Toward the risk assessment of ship navigation in Arctic Sea Route under decreasing ice condition

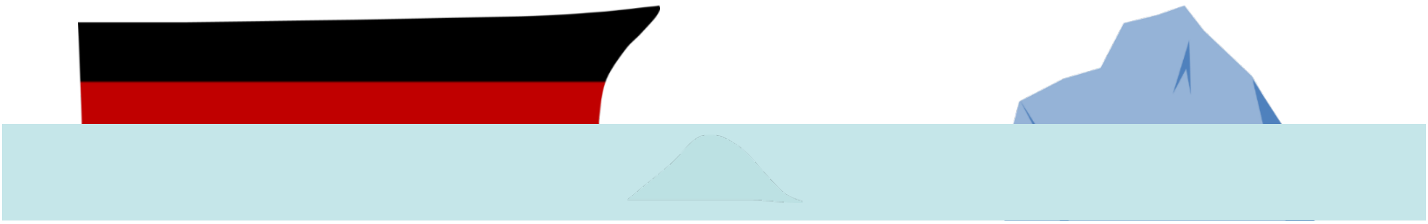
Akihisa Konno
(Kogakuin University)

Outline

- Background and motivation
- How to assess the risk of collision
- An example case
- Conclusions and future perspective

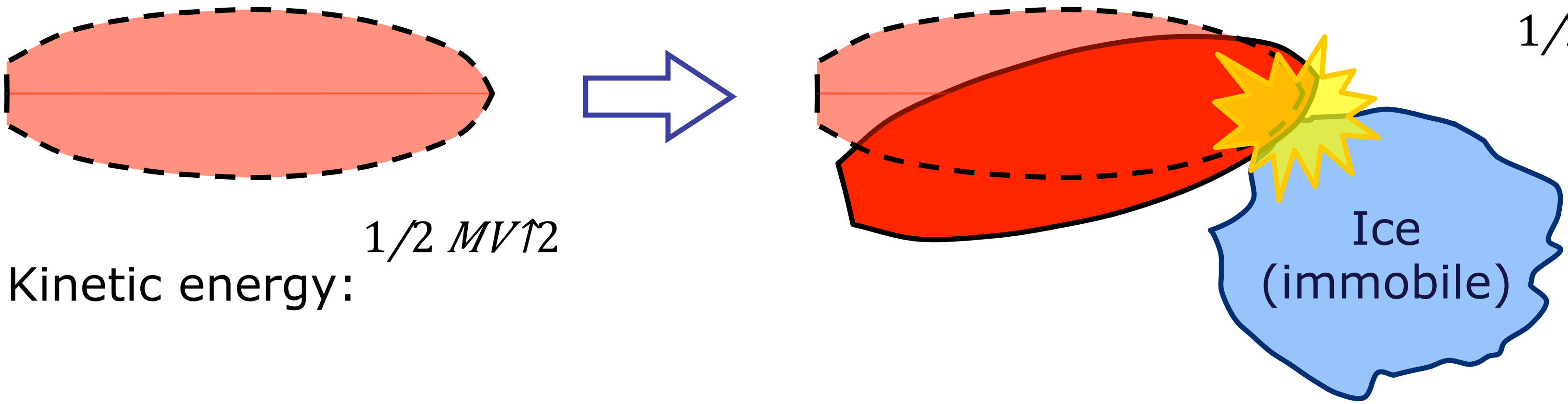
Background

- Arctic Sea Route (Northern Sea Route and North West Passage) has become increasingly available.
- Independently floating ice (multi-year ice, icebergs and bergy bits) are increasing along the route. They increase the risk of ship collision with an ice floe.



Background: energy based estimation of collision force

Crushing energy = Effective kinetic energy: $\frac{1}{2} M_e V_n^2$



Kinetic energy: $\frac{1}{2} M V^2$

- Basis for IACS URI
- A part of ship's kinetic energy is expended in crushing.
- M_e: effective mass; $M_e = M_{ship}$/(mass reduction factor)
- Mass and motion of the ice are not considered.
- Is it applicable to collision with a small ice piece ?

Objective of this study

Propose a new method to estimate ice collision force for a small ice piece.

- Effective kinetic energy is replaced with a simple and straightforward estimation of energy consumption.

Outline

- Background and motivation
- How to assess the risk of collision
  - Ice type and size
  - Velocity of the ice before collision
  - Kinetic energy consumed by the collision
  - Maximum load on the ship hull
- An example case
- Conclusions and future perspective

Ice type and size

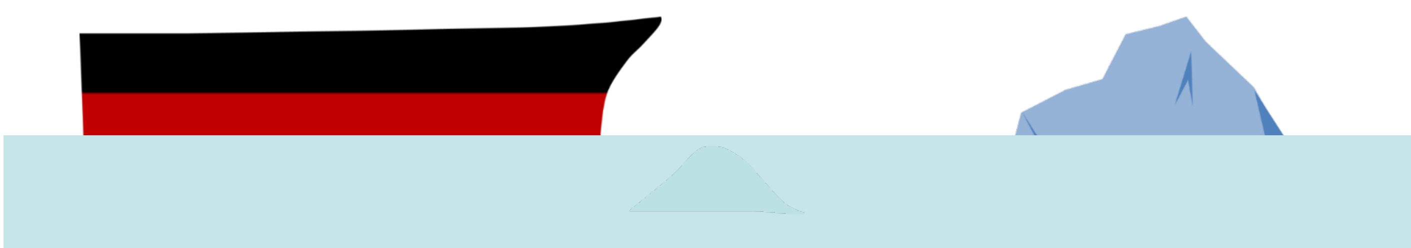
- A bergy bit is assumed because it is difficult to detect this kind of ice with a ship's radar.
- Typical size of bergy bits: 10 to 15 m

"Bergy bit"
Photo by adactio / CC BY 2.5

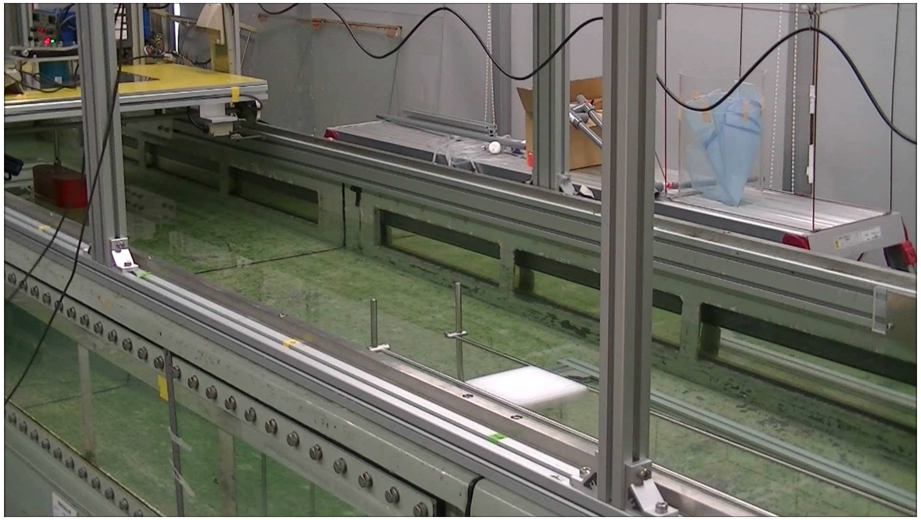
Motion of a bergy bit before collision

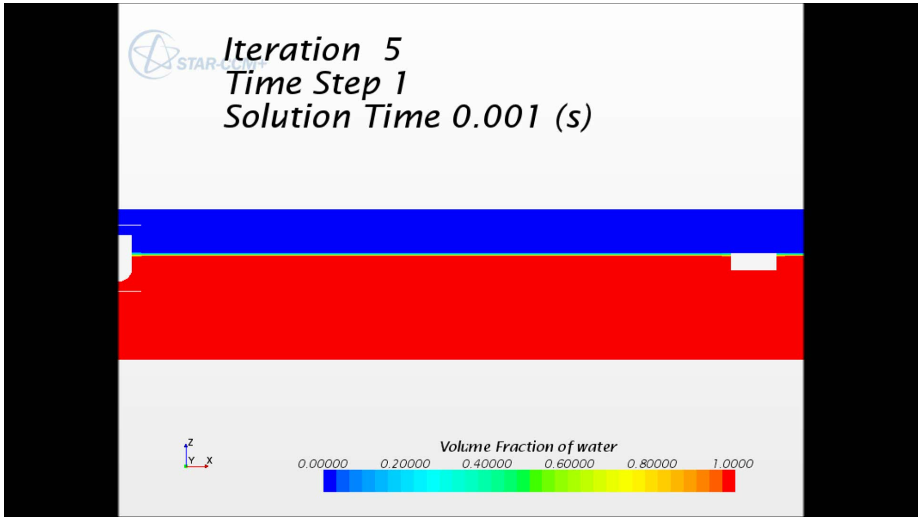
- Ice moves by waves propagated from the ship.
- The velocity of the ice piece is estimated as a linear function of the ship speed:

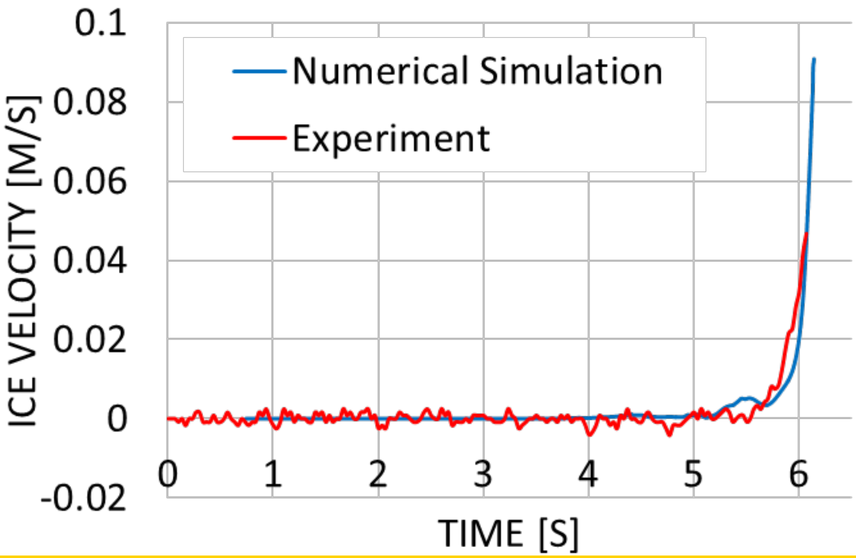
$$v_i = \alpha v_s$$



Estimation of α



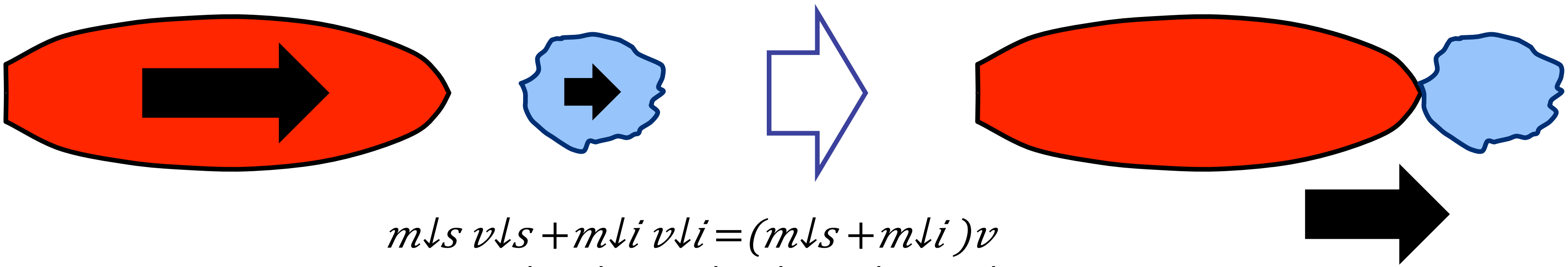




- Model ship speed: 0.5 m/s
- $\alpha \doteqdot 0.2$???
- Shigihara, Ishibashi and Konno, POAC'15, 2015.

Velocity after collision

- The velocity of the ship and ice after collision is estimated using momentum conservation theory.

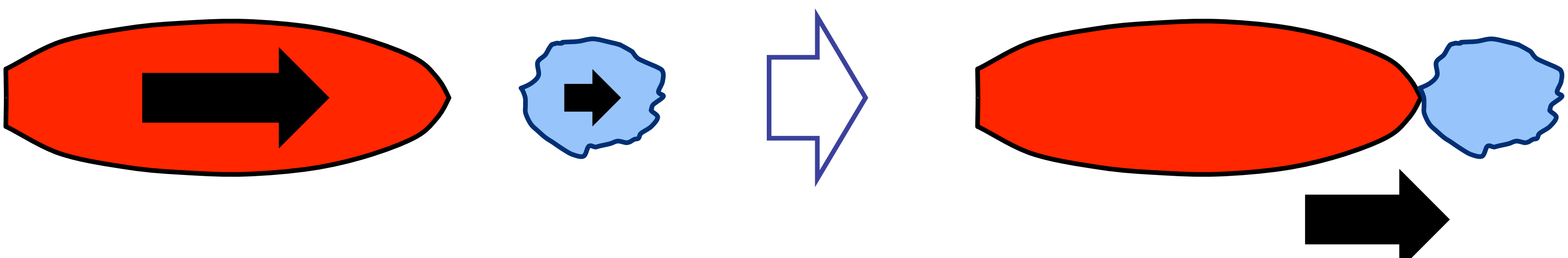


$$m_s v_s + m_i v_i = (m_s + m_i) v$$
$$\leftrightarrow v = m_s v_s + m_i v_i / m_s + m_i$$

- Simple heads-on collision is assumed at this time.

Energy consumption

- Kinetic energy consumed by the collision is estimated using the velocities before and after collision.



$$\Delta E = 1/2\, m_s v_s^2 + 1/2\, m_i v_i^2 - 1/2\, (m_s + m_i) v^2 = 1/2\, m_s v_s^2 + 1/2\, m_i v_i^2 - 1/2\, (m_s + m_i)(m_s v_s + m_i v_i / m_s + m_i)^2$$

Maximum load on the hull

- The method to estimate the load on the ship hull from energy consumption is borrowed from Daley and Kim (2010).

$$F_n = P_0 f_a^{(1+ex)} \left(\frac{\Delta E (d(1+ex)+1)}{P_0 f_a^{(1+ex)}} \right)^{\frac{d(1+ex)}{d(1+ex)+1}}$$

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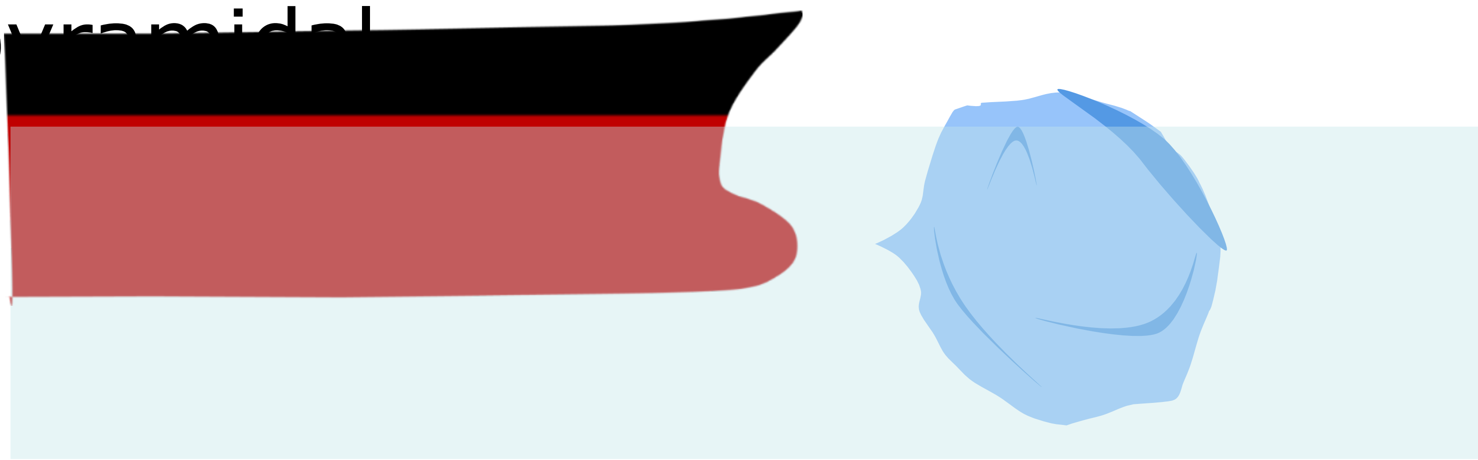
An example scenario

- A head-on collision of a ship with a bergy bit.
- The shape of the ice is assumed nearly spherical, but the contact edge of the ice is assumed pyramidal.



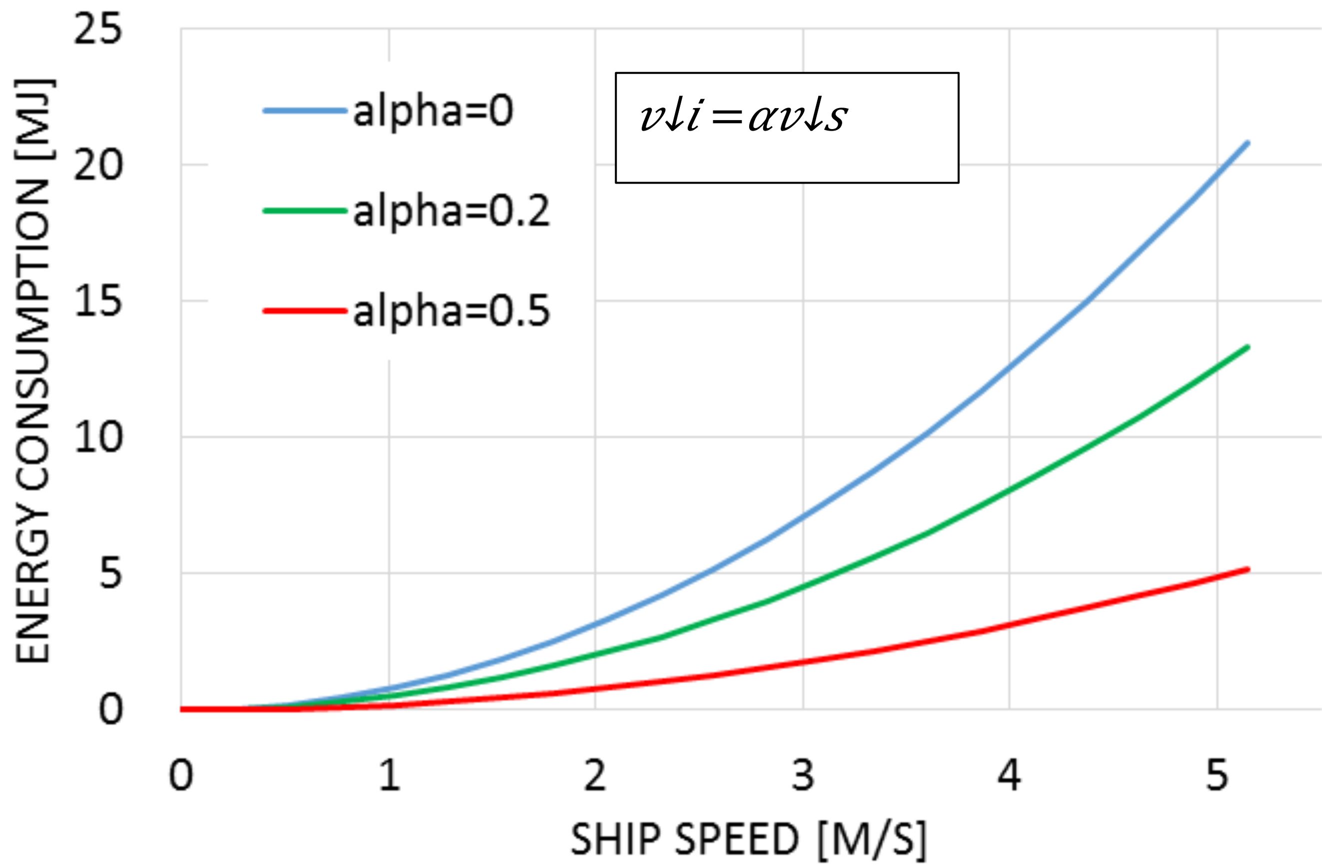
Parameters

Parameter		**value**	**unit**
Mass of the ship	M	150	kT
Ice pressure term	P_0	3.0	MPa
Exponent on pressure-area function	ex	-0.1	
Pyramidal angle	ϕ	150	deg.
Representative length of the ice		15	m
Density of the ice	ρ	900	kg/m^3

- Variables: ship speed (0 to 10 kts) and α (0, 0.2, 0.5)

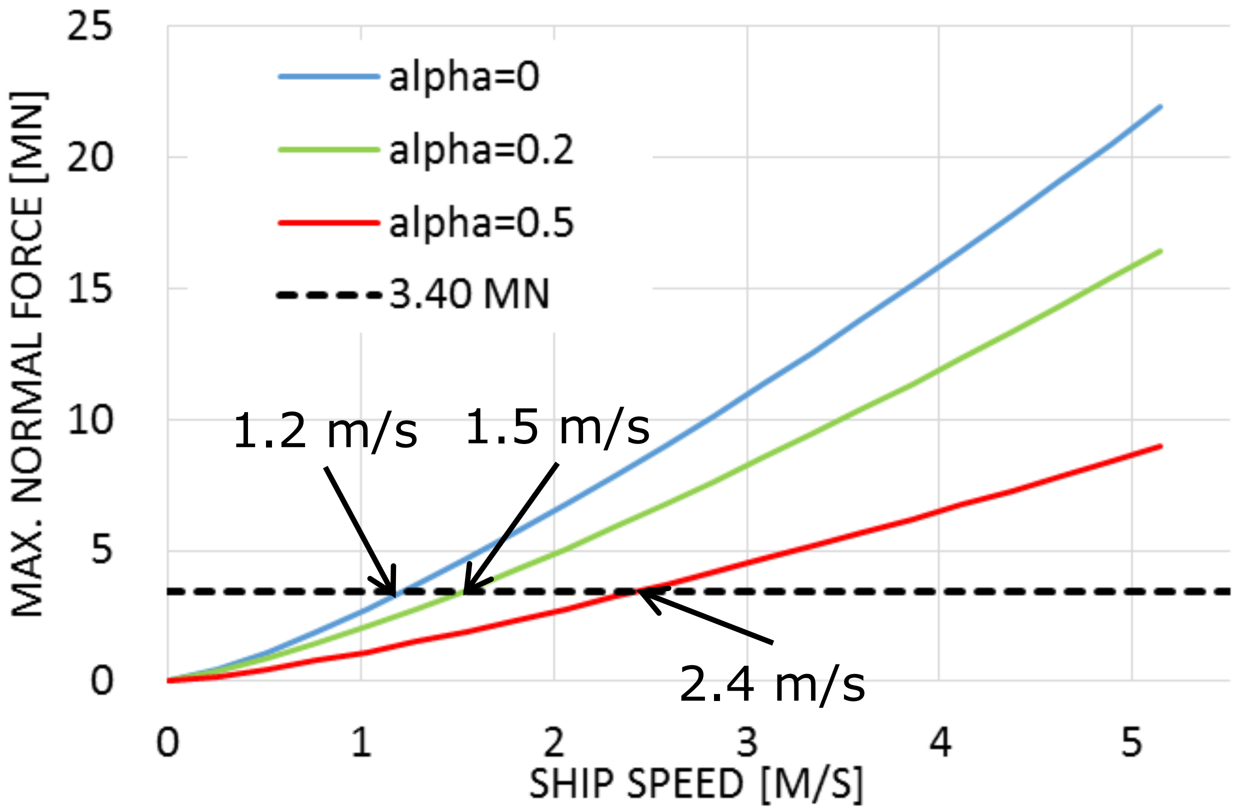
$$v_i = \alpha v_s$$

Results: energy consumption



- Effect of α is significant.

Results: max. normal force



- Limit speed in Daley and Kim (2010): 2.5 m/s

Discussion1/2

- The present method uses momentum conservation theory so that the calculation of energy consumption is straightforward.
- The method is an idea suitable for investigation of the collision of a ship and an ice floe, and thus a method suitable for assessing the safety of navigation in decreasing ice condition.

Discussion 2/2: issues

- Examination of the ice velocity before a collision is insufficient.
- The method should be extended so that an oblique collision to a ship bow can be treated.
- The deformation of a ship is not taken into consideration in the present study.

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Conclusions and future perspective

- The scenario of ship collision with a small ice floe at the normal, open-water navigation speed is examined, and the new method of evaluating a maximum normal force is proposed.
- The maximum force as a result of an analysis becomes an appropriate magnitude.
- Consideration of an oblique collision and other issues are required for further investigation.

Acknowledgments

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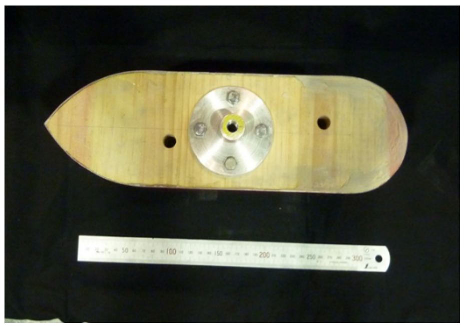
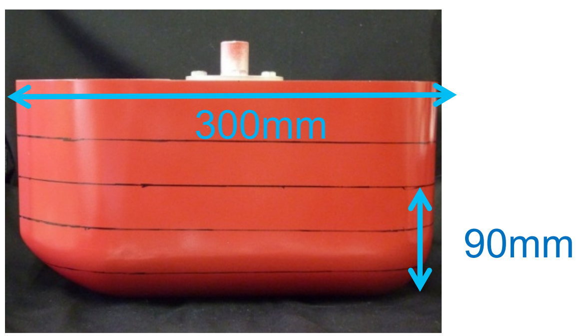
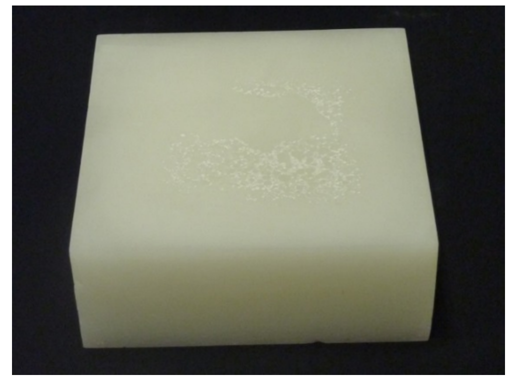
Thank you for your attention!

Model ship and Synthetic ice







Synthetic ice

・Made of polyolefin

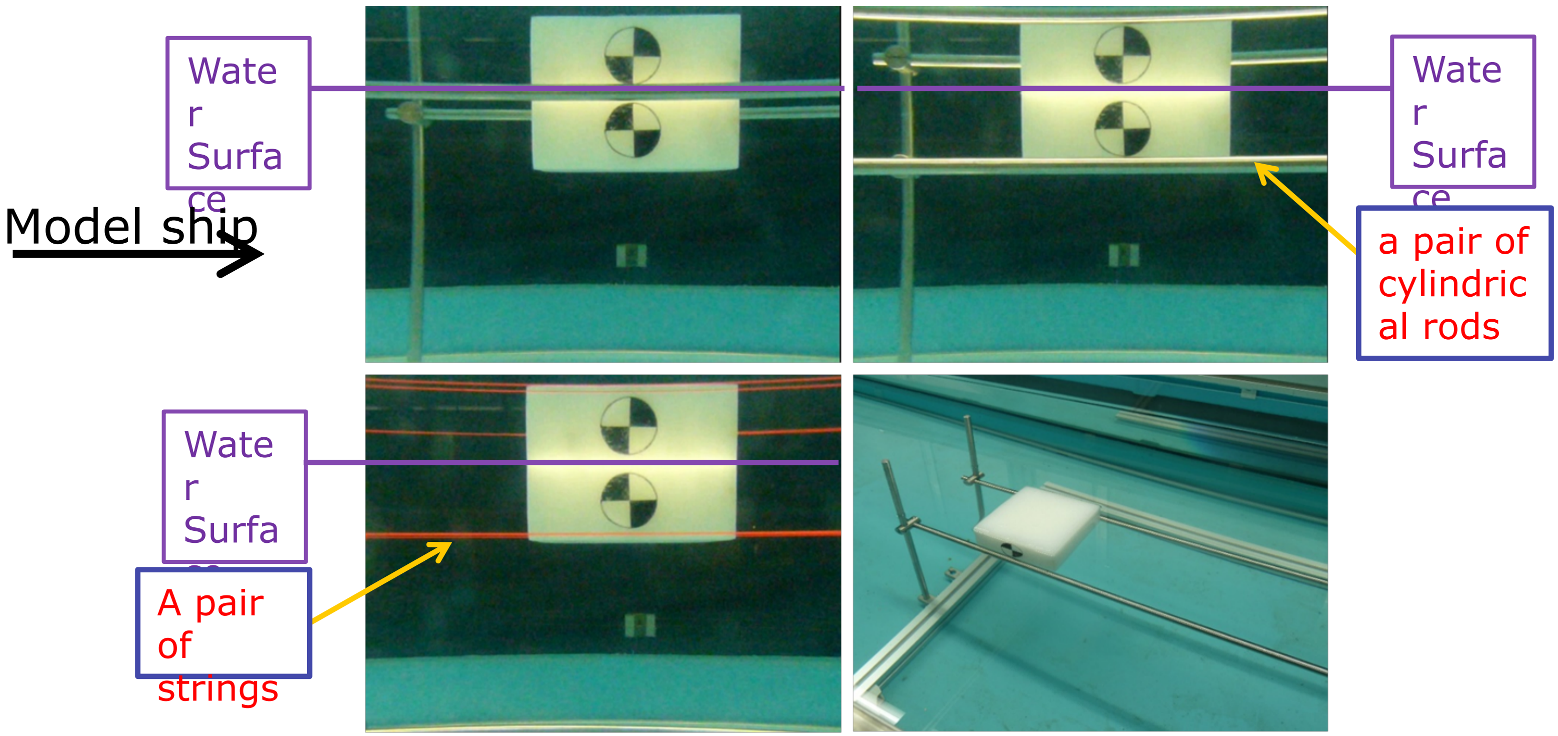
150 mm ×150 mm ×60 mm

・Density: 902 kg/m^3

(Close to that of the sea ice)

Restriction of motion of the synthetic ice

Motion of the ice piece is restricted to surging, swaying and pitching



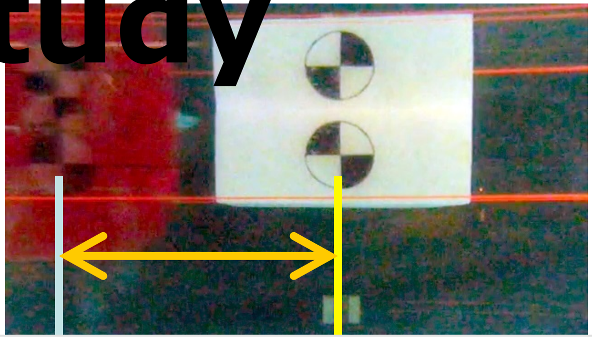
Improvement from previous study

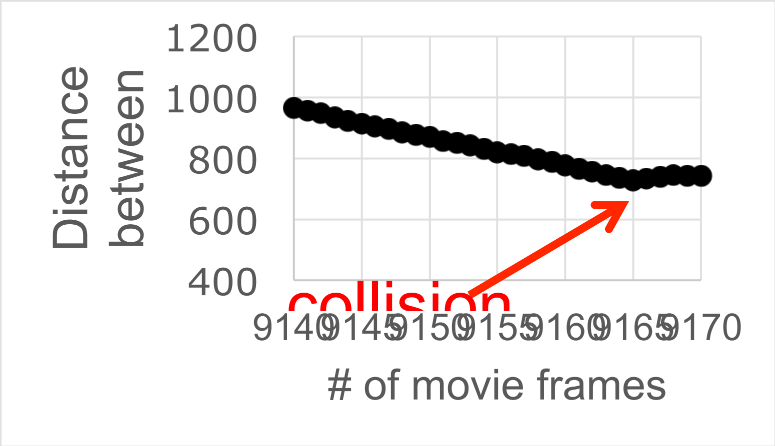
Experiment

- a new camera to take ice motions in 240 frames per second.
- markers on the ship and ice; we measured the distance of these markers to decide the instant of collision.
- stainless rods are replaced with strings to restrict ice motion. (will be explained later)

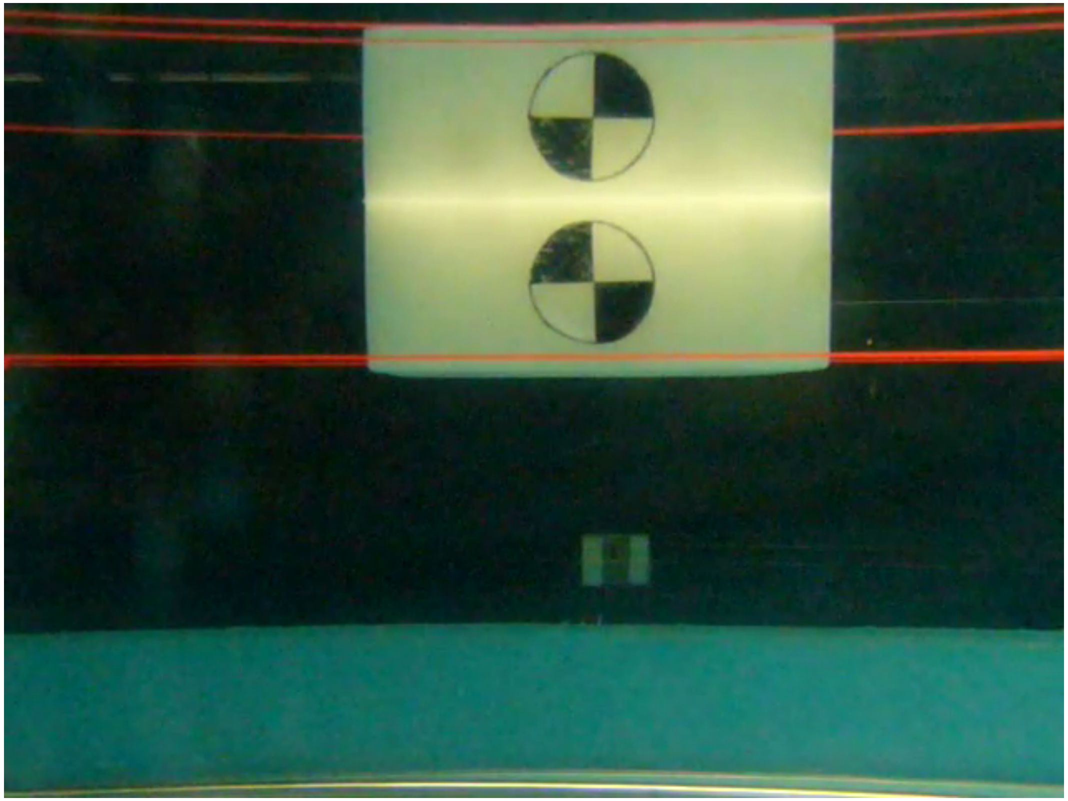
Simulation

- Ship velocity of simulation fits that of experiments to suppress starting wave.
- Reflection of wave from the surrounding walls is damped.





Movie of experiment

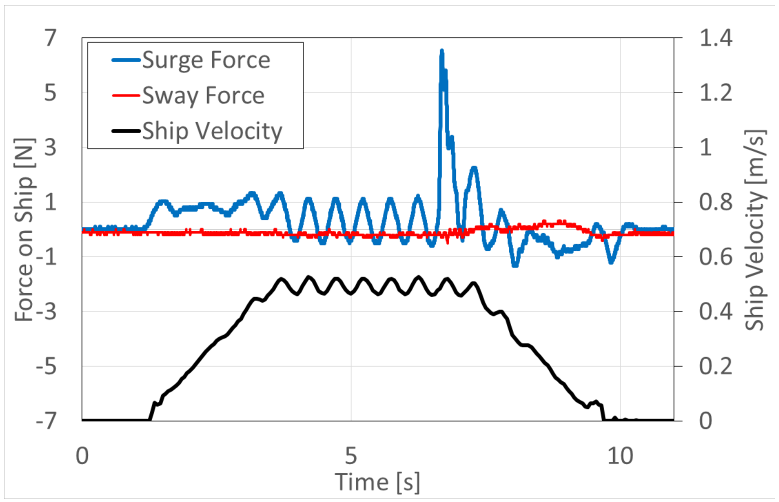


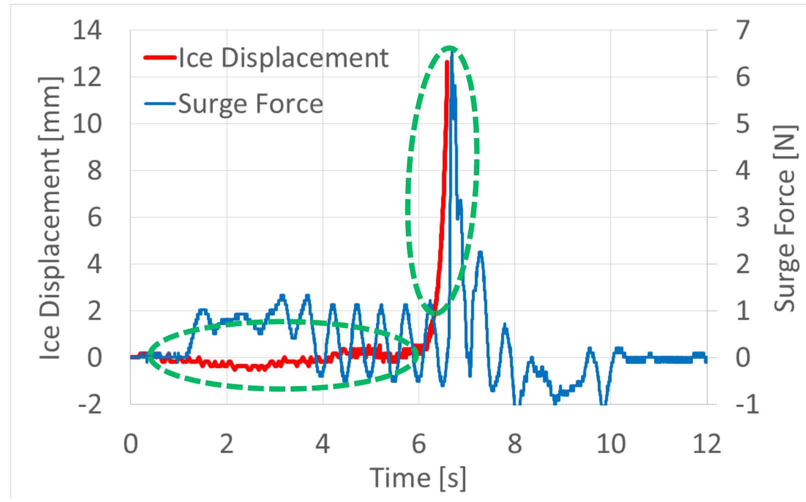
Underwater view

Ship velocity: 0.5m/s

a slow-motion replay: x 1/8

Experiment results

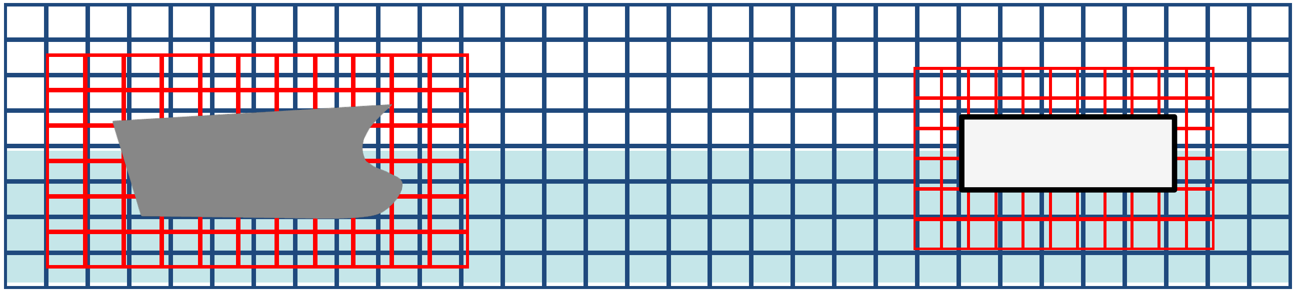




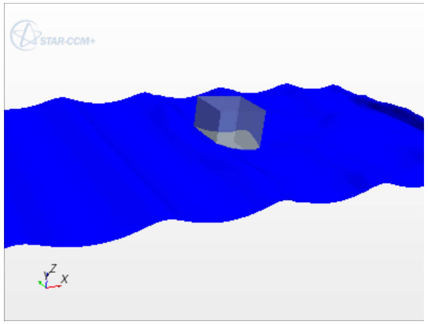
- The velocity oscillates in the experiment.
- We divide the motion to the two parts.
  - The earlier part represents the effect of experimental situations and is not essential.
  - The latter part represents the indirect effect of the ship through the water before collision.

Numerical simulation

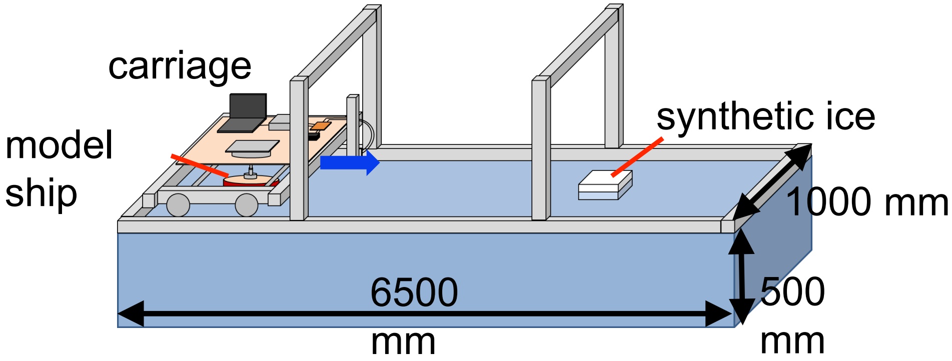
- We use the STAR-CCM+ v9

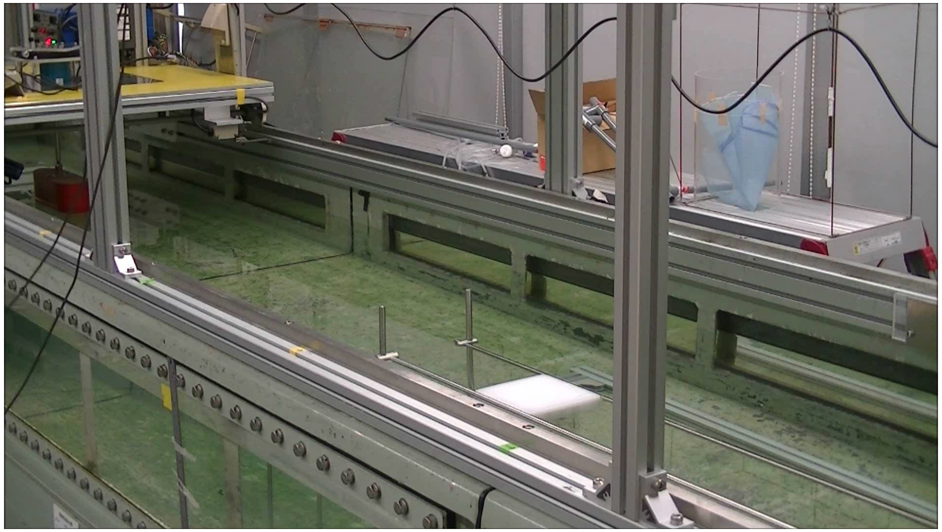


1. Overset method
   - used to represent motion of objects.
2. VOF method
   - Free surface is considered.
3. DFBI(Dynamic Fluid Body Interaction)
   - DFBI realizes motion of the ice.



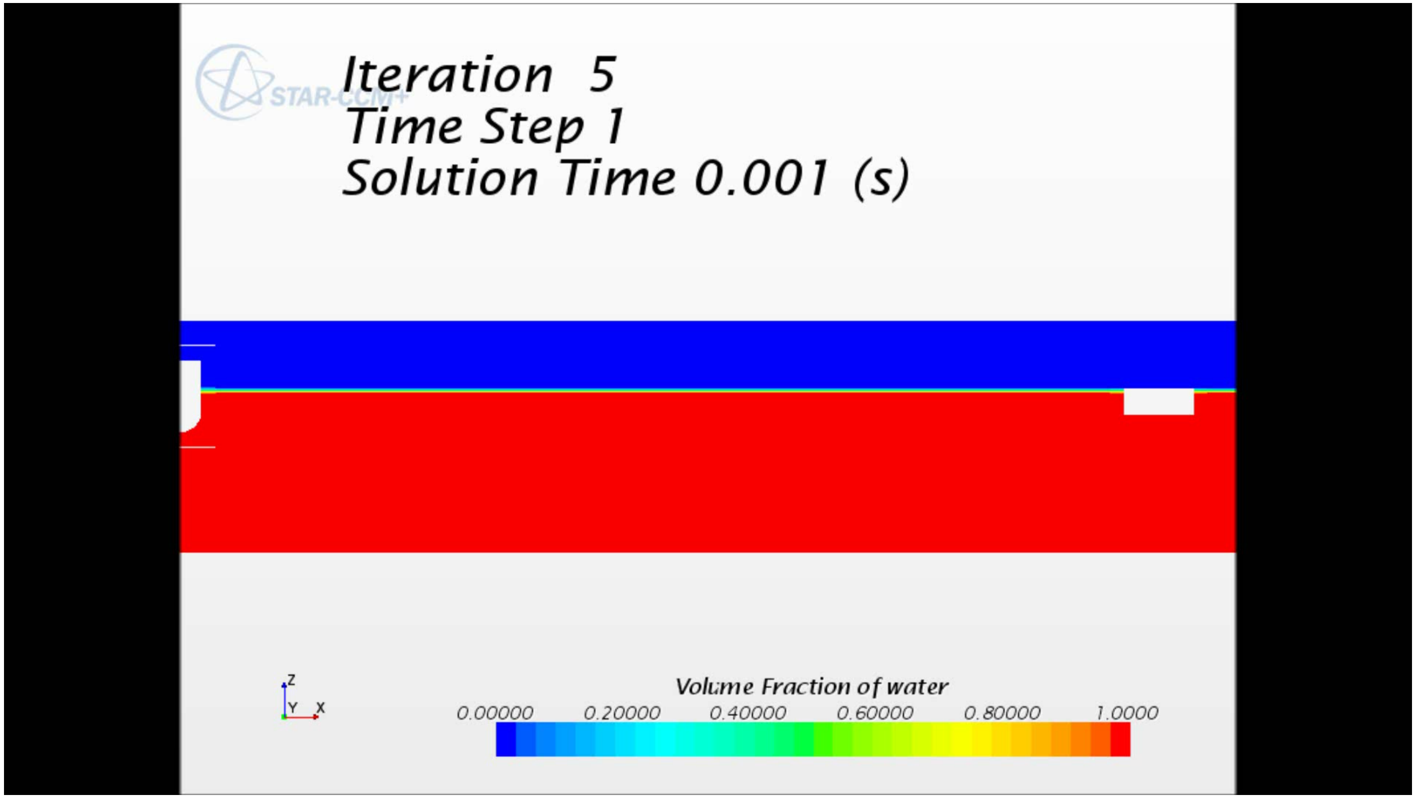
Estimation of α by small scale model test





- Ishibashi, Shigihara and Konno, IAHR Symp. on Ice, 2014.
- Shigihara, Ishibashi and Konno, POAC’15, 2015.

Estimation of α by numerical simulation

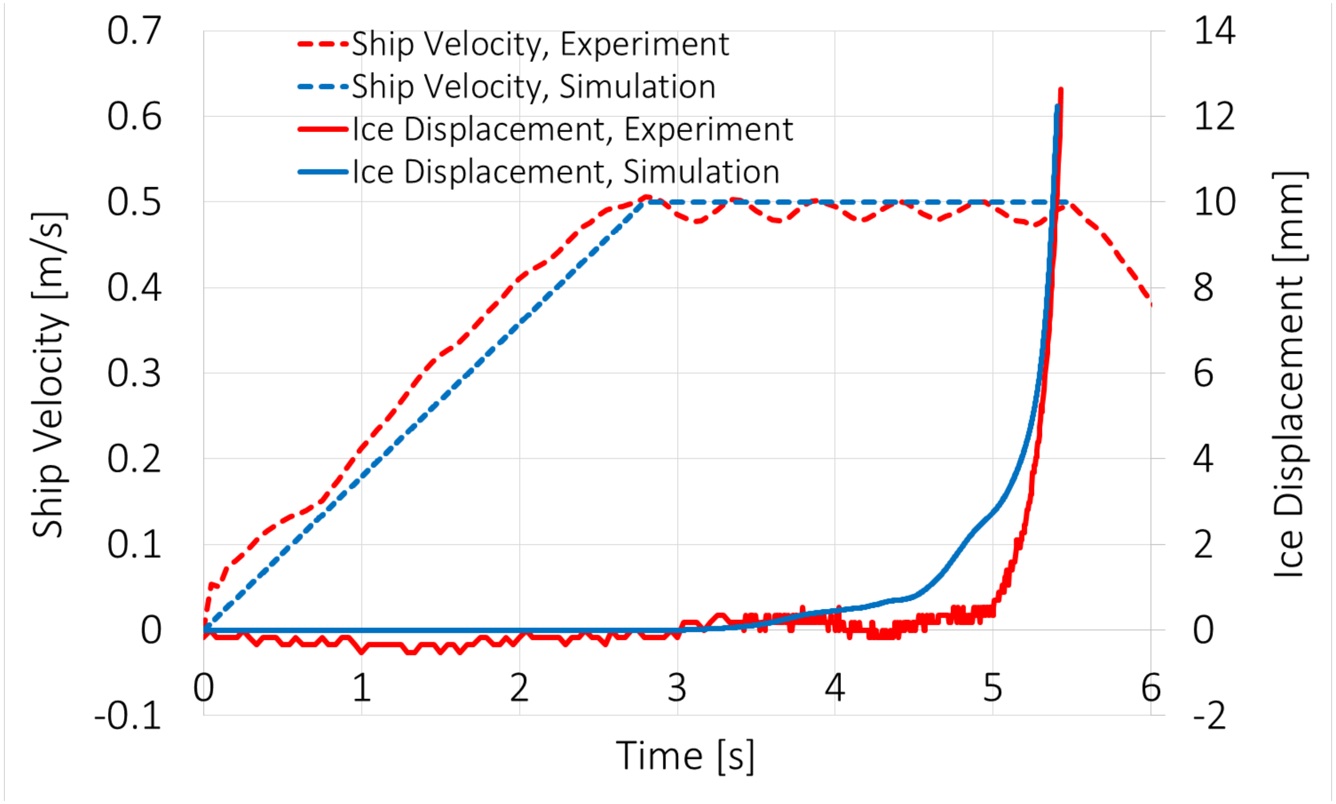


3-D simulation with Star-CCM + v8 and v9

VOF of water at the central section of the computational domain

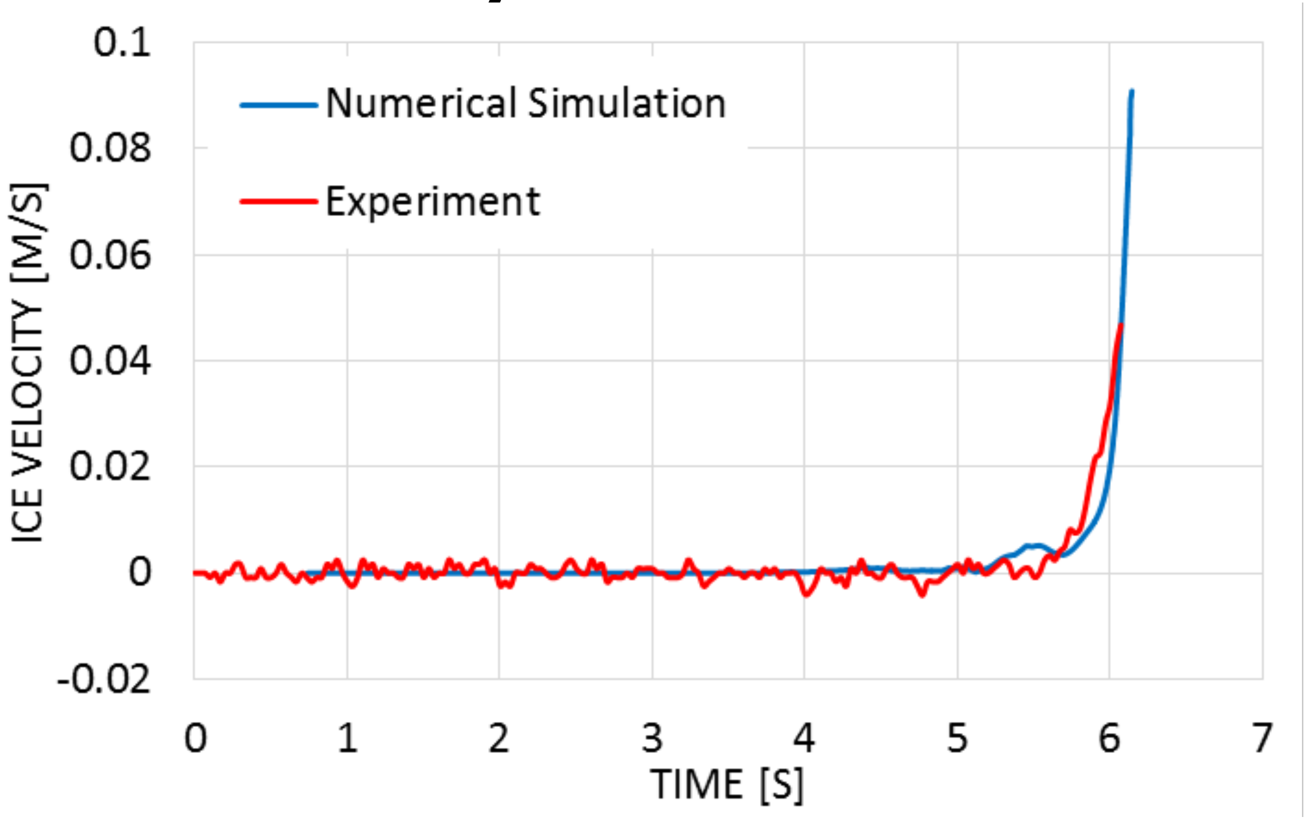
- Shigihara, Ishibashi and Konno, POAC'15, 2015.

Ice motion before collision



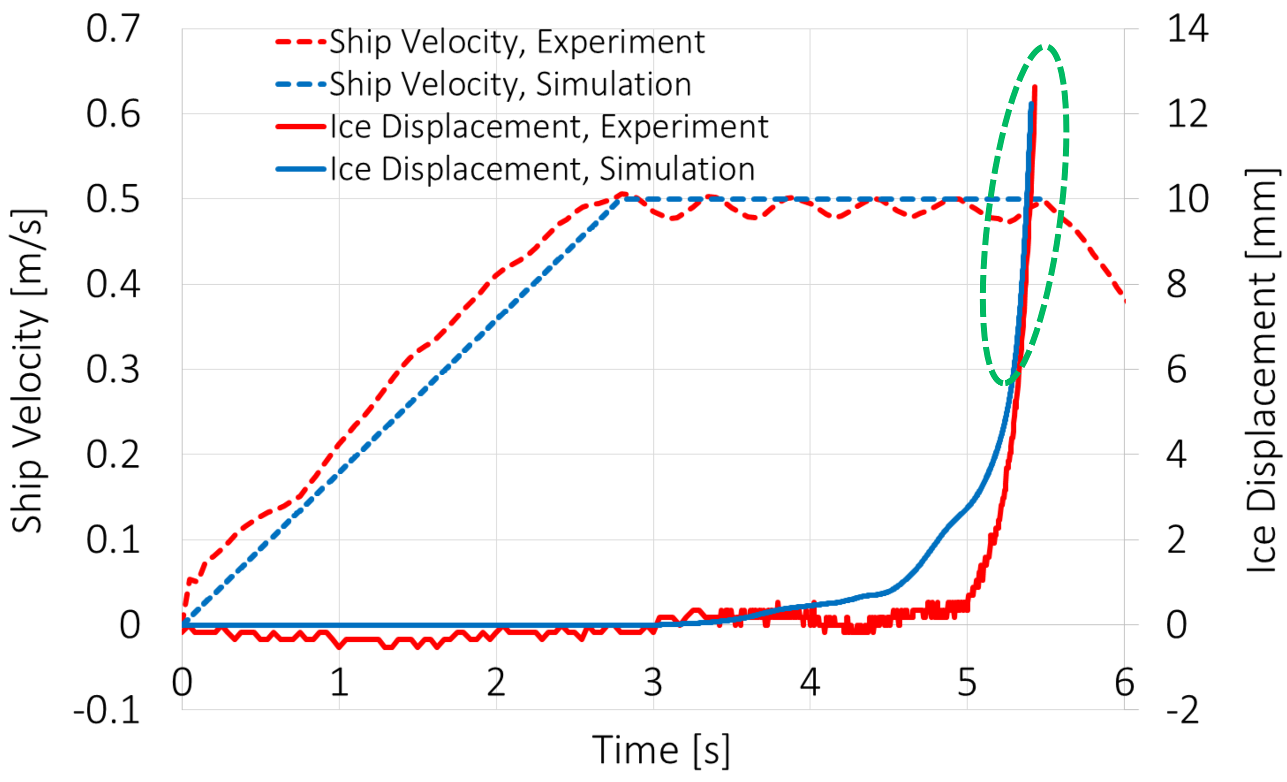
- Shigihara, Ishibashi and Konno, POAC’15 (2015).

Ice velocity before collision



- Model ship speed: 0.5 m/s
- $\alpha \doteqdot 0.2$???

Discussion



- Ice velocities before collision in the simulation and in the experiment agreed well each other.
- The simulation produces a good estimation of the relative velocity of the ice against the ship immediately before the collision.

発表メモ

- 発表時間:20分
- 15分ぐらいしゃべる?