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Comparison of Ice Load Development on Non-Planar Surface

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It is important to understand the sequential ice load that develops on ships during ice-structure interaction when the ship's structure may not be a planar surface. Laboratory tests have traditionally been performed on the basis of the assumption that the shape of the structure is perfectly flat or slightly concave. This study is designed to consider cases where the structural shape is a concave conical or wedge shape. The results obtained are compared with flat-surface test conditions. Trends in force-displacement, pressure-area curves, contact area, and changes of pressure within the contact region are evaluated. The pressure distribution on the non-planar surfaces shows a significant difference and induces a higher ice load in comparison with a flat surface.

INTRODUCTION

Ice-strengthened ships, equipped with a data measuring system, have been used to collect ship-ice collision data in the Arctic since there has been a demand for full-scale data for practical design and research purposes. Field tests were started in the 1970s, led by industries and research institutions from all around the world. Along with full- and medium-scale tests in the field, laboratory-scale ice experiments were carried out by universities and research institutions (Akagawa et al., 2001; Daley, 1994; Frederking, 1999, 2004; Masterson and Frederking, 1993; Sodhi, 1998, 2001, 2006; Sodhi et al., 2006; Takeuchi et al., 2002; Tuhkuri, 1995). Based on the test results of these full- and model-scale laboratory ice experiments, the researchers were able to increase their understanding of ice-structure interaction.

Most ice load measurements, whether performed in the lab or field, have considered the structure to be a nearly rigid body with only small elastic deformations. This represents the fact that most laboratory and field trial tests have been performed on the basis of the assumption that the structural shape is flat. As a result, ice pressure models and data have ignored the effects of surface structural deformations or local concavity. Therefore, little information is available for cases where the structure is concave due to plastic deformation or to specific areas with intentional structural concave shapes. However, the nature of ice-structure interaction could be quite different when the permanent plastic deformation of the structure or surface concavity is considered.

Ice-strengthened ships can encounter overload conditions during service periods in the Arctic owing to a variety of environmental conditions. In these cases, the ship's structure may be subjected to ice loads that exceed the intended design loads. As a result, the ship's structure can experience a plastic state that was never intended to occur. Plastic deformation due to overload conditions is not a common consideration of design conditions, and most existing studies and test data remain within elastic conditions. Consequently, existing references are generally not suitable for investigating ice-structure interactions beyond the plastic limit.

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Interest in structural locations other than the main hull structure, where ships may experience ice loads while operating in the Arctic, has also increased recently. For example, broken ice pieces can pass around a ship's propulsion system, impacting the structure around the podded propulsor in ice-strengthened ships. Consequently, the structure can experience an ice impact load.

In both cases mentioned, the ice will impact a convex- or concave-shaped surface rather than a flat surface. There is some evidence that concave-shaped structural areas may act to increase ice loads and pressures by increasing the confinement of extruded ice during impact. E. Kim (2014) examined ice drop tests and numerical simulation results against a deformable structure (a ductile event), and the results represented comparatively higher loads than the results for other cases. However, a confinement effect of the structural shape was not discussed.

The purpose of this study was to investigate ice impacts with concave-shaped indenter surfaces in order to determine if the structural shape of the impacted surface has a significant effect on the apparent ice loads and pressures.

TEST CONDITION

Ice Sample Preparation

A 250-mm-diameter cone-shaped ice sample was prepared in the laboratory. For preparation of the ice sample, destilled, de-aired, and deionized water was prepared and kept in a fridge to chill the water close to 0°C (to prevent melting ice chips during the mixing process) and was mixed into an insulated cylinder with ice chips produced from commercial ice cubes. The chips were sieved to exclude grain sizes smaller than 4 mm. The insulated cylinder was then placed in a freezer (with a subfreezing temperature between −30°C and −20°C) for at least 48 hours to freeze completely. As shown in Fig. 1, the insulated cylinder was wrapped around the side portions and covered on the top by insulation material. This arrangement will have led to unidirectional bottom-up ice growth as an intended control. As a result, the ice sample had a uniform polycrystal with a homogeneous crystalline structure. This procedure may not perfectly exclude bubble or crack growth. However, ice samples were kept as constant as possible through the following of the same procedure to achieve a test repeatability, which is more significant than a completely bubble- and crack-free ice sample. Once the ice sample was completely frozen, it was removed from the insulated cylinder and mounted on ice sample shaving equipment to achieve the desired cone angle, as