TECHNICAL CHALLENGES ASSOCIATED WITH ARCTIC LNG DEVELOPMENTS:
A CLASS SOCIETY APPROACH

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ABSTRACT

With its footprint found throughout the LNG chain and one which can be traced back to the very earliest beginnings, Bureau Veritas has an unparalleled knowledge and experience of the LNG industry. As the industry has developed, Bureau Veritas has been found at the forefront of these developments and with the Arctic being the next major frontier to be conquered we are understandably focusing our attention on the issues linked with the development of Arctic LNG exploration and the associated shipping needs and ensuring that our rules, technical standards and software are adapted and developed accordingly.

There are a number of challenges for operation in extreme climates which need to be considered and overcome, such as low temperatures, ice, specific natural conditions and the vulnerable eco-system, all of which will impact in some way the design and operation of LNG carriers in these regions and provide specific technical challenges which need addressing.

The paper considers the technical issues, discuss the studies which should be performed and the tools and methodologies which can be used to validate Arctic LNG carrier designs and the associated technology, whilst providing feedback and return of experience gained from specific projects we have been involved in.

1. INTRODUCTION

The global warming and the reduction of the ice sheet in the Arctic Ocean have some consequences as increase accessibility to:

- Natural resources as Oil and Gas. For example, the reserve of Oil & Gas in Arctic regions are estimated to about one quarter of the world proven resources,
- Some maritime routes which were very difficult to operate, leading to reduction of distances. For example, the route from Rotterdam to Yokohama should be reduced from 11250 miles to 7350 miles by using the Northern Sea Route

However, operate in the Arctic regions and his extreme climates and conditions leads to challenges. Some of these challenges are listed hereafter:

- Cold temperature difficult for personnel, equipment, structures…
- Ice sheet covering the sea,
- Icebergs,
- Polar Night,
- Extreme environment with severe storms,
- Distance to supporting basis,
- Environment extremely sensitive to emissions and pollution…

During the last years Bureau Veritas was involved in several projects of Offshore (Barents Sea) and LNG carriers (Kara Sea) intended to operate in Arctic environment.

This paper presents some work of verification carried out during these projects.
2. CLASS RULES FOR ARCTIC

Bureau Veritas has a set of rules for the Classification of steel ships and for the Classification of Offshore Units. In addition to these general rules, Bureau Veritas has developed guidelines and Rules notes which are complementing the rules. The main rules concerning Arctic are briefly described hereafter.

- Ice Class Rules (Rules for steel ships, Part E, Ch. 8 - NR467.E2 DT)
  The Rules and regulations for steel ships (see Part E, Chapter 8) propose Ice Class notations from Ice Class IA super to Ice Class ID which are aligned with the Finish Swedish Ice Class. These Ice Class Rules are suitable for first year ice typically the ice of the Baltic Sea.

  The Finish Swedish Ice Class has several years of experience in service and has become a standard for the industry.

- NR 527 DT R01 E: Rules for the Classification of POLAR CLASS and ICEBREAKER Ships.
  In 2005, IACS published Unified requirements I1, I2 and I3 concerning unified Polar Class Rules (PC Rules).

  In addition to conventional Ice Class Rules, the Unified Requirements I1, I2 and I3 were published in the Rule Note NR 527.

  The Polar Class notations are suitable for environment from first year ice to multi year ice.

  The following figure provides the area of hull reinforcement for Polar Class Rules.

  ![Figure 1: Polar Class Rules, Area of Reinforcement of the Side Shell](image)

  Ice Class as Polar Class Rules require both hull reinforcements in different hull areas and also a minimum propulsion power.

- Cold notation (Rules for steel ships, Part E, Ch. 10, Sec. 11 - NR467.E2 DT):
  The COLD (H \( t_{DH}, E \ t_{DE} \)) notation provides requirements to deal with low ambient temperatures, frozen spray (ice accretion) and reduced effectiveness of components.

  The cold temperature is the first particularity of the Arctic environment. The minimum temperature measured on the earth was about -90°C. But it was measured onshore, far of the seas. Offshore, the temperature, despite thick ice sheet, cannot be so low. It is generally not less than -50°C for long periods. The colder
temperatures on sea are generally measured close to the coast, or in the harbours. However, for temperature of about -50°C, ships are to be designed according to the COLD notation.

The following items are covered by the COLD notation:
- Material class and grade selection for low air temperatures on exposed area,
- Stability with accretion of ice,
- De-icing including Ballast tank de-icing,
- Propulsion and other essential services (e.g. firefighting, lifesaving, mooring equipment, cargo equipment particularly when located on exposed deck)
- Electricity production,
- HVAC,
- Crew protection and elimination of ice where necessary for safe access
- Heating systems…

3. GUIDELINES

Several guidelines have been developed to provide information to the ship designers and the ship owners. Most of these documents were developed in relation with recognized Institutions from different countries in the world such as Russia, Finland, Canada.

We present hereafter the main guidance notes developed for Arctic operations.

- **NI 543 DT R00 E: Ice reinforcement selection in different world navigation areas (Jan 2009)**
  This note aims at helping yards, owners and designers to understand the applicable local authority requirements, concerning Ice Class on the different seas of the world. The correspondence between the different sets of class and statutory requirements, which is essential for an Arctic project, are covered in the document.

- **NI 565 DT R00 E: Ice Characteristics and Ice/Structure Interactions (Sept 2010)**
  Based on the ISO and API standards, this guidance note proposes simple formulas for the determination of the ice induced pressure on the hull. The hull scantlings of the hull and structures may be assessed to resists against this pressure.

- **NI 584 DT R00 E: Propulsors in ice**
  Guidelines for the design of the Propulsors in ice were published in 2012. This note provides information for the design as interaction with ice, including ice scenarios, recommendations for materials, the machinery and electrical installations.

4. RISK ANALYSIS

During the last years, several risk analyses were carried out to assess the risk of Offshore platforms operations and LNG transportation in the Arctic environment.

There are many technical concerns to address during the design of an Arctic LNG Carrier, related to hull deformation on LNG cargo containment system (CCS) integrity, fatigue strength for extreme wave environments and winterization.

Involved in the early design stage of different Arctic LNG projects, Bureau Veritas participated to different Hazard Identification (Hazid) workshops to ensure that all hazards were identified for each project and where existing safeguards were deemed inadequate or insufficient, actions for improvements and necessary studies were suggested for the next phases of the project.
One Hazid workshop, called a Marine Hazid, focused on the West part of the Northern Sea shipping routes and scrutinized hazards likely to occur during an LNG Carrier navigation in open sea water partially under ice conditions with or without icebreaker assistance, during her transit in ice channels, during her berthing and anchoring in port and during LNG loading at a jetty with possible simultaneous activities. The impacts of the natural, environmental and manmade hazards on the LNG Carrier operations were assessed as well as the impacts of the LNG Carrier operation on the surroundings, on the personnel safety, the environment, asset damage and the reduction or loss of ship operation. This workshop led to the issuance of 100 recommendations, half of them requiring the implementation of technical solutions.

Another Hazid workshop was performed to assess the basic design of a 170,000m³ Arctic LNG Carrier fitted with a membrane type CCS during her transit and loading operations in Arctic waters. The main areas and equipment of the Arctic LNG Carrier which were studied were Hull & Stability (Cargo tanks, Hull structure, Ballast tanks, Cofferdams), Exposed Cargo Deck (piping systems and supports, valves, vent masts, control & instrumentation, water curtain system, drip trays, Cargo Compressor / Electric Motor Rooms, Fire & Gas detection, deck water spray system, dry powder), Machinery Systems (propulsion, air intakes, sea inlets, overboard discharges at sea) and other exposed decks and superstructures (emergency power, escape routes, life boats & rafts, davits, navigation & communication equipment, anchoring & mooring equipment).

The assessment of different hazards, such as extreme weather (e.g. air and sea water temperature, static electricity, magnetic storms, ice formation and accretion, high latitudes), LNG Carrier navigation, equipment operation, accessibility and maintenance in extreme conditions (ice cover, ice floes, icebergs, ice channel edges, ice ridges, hummocks, ice compression, ice jet) led to the issuance of 115 actions.

The workshop led to define the top priority actions or recommendations to be undertaken.

Figure 2 shows the distribution and priority classification of the actions on different parts of the ship.

![Figure 2: Number of Actions per Priority and System](image)

5. IceSTAR ANALYSIS

Nowadays the Classification Societies rules, international codes, standards and local authorities’ requirements are based on theoretical derivation and in-service experience of existing vessels. The active navigation in arctic seas, new types of the ice-going vessels and especially demands for large tonnage ice-going ships require developments of new tools to ensure safety of humans’ lives, vessels, cargos and vulnerable Arctic environment. Application of common approaches for new types of offshore units or larger tonnage oil tankers and LNG carriers, intended for operation in ice-covered seas, can result in serious
accidents and significant consequences. Therefore, the basic design appraisal requires new tools to predict ice load actions on vessel hull. Bureau Veritas in cooperation with Saint-Petersburg Technical Marine University developed new software for direct analysis of hull structure strength. The main goal of the development is a prediction of ice loads exerted on ship hull, allowing for ice features, and analysis of possible ship and ice interaction scenarios, ship hull geometry, and ice mechanical properties.

The initial step in direct calculation of ice loads is an identification of the probable ship and ice interaction scenarios and extraction of design ones. An ice navigation experience in ice-covered waters allows selection of following design scenarios depicted in Figure 3 and Table 1:

- Glancing and reflected impacts against ice floe;
- Moving in ice field (icebreaking mode);
- Maneuvering in ice.

These scenarios, for both ahead and astern navigation in case of double acting ships, can be modeled in the software by combination of various kinematic and environmental parameters. The ship motion is described by ship velocity, direction of ship motion – ahead or astern, trajectory of ship motion – straight motion or gyration, gyration radius, angles of roll and yaw. The geometry and mechanical properties of ice is described by thickness, mass, shape of ice edge, Poisson ratio, Young modulus, ice crushing and flexural strength.

![Figure 3: (I) Glancing and Reflected Impact, (II) Icebreaking (Ahead), (III) Maneuvering in Ice](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Contact region</th>
<th>Navigation mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glancing impact</td>
<td>Bow, Shoulder, Stern (DAS)</td>
<td>Ahead and astern navigation in broken ice of different concentration</td>
</tr>
<tr>
<td>Reflected impact</td>
<td>Bow, Shoulder, Stern (DAS)</td>
<td>Ahead and astern navigation in broken ice of different concentration</td>
</tr>
<tr>
<td>Icebreaking</td>
<td>Bow, Shoulder, Stern (DAS)</td>
<td>Ahead and astern navigation in ice field</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>Bow, Shoulder, Midbody, Stern</td>
<td>Gyration in ice, maneuvering in channel</td>
</tr>
</tbody>
</table>

The direct calculation method builds on three key tasks: (1) developing of ice failure model, (2) solution of two bodies’ impact problem, and (3) calculation of ice load parameters. The mathematical model of ice failure builds on hydrodynamic model proposed by Kheisin and Kurdyumov. The model takes into account wide range of both kinematics parameters of impact and mechanical properties of ice and allows consideration of the flexural, crushing and buckling ice failure modes. The ship impact against ice is considered as an oblique eccentric inelastic interaction of two bodies. The oblique eccentric inelastic impact can be transferred to a direct central one by ship mass and speed reduction coefficients using Popov’s approach. The calculation results are presented by contact pressure, total contact force, line load intensity,
and height of contact zone (see Figure 4). The determination of these ice load parameters builds on a solution of a ship motion equation and a hydrodynamic model of solid body impact against ice. Therefore, the proposed direct calculation method takes into account a wide spectrum of external variables and allows estimation of ice loads beyond existing regulations’ requirements.

Figure 4: Distribution of Ice Load Parameters along Ship Hull

The results of IceSTAR may be taken into account to assess the strength of the ship hull using Finite Element Method, or any other method.

6. STRUCTURAL ANALYSIS

If the question of the resistance of the ship hull against a hard ice is important, it becomes fundamental when a LNG carrier is considered. Effectively, a tank failure following a large double hull deformation will induce a liquefied gas leak with severe consequences. This point was raised during the Risk analysis describe paragraph 4 above.

The verification of the behaviour of the hull structure and of the tanks of a typical 150000 m³ membrane type LNG carrier, class PC 3, i.e. designed to navigate all around the year in 2m thick ice or more, one year ice with possibility of inclusion of multi-year ice was carried out.

The aim of the analysis is to determine by FEM direct calculations, the stress levels, the hull structure and membrane maximum deformations of a LNG carrier and to verify their compatibility with existing acceptance criteria. With this regard, the steel ship classification rules and the NR 527 (see paragraph 2) are applied. A coarse mesh model, extended to 3 cargo tanks, was developed to represent the primary structure behavior (see Figure 5).

Figure 5: Midship Region 3D Model
The ice pressure applying on areas of small dimensions, the deformations are local, so, in order to determine them with precision, a fine mesh model is developed, on which the ice loads and the limit conditions coming from the coarse mesh model are applied.

The ice load is applied at different locations on the shell to represent the possible cases versus ship loading and contacts with the ice during navigation.

For the coarse mesh model the following cases are analysed:

- at bottom, ship central axis, middle of tank
- lateral bottom, middle of tank
- side shell, ballast draft, middle of tank
- side shell, full load draft, middle of tank
- bilge, middle of tank

Figure 6 shows how the patch pressure is applied to the hull, and Figure 7 shows the deformation of the hull. The deformation of the double bottom, along the ship breadth, in case of patch pressure applied on the bottom, is given in Figure 8. It is verified that the deformations are compatible with the cargo containment system.
Figure 8: Double Hull Deformation along the Ship Breadth

The verification by direct FE calculation of the stresses and deformations of the structure in the tanks region of a 150,000 m³ membrane LNG carrier shows that the application of membrane type LNG carrier are feasible in Arctic environment and led to significant increase of weight of the hull.

7. LIQUID MOTION ANALYSIS

One of the questions which were raised during the risk analysis described paragraph 4 above, was to assess what happens with liquid motion in case of frontal or lateral collision with ice or iceberg.

A specific methodology was developed to assess the strength of the different parts of the vessel. This methodology may be summarized on Figure 9.

Figure 9: General Methodology of Sloshing Assessment

This methodology includes the following steps:

- Hydrodynamic analysis,
- Model tests,
- Numerical simulation,
• Assessment of the safety factor of the containment system,
• Assessment of the strength of the hull under sloshing loads,
• Assessment of the pump mast.

In this methodology, the tank is modelled and subject to a numerical simulation. Figure 10 shows a typical model of the liquid motion numerical simulation in a cargo tank.

![Figure 10: Model for Numerical Simulation of Liquid Motion Assessment](image)

The methodology for liquid motion analysis has been subject of 2 guidance notes NI 554 and NI 564, for ships sailing in open sea.

In case of collision with ice or iceberg, the acceleration taken into account may be taken from PC rules (see chapter 4 above) or from a collision analysis.

8. CONCLUSION

As the LNG industry has developed, Bureau Veritas has been found at the forefront of these developments and with the Arctic being the next major frontier to be conquered we are understandably focusing our attention on the issues linked with the development of Arctic LNG exploration and the associated shipping needs.

There are a number of challenges for operation in extreme climates which need to be considered and overcome, such as low temperatures, ice, specific natural conditions and the vulnerable eco-system, all of which will impact in some way the design and operation of LNG carriers in these regions and provide specific technical challenges which need addressing.

This issue was addressed through different means:
• Rules and guidelines developments,
• Software developments
• Risk analysis
• Specific studies as liquid motion analysis, strength analysis

The studies presented in this paper have shown an approach to address these challenges.