the influence of dynamic effects, and its stability;
- identifying and describing the design modes of ship motion in ice classified as an independent motion in ice or a motion in ice channel following an icebreaker, as a continuous motion in ice or a ramming in ice, as a motion in solid ice or a motion in broken ice of different concentration, as a rectilinear motion in ice or a gyration (maneuvering) in ice; as an ahead motion in ice or an astern motion in ice;

- analyzing the ship icebreaking capability in failed and non-failed solid ice;
- assessing the influence of non-standard ice conditions on magnitude of attainable (i.e. complying with the ice performance requirements) speed of ship motion in ice;
- determining the design values of attainable speed of ship motion in ice for each combination of influencing random components in an analytical way with the use of accepted semi-empirical method;
- modeling the random distribution for frequency of impact impulses within the ship hull length at the actual waterline level;
- determining the design (as a rule, maximum) values of ice load parameters for each combination of influencing random components in an analytical way with the use of accepted direct calculation method, including the depth of penetration into the ice, height, length and area of contact zone (geometric parameters), the ice load intensity, linear ice load and total contact force (force parameters) as well as the impact duration;
- refining (i.e. estimating in the second approximation) the total number of impact impulses within the entire route of ship navigation in ice and within its separate sections based on design values of attainable speed of ship motion in ice and impact duration;
- accumulating, grouping and processing the results of modeling the stochastic ice loads on ship hull with the use of methods of computational mathematics, probability theory and mathematical statistics.

The basic flow chart displaying the process for probabilistic simulation of ice loads acting on ship hull is illustrated in Figure 1. The main procedures being executed could be combined into seven enlarged blocks (highlighted in the different colors) that are “Initial Data”, “Randomness Sources”, “Ice Cover”, “Hull Form”, “Ice Performance”, “Ice Loads” and “Results Processing”.

The effective application of proposed method for modeling the stochastic ice loads on ship hull does not appear possible without developing the special-purpose software that enables to conduct the multiple targeted computer experimentation. To solve the stated problem, the first release of software was prepared and registered under direct participation of authors of this paper (Yakimov & Tryaskin, 2012). However, at the present time, the developed software should be justifiably recognized obsolete, since it does not take into account the substantial changes and additions introduced for several years into the theoretical background of studies as well as the aspects for further practical use of obtained simulation results. Proceeding from the foregoing, it is planned to update the first release of software (Yakimov & Letova, 2017).

HANDLING OF OUTPUT DATA OF PROBABILISTIC SIMULATION OF ICE LOADS ACTING ON SHIP HULL

The most complete form for representing the results of probabilistic calculation is the distribution law obtained for a random variable. It is deemed as a set containing all possible variable values and probabilities corresponding to the given values, while the deterministic solution implies only one of possible values for a variable under consideration without estimating its probability. From the mathematical standpoint, any random variable is in an exhaustive way described by its distribution law. To represent the results of probabilistic calculation in a more simplified form, it is sufficient to find some quantitative characteristics. They should define the basic properties of a random variable, primarily, with regard to the position of center of grouping the values (e.g. expected mean, median, mode) and to the degree of scattering the values relative to the grouping center (e.g. variance, standard deviation, variation coefficient). The stated characteristics are directly associated with the

distribution parameters through the moment generating function and allow to give the approximate probabilistic estimate to a random variable under conditions where its distribution law is unknown.

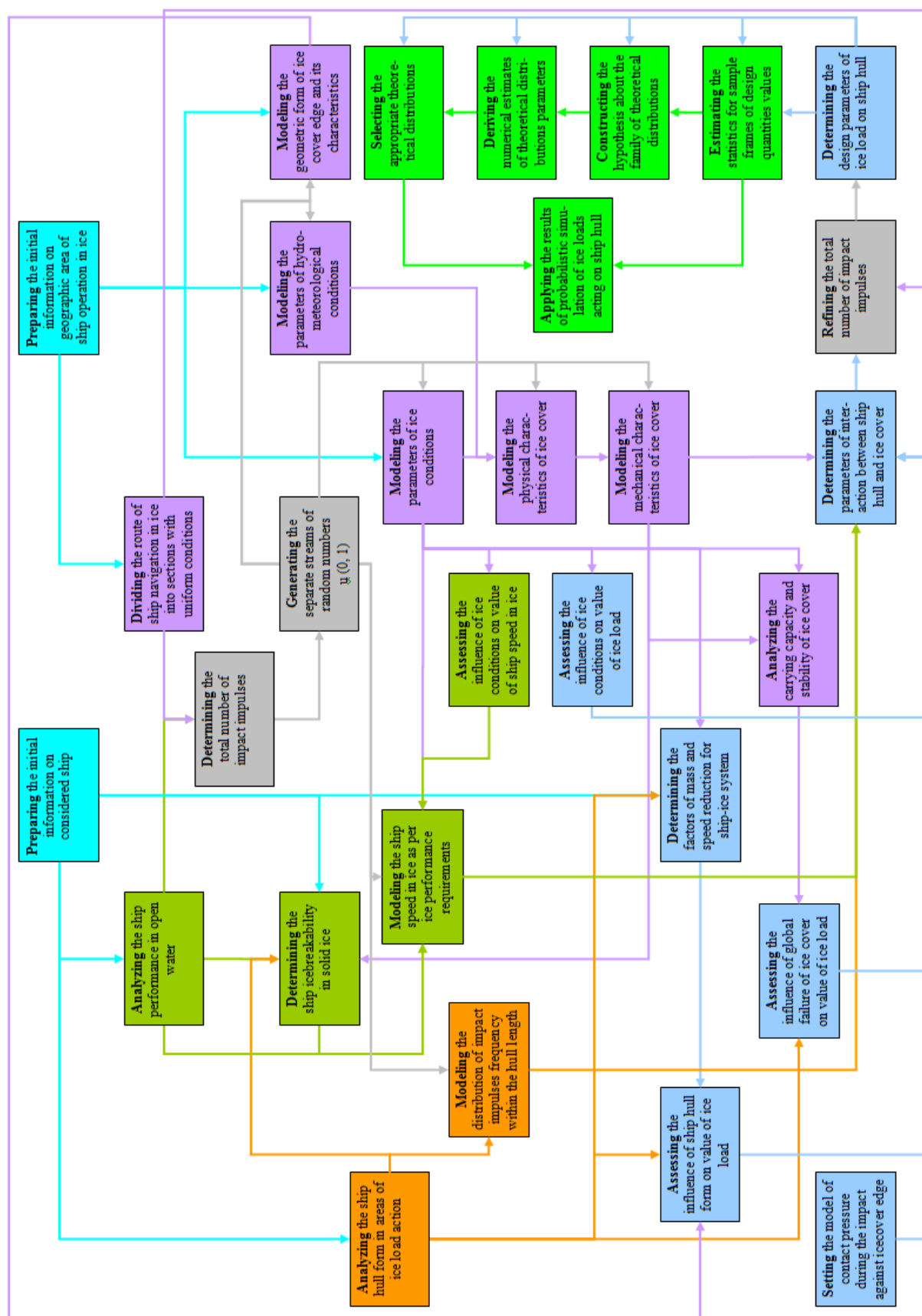


Figure 1. Implementation sequence for probabilistic simulation of ice loads on ship hull

Thus, the final objective of implementing the method for probabilistic simulation of ice loads acting on ship hull involves as follows:

- firstly, to determine on a reasonable basis the appropriate continuous theoretical distributions that appear the closest to the true distributions underlying the obtained results of modeling the design ice load parameters being of stochastic nature;
- secondly, to estimate in an unbiased manner the statistical characteristics for sample sets of random values of design ice load parameters.

The substantiated determination of theoretical distributions should provide for utilization of goodness-of-fit tests to perform the formal statistical check of zero hypothesis as well as for approximation of modeling results with the allowable accuracy.

In the context of modeling, the theoretical distributions (if their application is possible and in the case of their correct selection) have a number of advantages compared to the empirical distributions (Law & Kelton, 2000):

- theoretical distribution “smoothes” the modeling results and furnishes with the information about the general distribution underlying them, regardless of amount for available data;
- theoretical distribution allows to generate the values outside the area of modeling results which is required in the cases where the design characteristics of a process are to a considerable extent defined by probability for occurrence of “extreme” events;
- use of pre-specified form of theoretical distribution for one or another random variable could sometimes be caused by presence of substantiated “physical” reason;
- theoretical distribution constitutes an optimal way to represent the set of values of modeling results that ensures the high speed and low memory consumption for computing machinery;
- theoretical distribution could be changed by means of relatively simple calculation procedures in order to analyze the modeling results.

The fitting of a specific theoretical distribution in an ordinary way involves the implementation of three consecutive stages:

- formulating the hypothesis concerning the appropriate family of theoretical distributions with the use of available preliminary theoretical information about the “nature” of a random variable and various heuristic techniques (including the plotting of bar and block charts, output of summary statistics, etc.);
- deriving the numerical estimates for parameters of theoretical distributions accepted for consideration through the data on sample set of random values of a design variable with the use of moment method and/or maximum likelihood method;
- determining the appropriate (from the accepted for consideration) theoretical distribution that appears the closest to the true distribution underlying the obtained results of modeling a design variable with the use of various graphical procedures (including the plotting of bar charts, cumulative curves, P-P and Q-Q charts, etc.) and goodness-of-fit tests (e.g. Pearson test, Kolmogorov-Smirnov test, etc.).

Following the systematization and analysis of a considerable amount for test results of modeling the stochastic ice loads on ship hull, it is recommended to apply the two-parameter distributions with the domain $x \in (0, +\infty)$ as design continuous theoretical distributions for maximum (peak) values of ice load intensity and linear ice load:

- Weibull distribution

$$f(x) = \alpha \cdot \beta^{-\alpha} \cdot x^{\alpha-1} \cdot \exp[-(x/\beta)^\alpha];$$

$$F(x) = 1 - \exp[-(x/\beta)^\alpha]; \quad (4)$$

- Gamma distribution

$$f(x) = \theta^{-k} \cdot x^{k-1} \cdot \exp[-x/\theta]/\Gamma(k);$$

$$F(x) = \int_0^x f(t)dt; \quad (5)$$

- Lognormal distribution

$$f(x) = \frac{1}{x \cdot \sqrt{2 \cdot \pi \cdot \sigma^2}} \cdot \exp\left[-\frac{(\ln x - \mu)^2}{2 \cdot \sigma^2}\right];$$

$$F(x) = \int_0^x f(t)dt, \quad (6)$$

where $f(x)$ is a density distribution function; $F(x)$ is a cumulative distribution function; $\alpha > 0$ and $k > 0$ are shape parameters for Weibull and Gamma distribution, respectively; $\beta > 0$ and $\theta > 0$ are scale parameters for Weibull and Gamma distribution, respectively; $\sigma > 0$ and $\mu \in (-\infty, +\infty)$ are characteristic parameters for Lognormal distribution.

It should be understood that the range of possible values of a random variable could outspread far in the area of extreme values and go into the infinity in theory, and also be highly extended even when restricting the extreme values, proceeding from the certain physical concerns. Thus, the use of probabilistic methods loses its meaning without considering the so-called “principle for practical assurance”. The essence of stated principle is that the practical realization of a random event is deemed impossible under some, quite low probability for its occurrence. The issue on magnitude of “quite low” probability pertains to the field of standardization, and therefore does not have the unambiguous solution and should be examined in each specific case taking into account a wide range of factors (Ekimov, 1975).

In particular, the principle for practical assurance could be construed with regard to the design of ice strengthened ship hull structures according to the currently valid requirements of the Rules of the Russian Maritime Register of Shipping (hereinafter referred to as the RMRS) as follows. As a guaranteed regulatory level of damageability for hull structures, it was accepted the implementation of separate damages, under complete exclusion of mass-scale damages, for about 5% of structural members out of their total number (i.e. with a probability of approx. 5%) throughout the entire ship service life (Appolonov, 2016). The further noticeable decrease in the given damageability level will require the multiple enhancement of ultimate strength for hull structures which is associated with the unreasonable overweighting of ship hull and appears hardly feasible in practice.

INTERPRETATION OF RESULTS OF MODELING THE STOCHASTIC ICE LOADS ON SHIP HULL

In terms of ice strength, the totality of possible modes of ship motion in ice could be divided into the following three areas:

- area of normal ship operation, or “green” area (marked with 1), including the motion modes in which the form changes and damages of hull structures are almost excluded;
- area of risky ship operation, or “yellow” area (marked with 2), including the motion modes in which the mass-scale damages of hull structures are excluded, but it becomes possible the occurrence of their separate damages with the residual strains (in fact, deflections) not exceeding the allowable values;
- area of ship damageability, or “red” area (marked with 3), including the motion modes in which there are implemented either the mass-scale damages of hull structures or their separate damages with the residual strains (in fact, deflections) exceeding the allowable values.

The boundaries between areas under consideration are set by design modes of ship motion in ice that comprise the allowable motion mode represented as a curve of allowable ship speed (marked with 1) and the dangerous motion mode represented as a curve of dangerous ship speed (marked with 2).

The graphical interpretation for the foregoing with regard to the differentiation of modes of ship motion in ice in terms of ice strength is shown in Figure 2 (Appolonov, 2016).

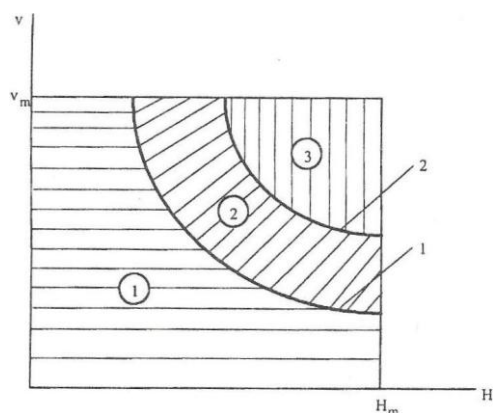


Figure 2. Modes of ship motion in ice in terms of ice strength

The allowable motion mode is traditionally related to the criterion of fiber yielding which corresponds to the initiation of first plastic strains in the structure. The dangerous motion mode is based on combined strength criterion being a compilation for criterion of ultimate strength which defines the transition of structure to the ultimate state and criterion of restricted plastic deformation which defines the formation of separate damage with a certain deflection in the structure. Proceeding from the basic principles for ice strength standardization accepted in the existing national practice, it is provided the following correlation between regulatory ice loads on ship hull and modes of ship motion in ice:

- ice load parameters determined according to the requirements of the “old” Ice Rules of the RMRS (that were in force from 1981 to 1998) conform with the allowable motion mode;
- ice load parameters determined according to the requirements of the “new” Ice Rules of the RMRS (that are in force from 1999 to the present) conform with the dangerous motion mode.

Thus, the direct comparison of modeled random values of design ice load parameters with their regulatory values gives the following practical opportunities:

- firstly, to estimate the regulatory exceedance probability for actual ice loads acting on ship hull during the ship operation in the ice conditions of specified navigation water area and season;
- secondly, to estimate the probability for ship entry into the “green”, “yellow” and “red” areas classified in terms of ice strength (see Figure 2) during the ship operation in the ice conditions of specified navigation water area and season and, as a result, to ascertain the actual level and character of damageability for hull structures.

It is known that the ice load intensity and the linear ice load serve as design (i.e. characteristic) ice load parameters for plating and framing structural members, respectively. Consequently, taking into account both given ice load parameters simultaneously, it is possible to draw the appropriate conclusions concerning the damageability for hull structures of both types.

Certain results of probabilistic simulation of ice loads acting on ship hull that have been obtained according to the developed solution are illustrated in Figure 3 through Figure 6. As a studied object, the Arctic oil tanker with a deadweight of approx. 17 kt was selected. The hull of ship under consideration complies with the currently valid requirements for the Arc5 ice

class as per national ice classification. The description of design mode of ship operation in the ice conditions is cited below, including the following general information:

- water area of ship navigation in ice, which was the traditional navigation lines of the Northern Sea Route located in the Barents Sea and in the East Siberian Sea;
- season of ship navigation in ice, which was April;
- type of ship navigation in ice by severity of ice conditions, which was medium, i.e. conforming with the moderate ice conditions;
- manner (or else tactics) of ship navigation in ice, which was the independent motion;
- trajectory of ship motion in ice, which was rectilinear;
- direction of ship motion in ice, which was ahead;
- condition of ship loading in ice, which was corresponding to the ship draught at the summer load waterline (SLWL).

As design ice load parameters, the maximum (peak) values of ice load intensity and linear ice load were accepted for investigation. Graphically, the modeled random values of both given ice load parameters were represented after their accumulating, grouping and processing as follows:

- in the form of density and cumulative bar charts for empirical distribution received through the data on sample set;
- in the form of density and cumulative functions for recommended continuous theoretical distributions fitted on a reasonable basis.

In the existing national practice, the allowable conditions of ship navigation in ice are established for each Arctic ice class within the framework of appropriate ice classification. Thus, with regard to the Arc5 ice class, the design conditions of ship navigation in ice provided when modeling the stochastic ice loads on ship hull and cited above are treated as allowable during the ship operation in the Barents Sea. However, the same conditions are deemed non-allowable during the ship operation in the East Siberian Sea because it is associated with a high risk of damageability for hull structures under their interaction with the ice cover (RMRS, 2018).

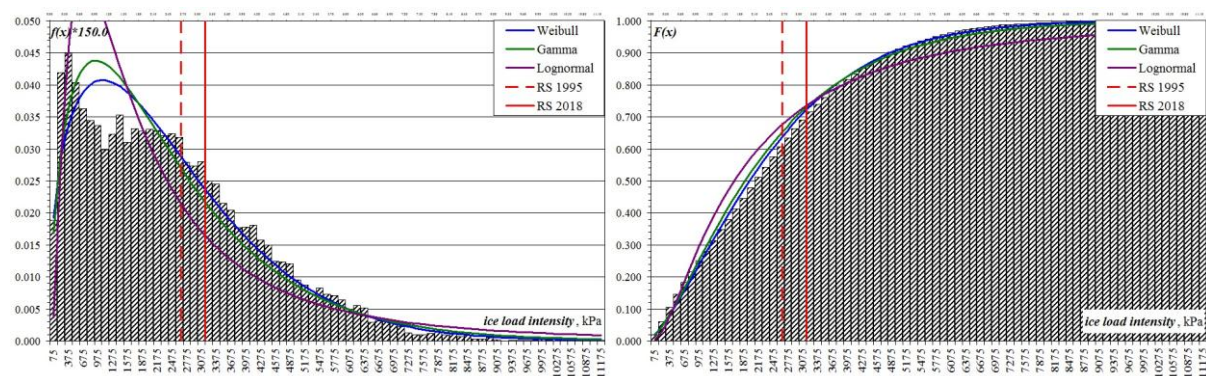


Figure 3. Distribution for maximum (peak) values of ice load intensity during the ship operation in the ice conditions of the Barents Sea: modeled random values ($EV = 2475.4$ kPa; $CV = 0.709$) & regulatory values ($p_{RS1995} = 2649.1$ kPa; $p_{RS2018} = 3148.3$ kPa)

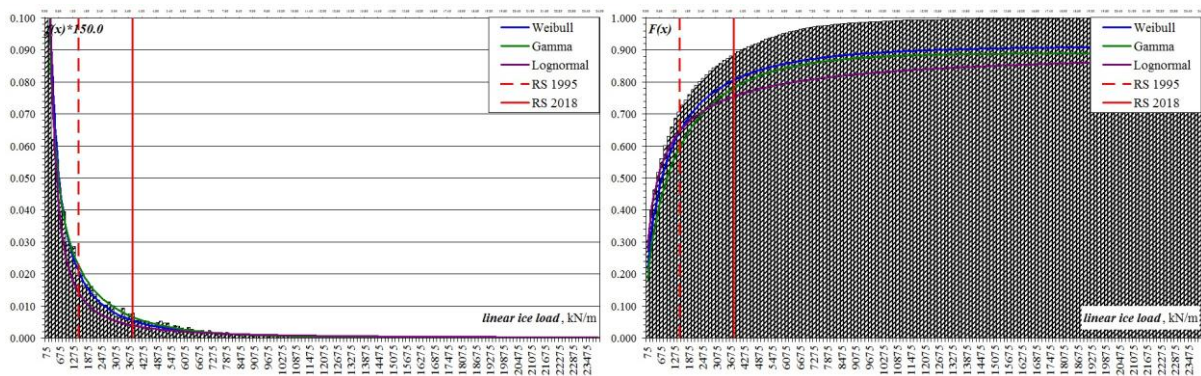


Figure 4. Distribution for maximum (peak) values of linear ice load during the ship operation in the ice conditions of the Barents Sea: modeled random values ($EV = 1452.6$ kN/m; $CV = 1.527$) & regulatory values ($q_{RS1995} = 1462.3$ kN/m; $p_{RS2018} = 3781.1$ kN/m)

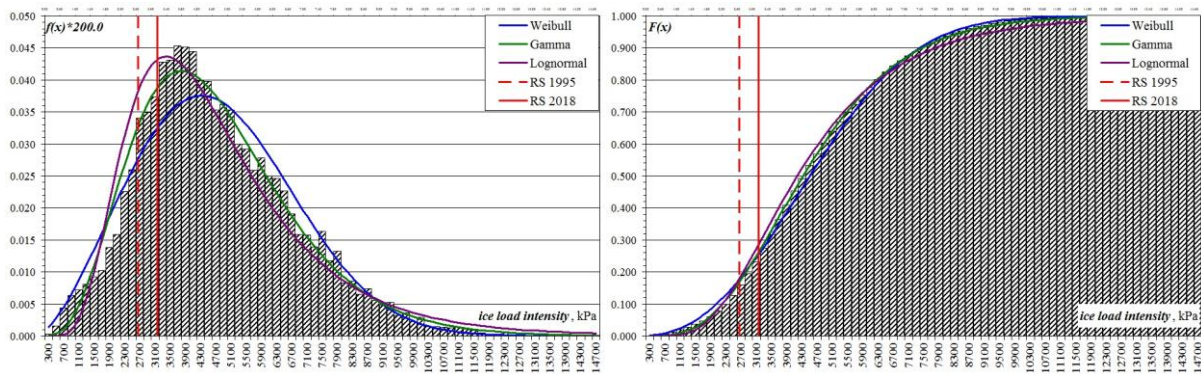


Figure 5. Distribution for maximum (peak) values of ice load intensity during the ship operation in the ice conditions of the East Siberian Sea: modeled random values ($EV = 4733.7$ kPa; $CV = 0.429$) & regulatory values ($p_{RS1995} = 2649.1$ kPa; $p_{RS2018} = 3148.3$ kPa)

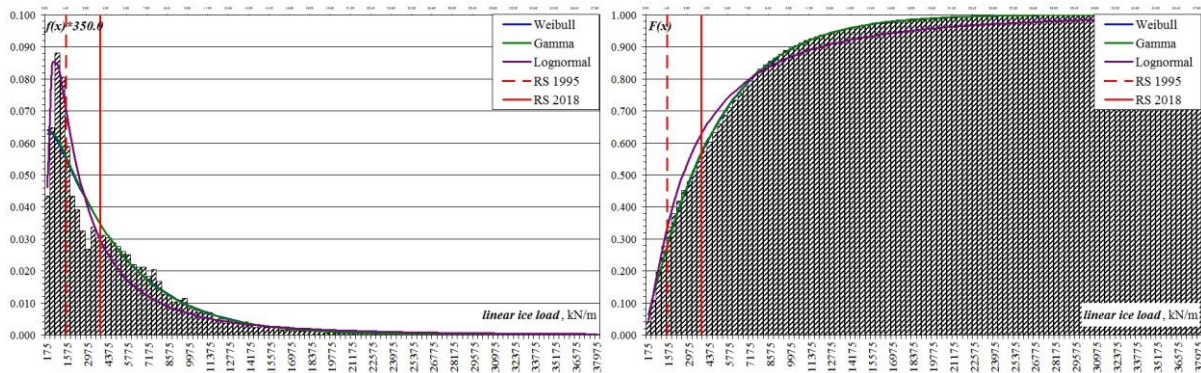


Figure 6. Distribution for maximum (peak) values of linear ice load during the ship operation in the ice conditions of the East Siberian Sea: modeled random values ($EV = 4634.5$ kN/m; $CV = 0.965$) & regulatory values ($q_{RS1995} = 1462.3$ kN/m; $p_{RS2018} = 3781.1$ kN/m)

In qualitative terms, the regulatory statements concerning the feasibility of ship navigation in ice within the specified water areas were to the full extent confirmed following the direct comparison of modeled random values of design ice load parameters with their regulatory values. The numerical values of probability for receiving of ice damages by both plating and framing structural members that were also estimated when considering together the modeling results and regulatory data should be recognized to a sufficient extent overstated compared to the level of damageability for hull structures underlying the ice strength requirements of

national regulatory documentation. The main obvious cause for observed overstating of appropriate probability values involves using the outdated release of special-purpose software to model the stochastic ice loads on ship hull. Prepared in 2012, it does not enable to implement the numerous amendments inserted in the recent years into the theoretical background of studies. The application of updated full-function release of software being under development at the present time will contribute to a sequential elimination of existing quantitative discrepancies and, as a result, completely confirm the adequacy and performability of proposed method for probabilistic simulation of ice loads acting on ship hull.

CONCLUSIONS

In the present article, the following general issues were considered related to researching the external environmental effects on marine infrastructure facilities under presence and influence of random components:

- fundamentals of method for modeling the stochastic ice loads on ship hull based on combination of probabilistic and simulation approaches and developed under direct participation of authors were outlined;
- detailed stepwise algorithm to implement the appropriate modeling process and its flow chart were submitted;
- key aspects of processing, representing and assessing the output data of probabilistic simulation of ice loads acting on ship hull were noted;
- certain results of modeling the random values of design ice load parameters were provided and interpreted applied to the real ice-going ship operating in the ice conditions of specified navigation water area and season;
- practically significant problems within which it is expedient to use the developed solution were formulated.

Based on information cited above, it should be concluded that the introduction of probabilistic simulation concept, together with the application of direct calculation methods, to assess and forecast the ice loads on ship hull will ultimately contribute to a considerable decrease in the damageability level and increase in the safety level for marine transport when operating in ice.

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