THE TARGET IS TO PREDICT THE COMPRESSION IN ICE IN A WAY THE FORECAST CAN BE USED IN SHIP OPERATIONS

The presentation is based on work conducted at ILS Oy and Finnish Institute of Maritime Research

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ICE DAY 2008
WHAT IS MEANT BY COMPRESSION IN ICE COVER?

Coverage < 1, stress = 0  
Coverage ≈ 1, stress ≥ 0  
Coverage ≈ 1, stress > 0  

Wind or current stress drives ice cover and stresses build up when coverage is 100%.

GEOPHYSICALLY COMPRESSION OCCURS IN CONVERGENT ICE AREAS

convergent region  
in-plane ice stresses are compressive but with small gaps of zero stress

divergent region  
in-plane ice stresses are very low or zero
GEOPHYSICAL MODELLING OF COMPRESSION

Solution of equation of motion using the wind and current drag as the driving forces

**VARIABLES**
- total sea ice concentration
- undeformed ice thickness
- rafted ice mean thickness and concentration
- ridged ice mean thickness and concentration
- ridge height
- ice velocity
- ice compression

The calculation is based on weather forecasts and is done on a discrete grid where one point represents usually a square nautical mile.

Equation of motion

\[
m \frac{D\mathbf{u}}{Dt} + \mathbf{f} \times \mathbf{u} = A(\mathbf{t}^+ + \mathbf{t}^-) - mg\nabla H + F
\]

Compression components

\[
\mathbf{F}_x = [V \cdot \sigma] = \frac{\partial \sigma}{\partial x} + \frac{\sigma}{\partial y}
\]

\[
\mathbf{F}_y = [V \cdot \sigma] = \frac{\partial \sigma}{\partial x} + \frac{\sigma}{\partial y}
\]

THE PROBLEM OF GEOPHYSICAL MODELLING IS THAT THE QUANTITIES ARE AVERAGES ON THE GRID POINT
THE USE OF AVERAGE QUANTITIES RESULTS IN 'SMEARING' AND EDGES CANNOT BE MODELLED

Modelling of channel closing in the Gulf of Finland
Ove Pärn, 2007

Channel width definition:
\[ D(t) = (1 - C(T)) D_{\text{GRID}} \]

DIFFERENT SCALES IN MODELLING THE COMPRESSION

Geophysical Scale
1 - 1000 km
Ridge-building Scale
10 - 1000 m
Structural Loads Scale
0.1 - 10 m
SUGGESTION FOR SCALING PRINCIPLE

Compression line load $q$ [kN/m]:

$q \sim L^{-0.7}$

$q \sim h_{eq}^{1.25}$

$L$ length scale

$h_{eq}$ equivalent ice thickness

ACTION OF COMPRESSION ON SHIPS

Compression is a hazard for shipping
ACTION OF COMPRESSION ON SHIPS

Russian system of identifying compression with the channel closing time after the ship

<table>
<thead>
<tr>
<th>Unit</th>
<th>0</th>
<th>1/4</th>
<th>1/2</th>
<th>3/4</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>No compression</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weak compression</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Significant compression</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Strong compression 2-3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Very strong compression 3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

nautical mile
ACTION OF COMPRESSION ON SHIPS

<table>
<thead>
<tr>
<th>Identified by</th>
<th>Ice pressure on the icebreaker and the ship</th>
<th>1 half</th>
<th>2 half</th>
<th>3 half</th>
</tr>
</thead>
<tbody>
<tr>
<td>The channel behind the icebreaker in green-white ice</td>
<td>The channel is closed slowly</td>
<td>The channel is closed, a pressure ridge formed in the channel</td>
<td>The pressure ridge moves out of line crossing</td>
<td></td>
</tr>
<tr>
<td>The behavior of the sea ice along the sides of the channel</td>
<td>Individual pieces of ice</td>
<td>Breaking along the ship’s side</td>
<td>Heavy breaking. The ice breaks up and falls into the channel</td>
<td></td>
</tr>
<tr>
<td>The behavior of the ship and the hull vicinity</td>
<td>The ship experiences occasional waves and sudden directional changes</td>
<td>Strong waves, the ice and the ship hull make use of the sea</td>
<td>Constant البل</td>
<td></td>
</tr>
<tr>
<td>The behavior of the ice at the channel edges</td>
<td>The ice flows across the channel</td>
<td>Ice flows because the icebreaker cuts the channel</td>
<td>Multiple breaking when the icebreaker moves</td>
<td></td>
</tr>
<tr>
<td>The effectiveness when the icebreaker encounters ships of UL or ULA class</td>
<td>The icebreaker has difficulty in cutting the icebreaker and the ship continuously</td>
<td>The icebreaker ship has to be cut transversely and the icebreaker meanwhile moves by running</td>
<td>The icebreaker ship is unable to move and the icebreaker moves by running and continuously recruiting</td>
<td></td>
</tr>
<tr>
<td>The speed of a sweep in the case of ice with ships</td>
<td>0.12 knots</td>
<td>0.2 knots</td>
<td>Average 4 knots</td>
<td>0.2 knots</td>
</tr>
</tbody>
</table>

ICE DAY 2008  Kaj Riska  14.2.2008
**ACTION OF COMPRESSION ON SHIPS**

**Resistance in compressive ice and in level ice**

\[ R_{iT} = R_{iT} + 2 \cdot L_C \cdot q_\mu = R_{iT} + 2 \left( \frac{V_S}{V_i} \cdot d \right) \cdot \mu \cdot q(L_{PAR}) \]

**High loads on the midbody**

\[ q = c_a(L) \cdot q(L = 60cm) \]
PREDICTION OF COMPRESSION

Based on HIRLAM weather forecasts and initialization based on the ice charts.
The direction of easiest motion (?)

PREDICTION OF COMPRESSION

Tailored ship predictions:

• Additional resistance
  \[ \Delta R_i = f(L\text{PAR}) \]

• Hull loading
  \[ q_{\text{design}} = f(k) = f(PA) \]

Added resistance using down scaled q to ship scale
Down scaled q divided by design q
VALIDATION OF PREDICTIONS

Two ice damage incidents in compressive ice in winter 2003

Tug outside Helsinki

Tanker from Primorsk

Pärn et al 2007

VALIDATION OF PREDICTIONS

Ice damage incidents in ice in winter 2003

Ove Pärn 2007
VALIDATION OF PREDICTIONS
ICECAM observations onboard IB Otso

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The identified locations of channel edges from corrected images.

Arrows: direction of compression
Stars: compressive ice incidents
FUTURE RESEARCH

Subjects requiring further elaboration:

• Down scaling principle
• Added resistance in compressive ice
• Direction of easiest motion
• Operative use of ship based forecasts