Outline

• Background
• Scenario-based design
• Scenarios and Rules
• Trend Analysis
• Design Development
Background

A new generation of Ice Class Ships is under development
Background

New routes and operating profiles are under consideration
Scenario-based design

• Ice class rules have evolved considerably

• The new IACS Polar Class Rules are based on extensive analysis of (successful and unsuccessful) operational experience

• However, many new ships and services are outside the bounds of experience and data

• Owners, designers, operators and regulators should consider Rules and Requirements as starting rather than end points

• Scenario-based approaches can inform and guide the design of ships of the future.
Scenario-based Operations

From the Liberian accident investigation report (March 2009):

Master’s statement:

“During my more than 20 years experience from ice navigation I didn’t feel any danger to pass this ice..especially as I was on an ice-classed vessel”

Investigator’s conclusion:

“The Master transitted the ice field with an overconfident attitude regarding the capabilities of the EXPLORER”
Direct Design Software:

v1 DDePS:
- Interaction between ship and infinite ice edge.
- Peak Ice impact loads solved by Popov Method (energy).

V2 DDePS:
- Time-history added.
- Additional cases (e.g. bulbous bow)

v3 DDePS:
- Interaction between ship and ice floe with the finite mass.
- Motions of ice and ship calculated.
Infinite Ice Scenarios


1a Head-on Wedge
1b Head-on Spoon
2a Oblique Wedge
2b Oblique Round
2c Oblique Pyramid
2d Oblique Spherical
3a Reflected Wedge
3b Reflected Round
4 Wedging
5a Midbody Wedge Glance
5b Midbody Round Glance
6b Midbody Floe Impact
Version 3 of DDePS contains solutions for these scenarios, in addition to the infinite ice cases.
DDePS V1 Example Case

Scenario: 2a ship striking an edge of the ice floe.
Scenario: 2a ship striking an edge of a finite ice floe.
Popov Impact Ice Load Calculation for finite ice

• Normal Kinetic Energy = Ice Crush. Energy

• For finite ice, the ice and ship mass are combined

• Find indentation (δ) → Find force, area, pressure.

\[
\frac{1}{2} M_{ee} \cdot V_{n\text{-}bef}^2 = \int_0^{\delta_m} F_n(\delta) \cdot d\delta
\]

\[
M_{ee} = \frac{1}{\frac{1}{M_{e\text{-}ship}} + \frac{1}{M_{e\text{-}ice}}}
\]

Ship ‘Popov’ Mass  Ice ‘Popov’ Mass
‘Time history’ Load Calculation

(Same assumptions as in Popov, except solution is in time domain, and can only be done numerically)

Solve two 2nd order Ordinary Differential Equations

Find indentation $\delta(t) \rightarrow$ Find force, area, pressure.

\[
M_{e\_ship} \frac{d^2}{dt^2} x_{ship}(t) = p_0 \cdot fa \cdot \delta(t)^{fx^{-1}}
\]

\[
M_{e\_ice} \frac{d^2}{dt^2} x_{ice}(t) = p_0 \cdot fa \cdot \delta(t)^{fx^{-1}}
\]

$\delta(t) = x_{ship}(t) - x_{ice}(t)$

no analytical solution: Solve for $x_{ship}(t)$ and $x_{ice}(t)$ by numerical integration
The ‘Popov’ solution is compared to the numerical solution and gives excellent agreement.

Time domain plots:
- Force
- Velocity
- Penetration
Finite Ice: Scenarios 2a

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Time domain plots:
- Force
- Velocity
- Penetration

BMT Fleet Technology

Ice Project
Scenarios and Rules

(Example)

• Double-acting ships are intended to encounter (break) ice going astern
• The strength of azipods is not sufficient to survive hitting heavy ice at high speeds
• Hull strength does not need to exceed pod strength
• Stern areas should be designed for impact scenarios at pod survivable speeds – not necessarily the nominal ice class speed
Trend Analysis

- Mathematical models allow exploration of the influence of factors such as size, speed, hull form
- This can inform decisions on absolute and relative hull strengthening levels for new ships and services
- It can also inform future research/data collection priorities
Example of Exploration

Table of Inputs: Ice Floe and Ship size

<table>
<thead>
<tr>
<th>Ship inputs</th>
<th>Hull Angles and Coordinates</th>
<th>Velocity</th>
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<tr>
<td>Ship</td>
<td>Ship Mass</td>
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<table>
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<th>Ice Angles and Coordinates</th>
<th>Ice Strength and Edge Shape</th>
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</table>
Time-history plots

Table of results: Force for 3 ships striking 3 Floes at 2m/s
Example: Pressured ice scenario

- Trend analysis indicates that pressure is a greater risk for smaller ships
Design Development

- Basic ice class may be driven by regulatory requirements (access limits)

- Detailed structural design should be driven by:
  - Operating profile;
  - Actual ice conditions
  - Scenario-based analysis of loads and risks

- This permits:
  - The most appropriate selection of nominal ice class;
  - The identification of supplementary ice strengthening features, as appropriate;
  - The development of efficient and produceable structural designs.
Thank You