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Experiments on level ice loading on an icebreaking tanker with different ice drift angles

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ABSTRACT

A series of tests was performed with a laboratory-scale model ship to simulate the effects of ice load parameters on an icebreaking tanker. A model of the icebreaking tanker Uikku was mounted on a rigid carriage and towed through an unbroken ice sheet in the ice tank of the Marine Technology Group at Aalto University. Two ice sheets and 11 different experimental configurations were used. The carriage speed, heading angle of the model ship, and ice thickness were varied, and the forces, accelerations, ice cusp sizes, carriage positions, and ice pile dimensions under the intact ice sheets were measured.

This paper includes results for the measurements of ice rubble loads against the model hull in the horizontal plane. Phenomena such as ice failure modes and ice rubble accumulation on the upstream side of the hull beneath the ice sheet were observed in some tests. The icebreaking lengths and dimensions of ice rubble were analyzed for some tests. The effects of towing speed, heading angle under the intact ice sheet in front of the hull, and the accompanying ice loads on the formation and build-up of ice rubble were analyzed. In addition, the evolution of ice rubble geometry, in cross sections and the horizontal plane, was investigated. There was good agreement over several orders of magnitude between the measured and calculated values of the lateral ice forces. These results are relevant to the modeling of ice loading on hulls and the design of moored or dynamic positioned structures for operation in ice-covered waters. Some parameters obtained from these tests can be used as input for future numerical simulations.

1. Introduction

As hydrocarbon exploration moves northward, there has been an increased interest in the study of stations for use in ice-covered waters. In Arctic waters, the presence of floating ice presents several challenges that relate primarily to level ice loads under dynamic ice conditions. Moored or dynamically positioned structures operating in ice-covered waters may experience extremely high loads due to massive accumulations of ice in front of the structures. Ice accumulation is considered to be a critical issue that affects continued operations of stations in icy environments.

Kovacs and Sodhi (1981) described the phenomena of shore ice pile-up and ride-up on Arctic and subarctic beaches and proposed the potential danger that they present to drilling platforms. Relevant load events for the Kulluk were reported by Wright (1999). These load events were the result of pressure in the ice cover that created ice accumulations in front of the Kulluk and maximum loads on its hull. Ettema and Huang (1988) carried out tests to model the motion of a ship through a thick layer of ice rubble (45% of the draft of the test hull) and related the resistance caused by ice rubble to the size of the ice fragments. Gurtner et al. (2008) recently performed model tests for the Shoulder Ice Barrier protective structure, in which they studied ice rubble buildup at the waterline where the structure sloped upward. Bonnemaire et al. (2008) conducted model tests on the Arctic Tandem Offloading Terminal, which consisted of two units: a turret moored offloading icebreaker (OIB) and an offloading tanker moored in tandem at the OIB aft. Special attention was given to observations of subsurface ice transport and underwater ice accumulation.

Croasdale (1980) considered two-dimensional systems and derived simple equations to calculate the ice forces on the sloping faces of structures. The total horizontal force on the sloping structure consisted of the forces necessary to break the ice and push the ice pieces up the structure. However, there were some limitations with this 2-D theory, which might be accurate for very wide structures and, most likely, for inaccurate for narrow structures. In addition, it modeled only a single layer of ice blocks riding up the slope of a structure. To improve the deficiencies and the underestimation of ice breaking forces by the 2-D theory, Croasdale et al. (1994) added adjustments for 3-D effects, such as in-plane compression, and took into account the effects of the ice rubble field in front of the structure. For vertical structures with wide necks and poor ice clearing capacity, he describes the process of ice rubble build-up shown in Fig. 1: (1) the ice sheet undergoes normal bending failure and rides up; (2) the ice continues to ride up the vertical shaft

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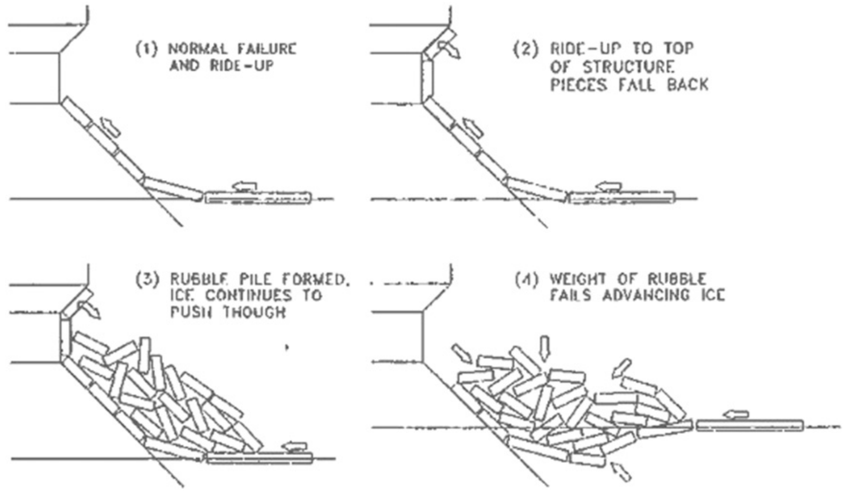

Fig. 1. Sequence of ice rubble buildup (Croasdale et al., 1994).

before ice blocks fall down onto the intact ice sheet; (3) a rubble pile forms in front of the structure; and (4) the intact ice sheet continues to push through the rubble and fail when it comes in contact with the sloping structure. This sequence is repeated. For a wide structure, the rubble is not cleared away from the structure in an efficient manner. Therefore, if a rubble field exists in front of the structure, additional forces are necessary to push the advancing ice sheet through the ice rubble, to push the ice blocks up through the ice rubble, and to lift and shear the ice rubble on top of the ice sheet.

Sea ice in the Arctic waters often changes direction as it drifts, due to changes in the directions of the current and wind. Drifting ice can approach a structure from any direction and interact with the vessel. The interaction geometry varies with changes in the ice drift direction relative to the heading of a hull at its waterline. Thus, loads introduced by the drifting level ice and the resulting ice rubble should be considered as design loads for station keeping systems in certain locations.

The primary goal of the present laboratory study was to measure the effects of level ice loads on fixed icebreaking tankers and to investigate the corresponding phenomena during the loading process at different constant ice drift directions and speeds. Ice failure modes at different parts of the hull and ice rubble accumulation underwater were observed with videos and photos, and icebreaking patterns were discussed for different cases. For some tests where ice rubble accumulations were generated, the process of ice rubble accumulation was analyzed in cross sections and horizontal planes and compared with the predictions proposed by Croasdale (1980, 1994). The corresponding transverse ice loads were measured for 90° heading cases and simply compared to the calculated loads based on Croasdale's 2-D and 3-D models.

2. Experimental setup

2.1. Test facility

The experiments were performed in the multifunctional ice basin of the Marine Technology Group at Aalto University. The tank is 40 m long by 40 m wide and 2.8 m deep. A carriage inside the tank moves in plane and can reach any point on the surface. A spray process was used to form fine-grained model ice. The number of spray iterations and the type of cooling process were used to adjust the ice thickness and strength, respectively.

2.2. Model of the vessel and data acquisition system

The MT Uikku is a double hull icebreaking tanker. The linear dimensions of the tanker were reduced to the model scale with a geometric scale factor, λ. Froude and Cauchy scaling was performed with the inertial, gravitational and crushing forces that are important in the ice model tests. A scaling factor of $\lambda = 31.6$ was used for these tests. The model ship was trimmed to an even keel without heel angle so that the center of buoyancy and the center of gravity were in the same longitudinal and transverse location. The particulars of the model and the full-scale vessels are given in Table 1.

The model ship was constrained so that the six force components could be measured. An upper frame with a stiff tube and long beam was used to connect the towing carriage, where the load measurement units were attached to the ship model (Figs. 2–3).

The following instrumentation was used in the tests (Figs. 2–3):

- An LFX-A-3KN compact 6-component force transducer with a built-in amplifier (3 kN capacity) was used to measure the applied ice loads. The transducer was mounted on the model ship to enable the simultaneous measurement of 3 forces in 3 axial directions orthogonal to the transducer and 3 moments around the axes. The output from this transducer was proportional to the loads caused by the ice forces on the hull at the waterline.
- A one-directional load cell with a capacity of 500 kN was used to measure the applied force in the yaw direction. The output from this load cell was proportional to the external yaw moment.
- A dynamic measurement unit (DMU) measured the liner accelerations of the model ship. Six fully conditioned analog signals were output by the DMU, which was connected directly to a data acquisition device without further buffering.
- Two cameras were used in this work. One camera was fixed to the bow of the model ship above the water and oriented backwards

Table 1
Primary dimensions of MT Uikku.

Item	Full scale	Model scale
Length [m]	150	4.75
Breadth molded [m]	21	0.67
Tested Draft [m]	9.5	0.30
Bow waterline angle [deg]	21	
Bow stem angle [deg]	30	
Block coefficient	0.72	