E-9093
Ice Class Ship Structures

by
Claude Daley
Professor of Ocean and Naval Architectural Engineering

Part 1 – Overview of Arctic Shipping Topics
Overview of Arctic Shipping

Ice –
What is it?
Where is it?
What happens to ice when ships sail into it?
What happens to ships sailing in ice?
Overview of Arctic Shipping

A partial list of topics of interest to ice class ship designers includes:

- Mechanical properties of *sea ice*
- Powering and performance of ships in ice
- Structural design of icebreaking ships
- Assessment of ice loads in various scenarios
- Model scale simulation
- Study of ice management
3 components of ice engineering

*Glaciology* is the name for ice science. It is the scientific study of all forms and properties of ice. *Glaciology provides one of the fundamental supports for ice engineering.*

*Newtonian* and *continuum mechanics* provides a second fundamental *support* for ice engineering. We can borrow much from Newton as we seek to understand how ice behaves as it contacts ships and structures.

The *third leg holding up much of ice engineering is empirical data from field and experimental observations*. Ice behavior is often exceedingly complex. Continuum mechanics models, smooth as they are, have never really explained the discontinuous mess that is broken ice. Ice engineers need to be aware of the empirical evidence and be skeptical of the various models that have been proposed to explain the observations.
Current Ice activities and issues

- Offshore Oil is very slow – especially in arctic
- Orphan Basin/Flemish Pass ? (38 B bbl)
- Increasing security, sovereignty issues
- Canada building icebreaker and AOPS
- USCG considering new Icebreaker
- US, Can Navies interested in ice edge operations
- Arctic shipping lanes are opening
- Arctic Cruise ships increasing
1. Development of Sea Ice
   - Types and Features
   - New Ice
   - First Year Ice
   - Second- and Multi-Year Ice
   - See
     http://nsidc.org/seaice/index.html
Sea Ice

New Ice

First season of freezing, rafting and ridge formation

First-Year Ice

Seasons of melting and refreezing (Polar regions)

Second-Year Ice (Summer)

Second-Year Ice (Winter)

Multi-Year Ice

Ice Class Ships
Pressure Ridges
Consolidation
Pressure ridges continue to freeze forming a consolidated layer. The ice in the consolidated layer is much thicker than the surrounding level ice.
Second-Year and Multi-Year Ice Compared to First-Year Ice

- thicker ice features
- greater contact areas
- higher total forces
- higher average and peak pressures

Multi-year ice inclusion in first-year ice
(Source: BP Petroleum Development)
Icebergs

Icebergs are found at sea, but are not really ‘sea ice’. They are very old, and present a risk similar to other types of old ice.

Eastern Canadian and Antarctic waters are especially prone to icebergs.
Pancake Ice
Re-freezing FY Pack Ice
### How to read Sea Ice Charts

<table>
<thead>
<tr>
<th>Color</th>
<th>Ice Type</th>
<th>Thickness</th>
<th>Egg Code #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>Ice Free</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Blue</td>
<td>&lt; 1/10 unspecified ice</td>
<td>&lt; 10 cm</td>
<td>1,2</td>
</tr>
<tr>
<td>Light Pink</td>
<td>New Ice</td>
<td>10 - 15 cm</td>
<td>4</td>
</tr>
<tr>
<td>Dark Pink</td>
<td>Grey Ice</td>
<td>15 - 30 cm</td>
<td>5</td>
</tr>
<tr>
<td>Green</td>
<td>Grey-White Ice</td>
<td>&gt;30 cm</td>
<td>6</td>
</tr>
<tr>
<td>Yellow</td>
<td>Thin FY (FY)</td>
<td>30 - 70 cm</td>
<td>7</td>
</tr>
<tr>
<td>Green Yellow</td>
<td>Medium FY</td>
<td>70 - 120 cm</td>
<td>8</td>
</tr>
<tr>
<td>Orange</td>
<td>Thick FY</td>
<td>&gt; 120 cm</td>
<td>9</td>
</tr>
<tr>
<td>Red</td>
<td>Second-year Ice</td>
<td>Old Ice</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>Multi-year Ice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**The egg code ->**

- **trace type**: 8
- **total coverage (1/10ths)**: 7
- **coverage of 3 main types (1/10ths)**: 133
- **3 main types (#)**: 141
- **floe size of 3 main types (see MANICE)**: 541

In this example, there is 7/10ths ice, made up of 1/10th medium FY, 3/10ths grey ice and 3/10ths new ice. There is also a trace of second year ice.
Grand Banks:
- Ice is occasional
- open pack
- Ice includes thick FY and glacial ice

Example

6/10th total ice concentration

1/10 of type “4.”, thick first year >120cm
4/10th of type “1.”, medium first year 70-120cm
1/10 of type “7.”, thin first year 30-70cm
with a trace of “7.”, old ice >2m

Main types are “4.”, “1.” and “7.” with trace of “7.”

Floe sizes for a, b, c, are small, medium and medium
Overview of Ships in Ice

- Hull Forms
- Types of Operations
- Potential for Structural Damage
Evolution of Icebreaker Hull Forms

- Spoon bow, e.g., Kigoriak
- 'White' type bow, e.g., Polar Sea
- Early icebreaker, e.g., Murtaja
- Non-ice shape

Ice Class Ships
Evolution of Icebreaker Hull Forms

- Rounded Landing Craft (e.g., Oden)
- Landing Craft with shear knives (e.g., Waas Bow)
- 2nd Generation Beaufort (e.g., Terry Fox)
Transit through Pack Ice

Pack ice is far more common than level ice. This is close pack, and is expressed as $9^{+}/10^{ths}$
Level Ice Transit
Independent
near track
turning
Level ice transit is the base case to evaluate performance of ice going ships, though it is actually a relatively rare occurrence.
Escort

In the Baltic, the cargo vessels are often smaller than the icebreakers. Both vessels are operating in a well used channel, kept passable by regular use.
Ramming ridges

In large ridges, ramming is often required.
Ramming heavy ice

In heavy multi-year ice, some ships must ram to make progress.

KIGORIAK
Potential for Ice Damage

level ice (within capability)
- little damage risk
Potential for Ice Damage

Heavy ice: rafted, consolidated, multiyear, glacial ice

- Can exceed hull capability
- Backing can cause stern/propeller/rudder damage
Ice Class Ship Design

- Hull form is designed for performance (low resistance, manoeuvring, seakeeping, cost)
- Engine is sized for performance and cost
- Strength of hull and machinery is sized for safety
- Structural hazards are result of extreme ice, unusual interactions (not regular operations)
Ice Class Rules

**Ice Class Rules** always specify strength requirements.
- Plate thickness
- Framing sizes
- ++

Some also specify performance requirements.
- Baltic rules contain power req.,
- ASPPR and PC do not.

Access Control is covered separately by reference.
- Canada has zone-date + ice regimes for arctic.
- Finland controls icebreaking support fees
- Russia charges an access fee for NSR
end of introduction