Technical developments for safe navigation in arctic waters

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Introduction

Climate statistics reveal that the yearly retreat of arctic ice is rapidly increasing. Due to global warming the arctic summer season has become warmer and longer, and this trend is expected to continue in the future. As a consequence maritime activities can be significantly extended. In the future the Northwest Passage and Northern Sea Route are likely to provide alternative shipping lanes for international trade. Whether or when these routes will become economically viable depends on the climatological developments as well as the availability and price development of fuel oil. The advantage of the arctic routes is that their distance can be up to 50% less than the present used routes via the Suez or Panama Canal. The main disadvantages are the (still) limited amount of ice free days per year, the strongly varying and therefore difficult to predict ice conditions and the technical requirements for ships to enable them to transit this harsh area.

Aside from the potential for new shipping lanes, the increased accessibility of the arctic region has already lead to an increase in regional traffic, which is mostly related to the exploitation of the natural resources in the area. There are large oil and gas reserves and their development is rapidly increasing both onshore and offshore. In addition there are ore mines and related industries, as raw materials and processed metals are exported via the arctic seas (mainly to Europe). The cruise market is also expected to grow, as more people become interested in exploring the natural beauty of the arctic region. On top of that, shipping and offshore activity in the sub-arctic region such as the Baltic Sea and the Okhotsk Sea is also rising, mainly in relation to the oil and gas industry.

In order to facilitate the increasing activity a variety of ships operating in arctic conditions is needed. Associated ship types include oil tankers & FPSOs, gas carriers & FLNGs, dry cargo ships and specialized cruise ships. In addition deep water tugs and platform supply vessels are required to install and support the offshore oil & gas production units, while escort and harbour tugs are essential to assist ships in manoeuvring in confined waters and ports. In order to ensure efficient and safe navigation, ship designs need to fulfill a number of technical requirements regarding hull form, ice strengthening, propulsion power and winterization (measures to ensure the proper functioning of ship borne systems and equipment, as well as safe working conditions for the crew, in cold weather conditions). On top of that, measures need to be taken to minimize the environmental impact of shipping in this highly sensitive marine area.

The selection of the technical requirements depends on the intended service of the ship, the season & location of operation, as well as the applicable national and international regulations in the area of operation. Most of the countries involved have developed their own national requirements and ice class designations, while class societies also have (at least partly) different requirements and class notations. A correct understanding of these different requirements is essential for a successful project, while it needs to be acknowledged that the correspondence between the different approaches is not always easy to find and consequently poses difficulties for ship operators and designers.

Another important issue is that the industry is rapidly moving forward in developing new designs for arctic navigation. Ice breaker independent navigation (often applying the double acting concept) is now common, while the increase in activity generates a tendency towards economy of scale effects and therefore larger ships. In order to facilitate the oil and gas industry the development of new types of arctic offshore units and gas carriers can be observed. Each of these developments has its own technical challenges which are not always covered by the existing regulations (traditionally based on the cumulative experience from the existing arctic fleet). Therefore it is essential that class societies and national authorities are undertaking a review of their standards and amend the regulations to take the present and the expected future developments into account.

As a class society Bureau Veritas has been taking this issue very seriously by setting up an extensive R&D program into arctic navigation. This program is founded on an extensive knowledge base, as it is being executed in close cooperation with leading institutions in arctic shipping, such as Aker Arctic and the St Petersburg State Maritime University. Combined with BV’s extensive knowledge and experience with ice
classed ships and offshore units the program is intended to provide ship owners and designers with valuable guidance for their arctic projects. This guidance will be provided in the form of guidance notes, calculation software (for design and operational purposes) and updated class rules.

The program essentially consists of 4 steps, as shown in Figure 1. The assessment of ice conditions (ice type, distribution, thickness, sea and air temperature distribution) for vessels operating in arctic waters has been completed and is used as input for developing a first principle approach for determining ice loads on the ship’s hull and appendices and the associated ice strengthening, as well as for formulating requirements for the main machinery and propulsion. BV’s recently developed winterization requirements are also under review in order to take into account experience feedback from arctic operation.

Figure 1: Outline of BV’s R&D program on arctic navigation

| 1. Assessment of conditions for vessels sailing arctic waters |
| 2. Hull structure (ice loading and structural response) |
| 3. Main machinery and propulsion |
| 4. Review of BV COLD notation for extreme arctic conditions |

The objective of this paper is to provide an overview of Bureau Veritas’ technical developments with respect to arctic navigation, which provides valuable guidance and information for interested parties, both experienced as well as newcomers.

Following the Introduction section, the section Assessment of arctic conditions will provide an overview of the conditions to be expected, as well as valuable guidance towards applicable rules and regulations and the correspondence between different sets of class and national regulations. The section Rules development provides the latest update with respect to new rules for ice classed ships, including ice breakers. In the section Hull structural assessment a detailed review of ice loading and the associated structural response, based on a first principles approach, will be provided. Useful mathematical models will be presented, as well as calculation software for their practical application. The section Machinery and winterization provides an outline of the key points with regard to the developments on machinery and propulsion systems, as well as winterization issues (including ship stability under ice accretion). Finally the Closure section will provide the main conclusions and recommendations.

Assessment of arctic conditions

To operate in ice conditions, ships need suitable reinforcements relying on the additional class notation assigned for navigation in ice. These additional class notations are divided into two categories:

- Ice Class notations [1];
- Polar Class notations [2].

Both notations provide requirements for hull strengthening and propulsion power, but do not consider any requirements for special fittings and equipment, which are covered by the COLD notation [3].

Ice Class notations range decreasingly from ICE CLASS IA SUPER to ICE CLASS IC, and are based on Finish-Swedish Ice Class Rules [4]. They are appropriate for first-year ice conditions, which mean that the ice is accumulated during one winter season. These conditions are typical of the Baltic Sea or the Saint Lawrence Gulf. In addition to the above notations, ICE CLASS ID can be assigned to ships operating in areas where first-year ice conditions are such that strengthening of the fore region, rudder and steering arrangements is deemed sufficient.

Polar Class notations range decreasingly from POLAR CLASS 1 to POLAR CLASS 7 and are based on IACS Unified Requirements concerning Polar Class [5]. They are appropriate for arctic ice conditions, which can vary from thick first-year ice to multi-year ice.

An overview of the equivalency between Bureau Veritas Ice Class and Polar Class notations and regulations issued by the Canadian authorities, the Russian Maritime Register of Shipping and the Finnish Maritime Administration is shown in Table 1. It is of importance to note that equivalency between ice classes are approximate and provided for informative purposes, but are not officially recognized (differences might appear depending on the chosen criteria for comparison). The only officially recognized equivalencies are
denoted in bold characters and concern the recognition of the equivalence of the Bureau Veritas Ice Class notations by the Finnish and Canadian authorities, as well as the equivalence between the 1972 and 1995 Canadian Arctic Classes.

Table 1: Equivalence table with Bureau Veritas Ice class and Polar class notations

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Year-round operation in all polar waters</td>
<td>&gt; 3.0 m</td>
<td>–</td>
<td>PC 1</td>
<td>Arctic Class 10</td>
<td>CAC 1</td>
<td>Arc 9</td>
<td>–</td>
</tr>
<tr>
<td>Year-round operation in moderate multi-year ice conditions</td>
<td>3.0 m</td>
<td>–</td>
<td>PC 2</td>
<td>Arctic Class 8</td>
<td>CAC 2</td>
<td>Arc 8</td>
<td>–</td>
</tr>
<tr>
<td>Year-round operation in second- year ice with old ice inclusions</td>
<td>2.5 m</td>
<td>–</td>
<td>PC 3</td>
<td>Arctic Class 6</td>
<td>CAC 3</td>
<td>Arc 7</td>
<td>–</td>
</tr>
<tr>
<td>Year-round operation in thick first-year ice which may contain old ice inclusions</td>
<td>&gt; 1.2 m</td>
<td>–</td>
<td>PC 4</td>
<td>Arctic Class 3</td>
<td>CAC 4</td>
<td>Arc 6</td>
<td>–</td>
</tr>
<tr>
<td>Year-round operation in medium first-year ice with old ice inclusions</td>
<td>1.2 m - 0.7 m</td>
<td>IAS</td>
<td>PC 5  PC 6</td>
<td>Type A</td>
<td>Type A</td>
<td>Arc 5</td>
<td>IAS</td>
</tr>
<tr>
<td>Summer / autumn operation in thin first-year ice with old ice inclusions</td>
<td>0.7 m</td>
<td>IA</td>
<td>PC 7</td>
<td>Type B</td>
<td>Type B</td>
<td>Arc 4</td>
<td>IA</td>
</tr>
<tr>
<td>First-year ice</td>
<td>0.5 m</td>
<td>IB</td>
<td>–</td>
<td>Type C</td>
<td>Type C</td>
<td>Ice 3</td>
<td>IB</td>
</tr>
<tr>
<td>First-year ice</td>
<td>0.4 m</td>
<td>IC</td>
<td>–</td>
<td>Type D</td>
<td>Type D</td>
<td>Ice 2</td>
<td>IC</td>
</tr>
<tr>
<td>Open sea with ice floes</td>
<td>–</td>
<td>ID</td>
<td>–</td>
<td>Type E</td>
<td>Type E</td>
<td>Ice 1</td>
<td>II</td>
</tr>
</tbody>
</table>

Navigation in the Canadian Arctic is very tough during the winter and a high degree of ice reinforcement is required in order to navigate at high latitudes during the harshest periods of the year. Other challenges concern the fact that charting is still uncertain in some parts of the Canadian Arctic and that, as a consequence of the global climate change, milder seasons in the Northwest Passage will lead to an increase in occurrence of icebergs and multi-year ice in main navigation routes. Table 2 presents a brief overview of the conditions that can be encountered in the Canadian Arctic during the winter. The figures reflect approximately the harshest conditions that can occur, but they are not to be used to a design purpose as they do not reflect the local extreme values.

The selection of the adequate additional class notation in the Canadian Arctic is guided by an extensive set of regulations. There are actually two systems that can be used by ships sailing in the Canadian Arctic: the Zone-Date System and the Ice Regime Shipping System. The former is extensively described in Arctic Waters Pollution Prevention Act [4], and consists in a division of the Canadian Arctic in 16 zones where ships are allowed to sail at certain dates depending on their level of ice reinforcements. This system is very explicit, but a main drawback is that this it does not allow a ship to sail outside the scheduled period, even if the conditions are milder than expected. This has led Canadian Authorities to set up an alternative system called the Arctic Ice Regime Shipping System [10]. The principle relies on a basic calculation, which depends on the real ice conditions in the area of operation, to assess whether a ship is allowed to sail or not. This system is more sophisticated because it takes into account the real ice conditions, but the drawback is that it implies to have on board an ice navigator with the proper qualifications and experience.

Traffic in the Russian Arctic is slightly more developed than in the Canadian Arctic although conditions are rather similar, see Table 3. Here again those figures reflect approximately the harshest conditions that can occur during the winter. The legislation to be followed is very different depending on whether the ships are to
enter the Northern Sea Route (NSR) or not. The boundaries of the NSR are marked by the island of Novaya Zemlya on the western side and the Bering Strait on the eastern side. Basically, the Northern Sea Route can be seen as a system of routes – depending on the instantaneous ice conditions – passing through the Kara Sea, Laptev Sea, East Siberian Sea and Chukchi Sea.

Table 2: Meteorological conditions in the Canadian Arctic

<table>
<thead>
<tr>
<th>Location</th>
<th>Ice season</th>
<th>Ice thickness</th>
<th>Ridges</th>
<th>Icebergs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaufort Sea</td>
<td>October – July</td>
<td>180 cm (FY) 320 cm (MY)</td>
<td>5-15 ridges/km 10-15 m high</td>
<td>rarely</td>
</tr>
<tr>
<td>Baffin Bay</td>
<td>October – August</td>
<td>160 cm (FY) 280 cm (MY)</td>
<td>–</td>
<td>&gt; 2000/year 12 months present</td>
</tr>
<tr>
<td>Davis Strait</td>
<td>October – August</td>
<td>160 cm (FY) 280 cm (MY)</td>
<td>–</td>
<td>&gt; 2000/year 12 months present</td>
</tr>
<tr>
<td>Canadian Arctic Archipelago</td>
<td>October – August</td>
<td>220 cm (FY) 350 cm (MY)</td>
<td>15-20 m high</td>
<td>few/year 12 months present</td>
</tr>
<tr>
<td>Greenland</td>
<td>January – May</td>
<td>50 cm (FY) 200 cm (MY)</td>
<td>–</td>
<td>12 months present</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>January – May</td>
<td>80 cm (FY) 200 cm (MY)</td>
<td>6 m high</td>
<td>450/year April to July</td>
</tr>
<tr>
<td>Labrador coast</td>
<td>December – July</td>
<td>100 cm (FY) 150 cm (MY)</td>
<td>10 m high</td>
<td>1000/year 12 months present</td>
</tr>
</tbody>
</table>

* FY: first-year ice; MY: multi-year ice

Table 3: Meteorological conditions in the Russian Arctic

<table>
<thead>
<tr>
<th>Location</th>
<th>Ice season</th>
<th>Ice thickness</th>
<th>Ridges</th>
<th>Icebergs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barents Sea</td>
<td>all year</td>
<td>150 cm (FY) 250 cm (MY)</td>
<td>–</td>
<td>50/year January to June</td>
</tr>
<tr>
<td>Pechora Sea</td>
<td>November - July</td>
<td>100 cm (FY)</td>
<td>5-10 ridges/km 10 m high</td>
<td>rare</td>
</tr>
<tr>
<td>Kara Sea</td>
<td>November - September</td>
<td>160 cm</td>
<td>5-10 ridges/km 12 m high</td>
<td>–</td>
</tr>
<tr>
<td>Laptev Sea</td>
<td>October - July</td>
<td>200 cm</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>East Siberian Sea</td>
<td>October - August</td>
<td>140 cm</td>
<td>5-10 ridges/km 12 m high</td>
<td>–</td>
</tr>
<tr>
<td>Chukchi Sea</td>
<td>October - June</td>
<td>140 cm (FY) 230 cm (MY)</td>
<td>5-10 ridges/km 10-15 m high</td>
<td>–</td>
</tr>
</tbody>
</table>

* FY: first-year ice; MY: multi-year ice

To navigate through the Northern Sea Route authorization is to be requested from the Ministry of Transports at least four months in advance. The full regulations for icebreaker assistance and ice pilotage in the NSR are included in the publication Guide to Navigating through the Northern Sea Route. This guide incorporates the following regulations, in force in the NSR [11]:

- Regulations for Navigation on the Seaways of the NSR;
- Regulations for Icebreaker-Assisted Pilotage of Vessels on the NSR;
- Requirements for Design, Equipment and Supply of Vessels Navigating the NSR.

Depending on the experience of the Master and officers with navigating in ice, ships may be required to have on board an ice pilot. The Ice Passport, or Ice Certificate, issued by The Arctic and Antarctic Research Institute (AARI) or the Central Marine Research & Design Institute (CNIIMF) is also compulsory for ships navigating the Northern Sea Route.

Ice conditions for the Baltic Sea are outlined in Table 4. They are much milder compared to the arctic seas, but show a large variation between the years.
Table 4: Meteorological conditions in the Baltic Sea

<table>
<thead>
<tr>
<th>Location</th>
<th>Ice season</th>
<th>Ice thickness *</th>
<th>Ridges</th>
<th>Icebergs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bothnian Sea</td>
<td>January - April</td>
<td>30 cm (FY)</td>
<td>4 ridges/km</td>
<td>4 m high</td>
</tr>
<tr>
<td>Bothnian Bay</td>
<td>December - May</td>
<td>70 cm (FY)</td>
<td>4 ridges/km</td>
<td>6 m high</td>
</tr>
<tr>
<td>Gulf of Finland</td>
<td>December - May</td>
<td>70 cm (FY)</td>
<td>4 ridges/km</td>
<td>5 m high</td>
</tr>
</tbody>
</table>

* FY : first-year ice

The regulation of traffic is done by means of restrictions issued by the authorities at certain dates, which are based on the real ice conditions. When restrictions occur they are usually raised and lowered gradually, especially in the Bothnian Bay and Gulf of Finland. The restrictions consist typically of a minimum required ice class plus a requirement concerning the propulsion power or the ship’s deadweight. Traffic restrictions are accessible through the internet on the Baltic Icebreaking Management website [12].

The objective of this system is to limit the number of ships with inadequate ice reinforcements and/or propulsion power in order to ensure efficient ice breaking services to all ships sailing towards and from the ports in the Baltic Sea during the winter. The aim is for ships to transit the ice independently as much as possible and that the icebreakers provide assistance mainly to ships stuck in ice or in difficulty. The different national administrations are responsible, in their own regions, for the transit and the icebreaking assistance of ships through ice. It is expected that the masters of ships transiting the ice are familiar and experienced with the navigation in ice with icebreaker assistance and pilotage is not compulsory.

**Rules development**

The worst expected ice condition for the proposed service of the vessel is the main parameter of influence for the selection of the ice class notation, but local legislation also has an influence. Bureau Veritas has published a Guidance Note (NI 543) that provides an overview of the ice conditions to be expected in the Canadian Arctic, Russian Arctic and Baltic Sea, as well as the corresponding BV and national ice classes and associated legislation. That will help ship owners, shipyards and designers planning arctic ventures to choose the appropriate level of ice reinforcement, propulsion power and winterisation.

Revision and harmonisation of ice classes is an important issue within IACS, as well as for the administrations concerned. BV actively participates in various working groups inside and outside the IACS. Work is being done on the revision of the IACS Unified Requirements concerning Polar Classes (especially UR I2), where a working group is tasked with the development and validation of rule amendment proposals on the basis of the list of possible improvements to UR I2. Among the different tasks treated by the project teams, BV is involved in the improvement of criteria for icebreakers, guidance on double-acting vessels, the criteria for quantitative welding, the definition of frame span and the requirements for engine output. BV also participates in the revision of the Finnish-Swedish Maritime Administration regulations concerning ice classes.

**Hull structural assessment**

The existing ice class and polar class regulations are the result of in-service experience with ships operating in ice and model experiments with existing designs. As described in the introduction, new ship types and propulsion systems, as well as larger ships are being introduced in the arctic. As there is little experience with these new ships and systems, it is difficult to assess the adequacy of the existing regulations. Therefore, the development of first principle strength assessment methods for ship structures under ice loading is needed to assess the novel designs and validate simplified rules. This section describes such method, as well as a practical application.

Ice navigation is closely associated with the risk of ship damage due to collision with the ice objects such as ice floes, ridges, icebergs etc. Every region is characterised by its own ice type, ice conditions and consequently its own ice collision scenario. Application of modern ice monitoring equipment and icebreaker assistance can reduce or diminish the risk of iceberg collision or ship damage during navigation in severe
ice conditions. Therefore, the most common hazard for ice class ships in any region of navigation is shipping in ice fields or among ice floes.

The analysis of ice navigation experience allows the selection of the most typical ice-ship interaction scenarios, which are shown in Table 5 and Figure 2. The ice-ship interaction scenarios represented in Table 5 are described by the mathematical model developed within the teamwork of Bureau Veritas and The St Petersburg State Marine Technical University. The mathematical model enables the determination of the ice load affecting the ship's hull during ice navigation. The basis of this mathematical model is the interaction of the ship’s hull and the ice floe, which is considered as an oblique non-central impact. The non-central impact can be transferred into a central impact by means of reduction coefficients of masses and speeds [13].

Table 5: Ice load scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Contact region</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glancing impact</td>
<td>Bow, shoulder</td>
<td>Moving in broken ice</td>
</tr>
<tr>
<td>Glancing impact</td>
<td>Midbody</td>
<td>Moving in channel, manoeuvring</td>
</tr>
<tr>
<td>Reflected impact</td>
<td>Bow, shoulder</td>
<td>Moving in broken ice</td>
</tr>
<tr>
<td>Icebreaking</td>
<td>Stem, bow, stern</td>
<td>Moving in ice field</td>
</tr>
</tbody>
</table>

Figure 2: Glancing and reflected impact (a), Ahead icebreaking (b), Astern icebreaking (c) & Moving in a channel (d)

Experiments of solid body impact against ice, conducted by Russian scientists, have revealed the existence of an intermediate layer in the contact zone between the ice and the object, as shown in Figure 3. The intermediate layer has both viscosity and plasticity properties.

Figure 3: Model of ship-ice interaction
The analysis of experiment data and solution of ship motion equation (1)

\[ M_v \frac{dv}{d\zeta} + \int p dA = 0 \]  

makes it possible to obtain expressions for the contact ice pressure \((p)\), the linear intensity of ice load \((q)\), contact force \((P)\) and vertical distribution of ice pressure \((b)\), see Figure 4. The values of these parameters depend on the ship speed \((v)\), the reduction mass \((M_v)\), which is characterized by ship and ice floe masses as well as impact direction, the hull shape form \((F)\), which depend on the angle of frame and waterline inclination at the point of impact and some physical \((a)\) and mechanical ice properties \((f)\).

Figure 4: Schematic view on contact area between ship and ice

The strength of a ship’s side structure (considered as a grillage) depends on the structural layout, scantlings of structural members and material properties, and does not depend on the ship’s mass, speed and the thickness and strength of the ice. Under these premises the hull strength cannot be assessed from the ice load point of view. Therefore, a connecting set of common parameters for ship structural strength and ice loads needs to be established, which quite naturally encompasses the contact pressure and the height of the contact area.

The design allowable strength of side structures \((\sigma=\sigma_{all})\) can be achieved by various combinations of ice pressure and height of contact zone. Therefore, the strength of ship’s hull structure and the parameters characterising the navigation conditions can be associated by the following set of equations (2), (3) and (4):

\[ p = p(b | \sigma = \sigma_{all}) \]  
\[ p = p(v,F,M_v,a,f) \]  
\[ b = b(v,F,M_v,a,f) \]

As mentioned above, the main parameter influencing the choice of a vessel’s ice class and consequently the level of ice reinforcement is the ice thickness \((H)\). Equating the vertical projection of the total contact force and the ice flexural failure force defined by (5)

\[ P = m \sigma_{ice,max} H^2 \]  

yields expression (6)

\[ p = p(b | H = \text{const}) \]

The curves \(p = p(b | H = \text{const})\) intersect the curve \(p = p(b | \sigma = \sigma_{all})\) as depicted in Figure 5. The intersection points correspond to points where the ship structural strength is equal to the ice crushing load with ice thickness \(H_1, H_2\) and \(H_3\). With increasing ice thickness \((H_1<H_2<H_3)\), the intersection points shift to an area of lower contact pressure \((p_1>p_2>p_3)\) and higher size of contact area \((b_1<b_2<b_3)\). Therefore, for every value of the ice thickness there exists a point where the ship structural strength is equal to the ice crushing load, providing the maximum allowable ice thickness for a given structural strength.

The solution of the system of equations (2) to (5) allows estimating not only the safe ice thickness for the ship’s hull, but also enables to calculate the safe speed of the vessel corresponds to the design strength.

The mathematical model of ice load estimation has been programmed in the in-house developed software IceSTAR, as shown in Figure 6. The IceSTAR software is intended for direct calculation of ice loads, taking into account ship-ice interaction scenarios represented in Table 5 and Figure 2. The software is very flexible, as it is capable of determining the ice loads acting at any location on the ship’s hull, while existing rules only
define the ice load acting on the lower part of the ship's hull as a percentage of the ice load acting on the level of the summer waterline. In the case of non-standard hull forms, IceSTAR provides a more accurate estimation of the ice loads.

The first type of calculation which can be performed by IceSTAR concerns to the ice load on the ship for the following ice navigation types:
- Ahead;
- Ahead with gyration;
- Astern;
- Astern with gyration.

The analysis of ship's hull form, ice characteristics and design conditions for operation enables the calculation of the ice pressure, linear intensity of the ice load, the contact force and the vertical distribution of ice pressure, see Figure 7.

The second type of calculation is determination of allowable speed curves, see Figure 8. Taking into consideration the input data of ship's hull structural strength, the ship's operational data (displacement, speed, etc.) and selected ice properties, the software calculates the safe speed of the vessel which corresponds to the given ice thickness and ice strength.

Output data of ice load calculations – in terms of pressure loads – can be transferred and analyzed by finite element method, which allows to carrying out more accurate estimation of the strength characteristics of the ship operating in ice conditions. Examples of such calculations are provided Figure 9, showing a non-linear finite element calculation for a product tanker (application of large deflection theory & non-linear material behaviour), and Figure 10, concerning the analysis of the deflection of the inner hull under accidental ice loading (ice floe collision), which is a critical factor for the safety of the LNG containment system.
Figure 7: Ice load parameters distribution along the hull of tanker: ahead and astern navigation

Distribution of ice load parameters along the ship hull during ahead navigation

Distribution of ice load parameters along the ship hull astern during

Figure 8: Allowable speed curve
Machinery and winterization

In addition to the Ice Class and Polar Class notations, which are largely dealing with structural reinforcements to withstand the ice pressure on the hull, machinery and winterization issues need to be addressed in order to navigate safely in ice and cold weather. The Bureau Veritas class notation COLD specifically deals with winterization issues such as steel quality of structures exposed to low air temperatures, ship stability under ice accretion, climatization of compartments containing engines, auxiliary & HVAC systems, de-icing & heating systems, de-icing devices and operation of deck machinery and equipment under low air temperatures. After having worked with the COLD notation for some years, the experience gained and newly obtained insights will be used to review the requirements of the notation for extreme arctic conditions.

Bureau Veritas' research program aims to generate ice load formulations for pod propulsors, commonly used in double-acting ships. In order to do so, ice loading scenarios have been developed in cooperation with Aker Arctic [15]. The severity of these ice load scenarios depends on a number of factors:

- Ice types found in the geographical areas of operation;
- Operational strategy and safety culture of the operator;
- Available technical means on board for detecting ice formations during poor visibility and receiving ice charts and real time ice condition related information.

For every ice type the ship’s attainable maximum speed and practical speed limit – taking into account prudent navigation using modern ice surveillance technology and good seamanship – are defined for both the astern and ahead operations, which are based on experience with full scale testing. Taking these considerations into account, a table of ice load scenarios for pods in both ahead and astern operations has been created. The basic scenarios consider both longitudinal and transverse load cases and assess the probability of occurrence of each load case. Load cases with low probability of occurrence are considered as extreme single events which determine the strength of the propeller blades, hull structure and supporting brackets. Load cases with high probability if occurrence, such as dynamic impact and milling loads, cause cyclic loading and may cause fatigue issues. An example of a typical load case is shown in Figure 11.
Closure

The increase of the annual ice retreat and the discovery of large oil & gas reserves in the arctic region open up growth possibilities for shipping and offshore activities in this challenging part of the world. In order to protect crews, ships and the sensitive arctic marine environment, good understanding of the challenges posed by navigating in ice and extremely cold conditions is essential. Key issues are ice reinforcement of the hull structure, ship hullform and engine power, robustness of propulsion machinery, winterization of ship borne equipment and, maybe above all, good knowledge and experience of crews navigating in ice.

Class societies have extensive experience with ice navigation and rules and regulations dealing with ice classed ships are since long available. At the same time concerned national authorities, such as Russia, Canada and Finland, also issue requirements which need to be complied with when navigating in areas under their jurisdiction. Good understanding of the applicable requirements, as well as the equivalency and differences between the different sets of class and statutory requirements is essential for a successful arctic shipping project. To this end Bureau Veritas has issued the Guidelines on the ice reinforcement selection in different world navigation areas (NI 543), providing comprehensive insight in the background and application of relevant class and national regulations. Specific attention is paid to the equivalence between class and national ice class notations.

BV is actively participating in international working groups concerning the development of rules and regulations. An important project is the revision of the IACS Unified Requirements concerning Polar Classes (especially UR I2), where BV is working on icebreakers, double-acting vessels and requirements for welding and engine output. BV is also participating in the revision of the ice class regulations of the Finnish and Swedish Maritime Authorities.

With the introduction of new ship types and larger vessels in ice conditions, Bureau Veritas acknowledges the need for further development of existing class and statutory rules and regulations to ensure adequate safety in areas with little in-service experience. Therefore an extensive R&D program has been launched to assess the applicability of existing rules and develop advanced analysis methods and tools for ice navigation. The main areas of focus are hull structural reinforcement, machinery and winterization requirements. In cooperation with St Petersburg State Marine Technical University a methodology for a first principle based assessment of ice loads on the ship’s structure has been developed. Application of the method allows a rational and detailed assessment of the loads to be expected in pre-defined ice conditions.
The results can be used to determine the required extent of ice reinforcement of the hull structure. At the same time the methodology can be inversely applied. That is, given the ship's hull structural strength, the safe speed in different ice conditions can be determined. Comprehensive and efficient application of the methodology has been achieved by the development of the software IceSTAR.

The hull loads calculated with the IceSTAR tool can be easily transferred to a finite element model to verify the adequacy of the hull structure. To this end, BV technical specialists have extensive experience with direct strength assessment methods, including non-linear mechanical behaviour.

The final stage of the R&D project concerns machinery and winterization requirements. In cooperation with Aker Arctic a deep analysis of the different ice loading scenarios for pod propulsors has been performed, which enables the derivation of the associated load and consequently strength requirements. Based on the experience gained since the introduction of the COLD notation, the requirements will be re-assessed and updated for application to extreme arctic conditions.

As a result of the developments described in this paper Bureau Veritas is actively contributing to reducing risks associated with ship operations in arctic conditions, therewith enhancing the level of safety of crew, ship, cargo and the natural environment.

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