NUMERICAL SIMULATION OF PRE-SAWN ICE TEST OF MODEL ICEBREAKER USING PHYSICALLY BASED MODELING

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ABSTRACT

Prediction of ice clearing resistance of an icebreaker by numerical simulation requires simulation of a flow field, with ice pieces colliding and scraping against the icebreaker hull. This paper presents a numerical method to simulate motion of ice pieces, including their mutual abrasions, interactions, and collision with a ship. Open Dynamics Engine (ODE) was incorporated into our simulation to allow the use of physically based modeling to illustrate these mutual interactions. Pre-sawn ice tests were simulated. Virtual fluid force and buoyancy were considered for each ice piece. Results showed that the simulation program appropriately modeled collision and mutual interactions among rectangular ice pieces and a ship. Parallelepiped ice pieces, which are represented as sets of triangles, did not behave well and tuning of ODE parameters was required. Contact points were also estimated using these simulations.

KEY WORDS: Numerical Simulation; Icebreaker; Pre-sawn ice test; Physically-based modeling; Collision

INTRODUCTION

An icebreaker is a ship that fractures ice sheets, thrusts ice pieces out of its way, and thereby maintains an open channel through ice. Performance of an icebreaker cruising through ice fields has been mainly evaluated using model experiments in an ice model basin. It is difficult to evaluate the performance of an icebreaker through varying many parameters because special facilities and skilled experts are necessary for ice model basin experiments, and because only a few experiments can be done for one prepared ice sheet. Because of these reasons, parametric optimization of icebreaker design is impractical at present.

To take measures to deal with this problem, the authors' group has begun development of a numerical method to simulate icebreaker performance under conditions that many ice pieces surround the ship hull (Konno et al., 2005; Konno and Mizuki, 2006). Studies of this kind are not reported frequently.

Physically-based modeling was incorporated into our simulation. Therefore, the program can be used to model collisions and friction that occur between an ice piece and a ship, and among ice pieces. As the first stage of this research, we specifically examined a simulation with a pre-sawn ice test so that breaking of ice need not be considered. In the simulations, ice pieces are modeled as rigid bodies. Results of the numerical simulations will be discussed.

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SIMULATION DETAILS

Physically-Based Modeling

To simulate icebreaker performance, it is necessary to address collisions and other mutual interactions among ice pieces and the ship. We incorporated the physically-based modeling (Baraff, 1997a,b) into our program to handle that situation.

Physically-based modeling is a method to simulate motions of numerous, independent solids with collisions, frictions and other constraints among solids. It is used in, for example, in computer games, computer graphics animation, and artificial reality to realize a physically reasonable motion of solids. A solid is often modeled as a rigid body, or a set of rigid bodies connected by some constraints such as joints. The motion of each solid is calculated by numerically integrating the momentum equation that is associated with the solid. Constraints such as boundary conditions, non-penetrating conditions and joints are not embedded into the momentum equation; forces or impulses that are attributable to the constraints are calculated explicitly.

Open Dynamics Engine and Implementation of Physically-Based Modeling

We used the ODE library developed by R. Smith (Smith, 2004) to implement physically-based simulations. The ODE is a library that facilitates implementation of physically-based modeling. This library has capabilities of collision detection, calculation of mutual interaction forces, integration of momentum equations and a simple animation.

An ice piece was modeled as a rigid body; breaking of ice is not considered. Its motion is specified by applying virtual force.

$$\boldsymbol{F}_v = \nu(\boldsymbol{v} - \boldsymbol{v}_f) \tag{1}$$

In that equation, $\boldsymbol{v}$ represents the ice piece velocity; and $\boldsymbol{v}_f$ is the velocity to be enforced. In addition, ν is an arbitrary positive parameter to control the stability of ice motion. Buoyancy of the ice pieces is also considered.

An icebreaker is also modeled as a rigid body. Its position and orientation are fixed: motion is prohibited.

Pre-sawn Ice Test

We simulated a pre-sawn ice test (Izumiyama and Uto, 1995). In the pre-sawn ice test, an ice sheet is cut into pieces with certain sizes and shapes and arranged appropriately. After that, a model icebreaker is towed through that ice field. Ideally, no ice-breaking phenomena occur. This experiment is intended to measure ice clearing resistance.

Calculation Domain, Model Ship and Ice Preparation

Table 1 shows calculation conditions. Figure 1 shows sizes and arrangements of ice pieces corresponding to conditions in Table 1. The calculation domain and location of a model ship are also shown in Fig. 1. Because this simulation is intended to simulate a model experiment, sizes were set to meet the conditions of the model experiment. This configuration is based on the pre-sawn experiment reported by Izumiyama and Uto (1995).

Three patterns of ice preparations were used for simulation. In cases (a) and (b), rectangular ice pieces were used with different sizes and arrangements to each other. In case (c), parallelepiped ice pieces, which have the same shape as those of a real pre-sawn experiment reported in Izumiyama and Uto (1995), were used. In ODE, a rectangular ice is represented as a ‘Box’, and a parallelepiped ice is represented as a ‘TriMesh’, which is a set of triangles.

Model ship B-060, which was designed by the National Maritime Research Institute, was used in this simulation. The ship was represented as a TriMesh, with 6000 (case (a) and (b)) or 18000 (case (c)) triangles.
External forces affected each ice piece, as shown in Eq. (1), where $v_f = 0.389\,\mathrm{m/s}$ and $\nu = 0.1\,\mathrm{N \cdot s/m}$.

RESULTS AND DISCUSSION

Behavior of Ice Pieces

Figure 3 shows the motions of ice pieces. Three cases of ice preparations are shown. Views of each image are explained in Fig. 2. The following results were obtained.

1. In all cases, ice pieces seem to behave appropriately, including colliding behavior.
2. Rectangular ice pieces behaved better. Simulations with rectangular ice pieces were stable; no penetration occurred.
3. However, it is curious that the motions of ice pieces in the port side differed from those of the starboard side despite their symmetrical simulation conditions.
4. The parallelepiped pieces did not behave as naturally as rectangular pieces. Some ice pieces penetrated the ship. Motions of ice pieces were unstable; ice pieces sometimes floated away unusually quickly.
5. Behavior of parallelepiped ice pieces depends on meshes of ice pieces and the ship, and the time step of simulation. Calculation parameters of ODE also require tuning. Figure 3(c) shows the best results. However, even in that result, penetrations of ice pieces against the ship and the fixed ice sheets were apparent, e.g., at 3 s, an ice piece penetrates the fixed ice sheet on the port side.

The above inappropriate results are attributable to inaccurate collision detection of ODE. Our simulation experience shows that TriMesh-TriMesh collisions sometimes do not work well. TriMesh-Box collisions behave better.

Simulation of Contact Points

Figure 4 shows contact points of parallelepiped ice pieces against ports of the ship in simulation case (c). Motions of ice pieces are also shown. Contacts between $\pm 0.2\,\mathrm{s}$ of a certain time are plotted; for example, contacts between $1.8\,\mathrm{s} \leqq t \leqq 2.2\,\mathrm{s}$ are plotted for $t = 2\,\mathrm{s}$.
These results show that this simulation can estimate, at least qualitatively, contact points of ice pieces against a ship. These results are not verified yet because we do not have experimental data to compare against our results. It is difficult to measure contact points of ice pieces in model experiments, especially in pre-sawn ice tests, for collisions are instantaneous and contact forces are weak.
Contact forces are not yet available in our simulation so that we cannot compare our results against experimental results by Izumiyama and Uto (1995). ODE does not provide application programming interfaces (APIs) to obtain contact forces, although they must be calculated somewhere in the library. The APIs to provide collision points are also not provided. For that reason, we modified the library to print the points. Simulations of contact forces are an important subject for this research because these forces directly affect the performance of icebreakers. It seems that we must enhance ODE to fit for our purpose, or find or implement another physics engine.

CONCLUSIONS

This research project was intended to simulate motions of ice pieces around an icebreaker. This paper described methods of numerical simulation of interaction between icebreaker and ice pieces. The ODE is a library that facilitates implementation of physically-based modeling. It was used to handle mutual interactions such as collisions between a ship and ice pieces.

Calculations were carried out to simulate the pre-sawn ice tests held in The Ice Model Basin at National Maritime Research Institute. The model ship B-060 was used for both experiments and simulations. Virtual fluid force and buoyancy were considered for each ice piece.

Three simulation results, which simulate pre-sawn ice tests, were presented. Collision and friction between ice pieces and a ship were simulated. Rectangular pieces behaved almost appropriately; however, asymmetric motion was found under symmetric boundary conditions. Parallelepiped ice pieces sometimes behave inappropriately. This seems to be the result of inaccurate collision detection of ODE. By tuning the meshes, time steps and control parameters of ODE, the behavior of ice pieces was improved.

Contact points of ice pieces against a ship were estimated by enhancing ODE. To obtain contact forces, further enhancement or better implementation of the physics engine is necessary.

ACKNOWLEDGMENTS

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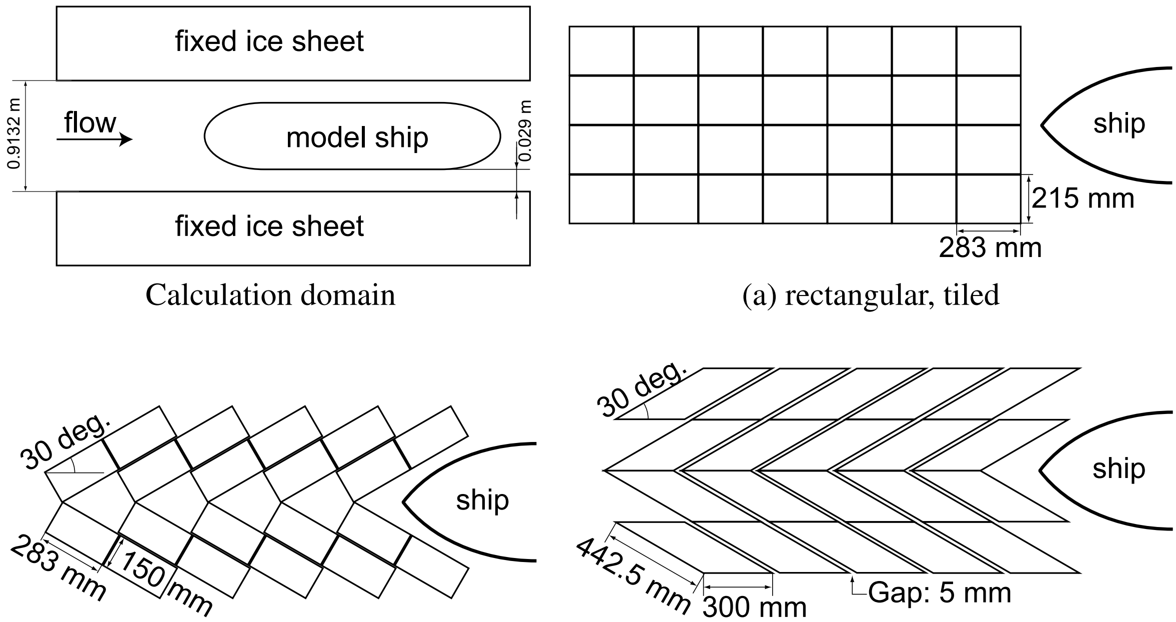
Table 1: Calculation conditions

Simulation case	(a)	(b)	(c)
Ice shape	rectangular	rectangular	parallelepiped
Representation in ODE	Box	Box	TriMesh
Number of polygons for an ice piece	—	—	44
Number of polygons for a ship	6000	6000	18000
Time step	0.01 s	0.01 s	0.005 s



Calculation domain (a) rectangular, tiled

(b) rectangular, rotated (c) parallelepiped

Thickness of ice: 29.5 mm

Figure 1: Calculation domain and initial placement of ice pieces

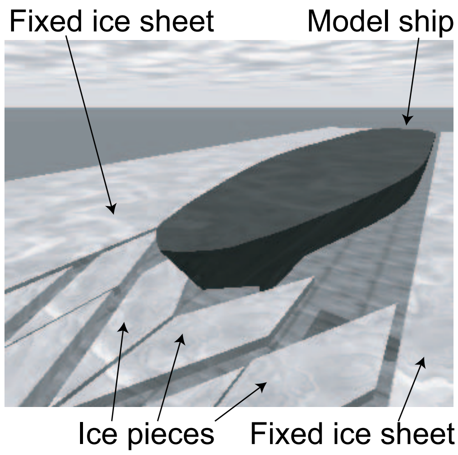
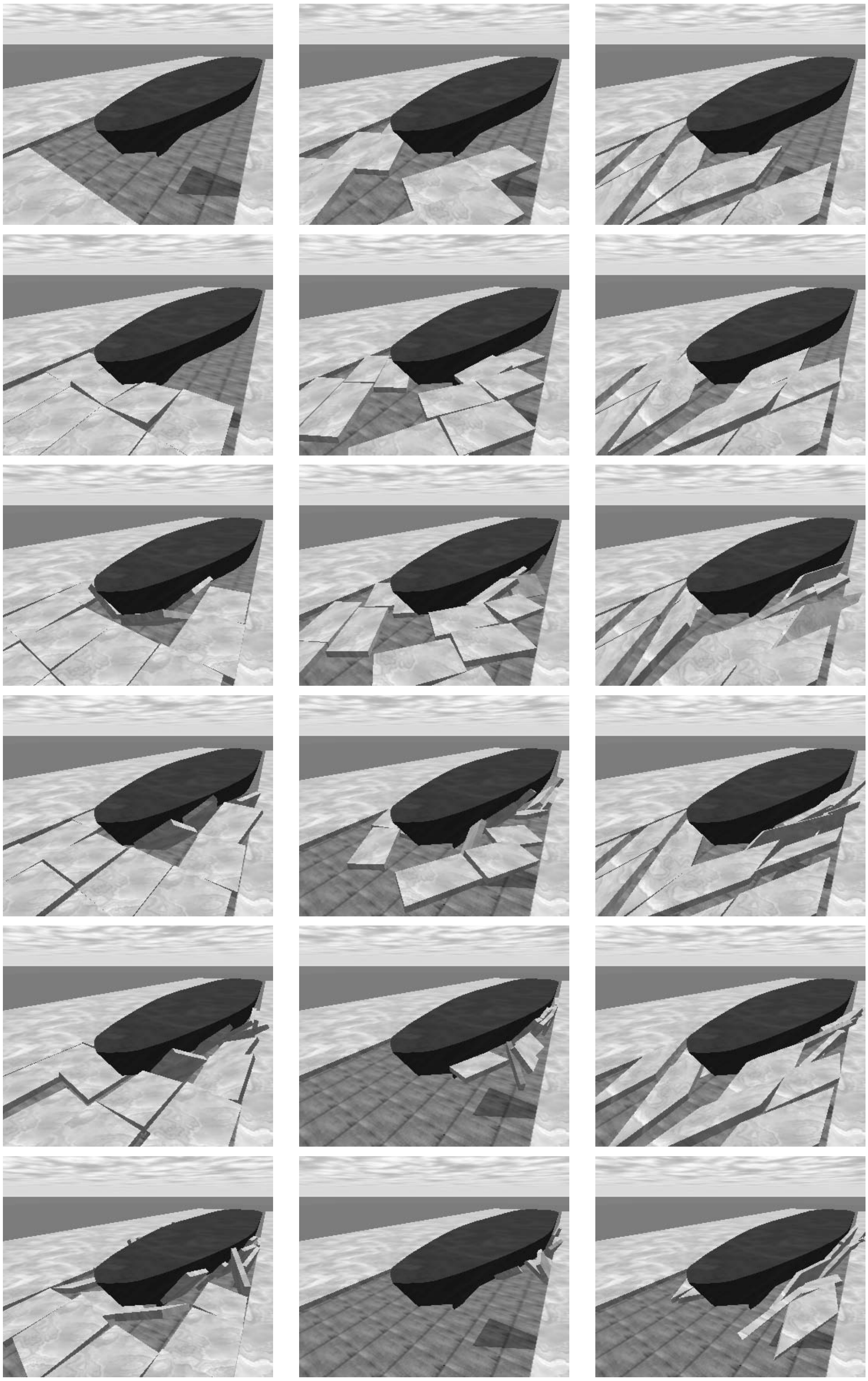


Figure 2: Explanation of motion view. Ice pieces are enforced to move from left bottom to right top.



Time: 0 s

1 s

2 s

3 s

4 s

5 s

(a) rectangular, tiled (b) rectangular, rotated (c) parallelepiped

Figure 3: Motion of ice pieces colliding with a ship. Three cases are shown.

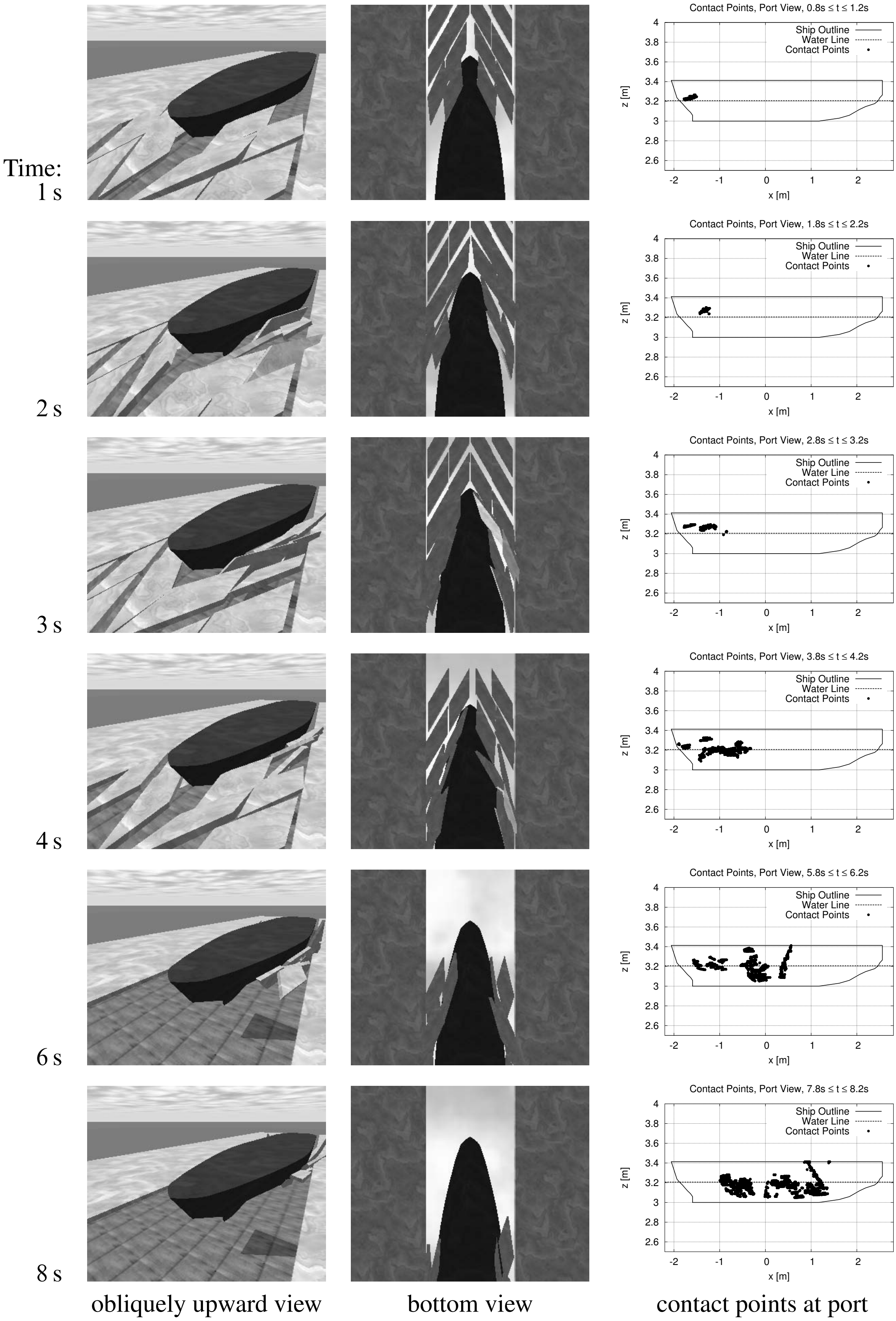


Figure 4: Motion of ice pieces colliding with a ship, and contact points of ice pieces against the ship hull. Case (c), with parallelepiped ice pieces, is shown.