Numerical simulation of ice-induced loads on ships and comparison with field measurements

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Motivation

- Ice-hull interaction
- Local ice load
- Global ice load
- Ship’s performance
Outline

- Introduction
- Numerical modeling
- Spatial distribution of local ice load
- Probabilistic distribution of local ice load
- Discussions
Sea ice

- Complexity
- Simplification: level ice
- Randomization: ice thickness and strength properties
Ice–hull interaction

- Crushing
- Bending
- Rotating
- Sliding

Source: Riska, 2010
Numerical modeling

- Valanto, 2001
- Liu et al., 2006
- Martio, 2007
- Nguyen et al., 2009
- Sawamura et al., 2010
- Lubbad & Løset, 2011

Source: Valanto, 2007

Source: Lubbad & Løset, 2011
Numerical modeling

- Su et al., 2010

\[ R_i = \delta \rho g h_i \left( \frac{B + T}{B + 2T} + \mu \left( 0.7L - \frac{T}{\tan \phi} - \frac{B}{4\tan \alpha} + T \cos \phi \cos \psi \left( \frac{1}{\sin \phi} + \frac{1}{\tan \alpha} \right) \right) \right) \left( 1 + 9.4 \frac{v}{gL} \right) \]

\( h_i \) (Lindqvist, 1989)
Numerical modeling

- Local ice load
- Global ice load
- Ship’s motion

Interaction
Numerical modeling

\[ \mathbf{F}(t_{k+1}) = \mathbf{F}(t_{k+1}), 0 = \mathbf{F}(t_k) \]

\[ \mathbf{F}(t_{k+1}) = \mathbf{F}(t_{k+1}), i+1 \]

Solve equations of motion

Update hull nodes

Detect the contact zones between ice and hull

No

Update the forces

Acceptable?

Yes

Update ice nodes

Next time step

\[ \mathbf{x}(t_{k+1}) = \left( \frac{6}{\Delta t^2} (\mathbf{M} + \mathbf{A}) + \frac{3}{\Delta t} \mathbf{B} + \mathbf{C} \right)^{-1} \cdot \left( \mathbf{F}(t_{k+1}) + (\mathbf{M} + \mathbf{A}) \cdot \mathbf{a}_k + \mathbf{B} \cdot \mathbf{b}_k \right) \]
Numerical modeling

- Convergence test
  - Global ice load
  - Discretization size of ice nodes: 1600, 800, 400, 200, 100, 50, 25 mm
  - Time step length: 0.032, 0.016, 0.008, 0.004, 0.002, 0.001, 0.0005 s
Numerical modeling

- **Computation time**
  - A 30-min icebreaking run
  - Discretization size of ice nodes: 1600, 800, 400, 200, 100, 50, 25 mm
  - Time step length: 0.032, 0.016, 0.008, 0.004, 0.002, 0.001, 0.0005 s

- **Real-time** simulation can be achieved by using a discretization size of 100 mm and a time step length of 0.01 s.
Numerical modeling

• Convergence test
  - Local ice load
  - Discretization size of ice nodes: 1600, 800, 400, 200, 100, 50, 25 mm
  - Time step length: 0.032, 0.016, 0.008, 0.004, 0.002, 0.001, 0.0005 s
Case studies

- *MT Uikku*
- *MS Kemira*
- *S.A. Agulhas II*
- *Tor Viking II*
- *CIVArctic vessel*

Local ice load

Global ice load and ship’s performance
Local ice load

- Ice-induced frame load

*Icebreaking tanker, MT Uikku*
Spatial distribution of local ice load

- 30 frames on different hull areas of MT Uikku are selected to investigate the spatial distribution of local ice loads in both straight going and turning operations:

Peak value
Mean value
Spatial distribution of local ice load

• Simulated peak loads with a non-exceedance probability of 99% (in a period of 30 minutes simulated in 0.34 m thick ice) on different frames around the hull:

This result suggests that it is possible that when a ship turns in ice, the aft-shoulder area is equally or even more vulnerable to ice damage, as compared with the bow area.

Similar results have been obtained by Izumiyama et al. (2005) and Valanto (2007) based on their experimental and numerical works.
Spatial distribution of local ice load

- Simulated mean loads (in a period of 30 minutes simulated in 0.34 m thick ice) on different frames around the hull:

This result suggests that when a ship turns in ice, the aft shoulder area may encounter much heavier turning resistance as compared with the bow area.

Time average: 7.28 kN/m

Time average: 129 kN/m
Probabilistic distribution of local ice load

- Statistical variation of the ice:
  - Ice thickness
  - Crushing strength
  - Bending strength
Probabilistic distribution of local ice load

- Statistical variation of the ice:
  - Ice thickness
  - Crushing strength
  - Bending strength
Short-term distribution of local ice load

- A 10-min time history of simulated ice loads on frame 196.5 in randomly varying ice conditions (average ice thickness: 0.125 m, average ship speed: 5.43 m/s):

Field measurements:
(Kotisalo & Kujala, 1999)
Short-term distribution of local ice load

- Distribution of the load peaks:

Data from Hänninen, 2003
Short-term distribution of local ice load

- Fitted probability distributions of the peak loads (in 12 hours) on frame 196.5 by using the Weibull model:

*Suggested by Kujala et al., (2009), based on field measurements*
Short-term distribution of local ice load

- Variation in the contact and icebreaking patterns:

![Graph showing load distribution over time](image)

- Ice load patch
- Contact length
- Frame spacing
- 350 mm

KMB: Arctic DP

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Short-term distribution of local ice load

- Probabilistic distribution of the simulated peak loads (in 12 hours) on frame 196.5 with varying or full contact:
Long-term distribution of local ice load

- Estimated long-term extremes based on the short-term distributions

Chemical tanker MS Kemira

The distribution of 12-hour load maxima measured on board MS Kemira and the estimated long-term extremes (Hänninen, 2003)
Long-term distribution of local ice load

- Distributions of simulated 10-min load maxima, \( w \), in the ice where the thickness, \( h_i \), is assumed to be normally distributed with a mean value, \( m_h \), and standard deviation, \( \sigma_h \).

\[
F_{W|H}(w|h_i) = \exp \left( -\exp \left( -\frac{1}{c_i} \left( w - u_i \right) \right) \right)
\]
**Long-term distribution of local ice load**

- Correlation between the distribution of simulated load maxima and the ice thickness:

\[
F_{W|h_i}(w|h_i) = \exp \left( -\exp \left( -\frac{1}{c_i} (w - u_i) \right) \right) = \exp \left( -\exp \left( -\frac{1}{k_i h_i} (w - k_{u_{1,1}} h_i - k_{u_{2,2}} h_i^2) \right) \right)
\]

\[
F_W(w) = \int_0^{h_{max}} \exp \left( -\exp \left( -\frac{1}{k_i h_i} (w - k_{u_{1,1}} h_i - k_{u_{2,2}} h_i^2) \right) \right) f_{H_i}(h_i) \cdot dh_i
\]
Summary

- Numerical modeling of ice–hull interaction *(based on empirical data)*
- Spatial distribution of local ice loads around the hull *(comparison)*
- Short-term distribution of local ice load *(comparison)*
- Long-term distribution of local ice load *(no comparison)*
- Global ice load and ship’s performance
References


References


Thank you for your attention!