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Influence of load length on short-term ice load statistics in full-scale

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ABSTRACT

This paper studies the frequency of ice loads of varying lengths and the occurrence probability of their magnitudes in full-scale. In these measurements, the four frames were instrumented with shear strain gauges on the Polar Supply and Research Vessel S.A. Agulhas II. The experiments were carried out on first-year ice in the Baltic Sea. An influence coefficient matrix based on analytical and numerical analyses was used to determine the load length in the horizontal direction. Rayleigh separation was used to define the load amplitudes. The measurements show that the ice loading has to be long in order for the shear-load maximum on a single frame to occur. Furthermore, the statistical study showed that the Weibull distribution gives the best fit to the measured loads on a frame. The probability distribution of the ice loads on a frame is exponential-like for short loads and lognormal-like for long loads.

1. Introduction

Natural resources and shorter sea routes have increased the activities and interest in the Arctic. Thus, the need for ice-capable merchant vessels and safe ships is increasing. The design of safe ships requires knowledge of ice-induced loads on the ship hull. However, the ship-ice interaction process is complex. The process starts with the ice failing through crushing. The contact area increases as the ship penetrates into ice. Then, typically, the ice bends until final failure occurs. In this process, the ice-induced force on the structure increases until the ice fails through shear or bending failure; see Fig. 1. The broken pieces are submerged under the hull as a result of the flow of water induced by the speed of the ship. A bending failure creates a cusp-like breaking pattern and a new breaking cycle begins after the ship reaches the edge of the ice sheet. The complexity of the process arises from the variation in the ice conditions (e.g. strength, thickness, first- or multi-year ice), ship operations (e.g. manoeuvres), and in the location and area of the contact (e.g. ship shoulder, mid-ship). As all the variations are embedded in the full-scale measurements, the knowledge of the ice-induced loads has been gathered by conducting full-scale measurements; see e.g. Ref. [1–6].

Full-scale measurements have shown that the magnitude and area of the ice-induced loading can vary significantly even in short-term measurements; see Fig. 2 and e.g. Ref. [9]. In the design of ship structures, the load is often considered as an average pressure over a certain area, i.e. a load patch; see e.g. Ref. [10]. The definition of an area can be divided into a global and local area. A global area denotes the projection of the structure onto the original shape of the intact ice field. A local area considers smaller sub-regions within the global area that are subjected to high local pressures [11]. The studies with data

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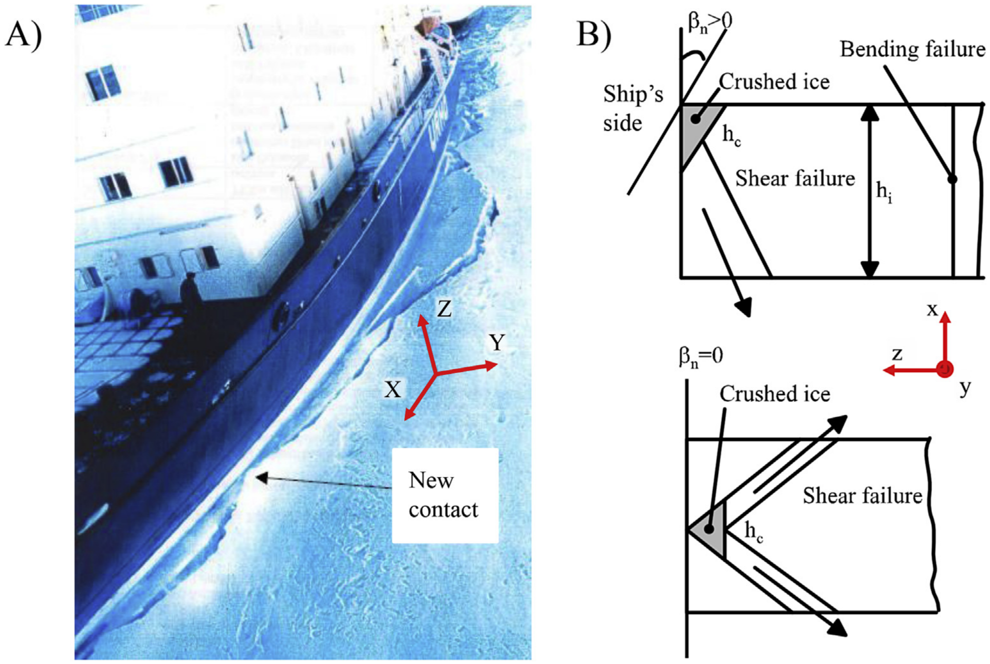

Fig. 1. A) The breaking pattern around the ship hull [7]. X, Y, and Z denote the global coordinate system common to ships. B) An idealization of the ice edge failure process [8]. β_n, h_c, and h_i denote the frame angle, contact height, and ice thickness, respectively. x, y, and z indicate the local coordinate system for the local structure common to the solid mechanics.

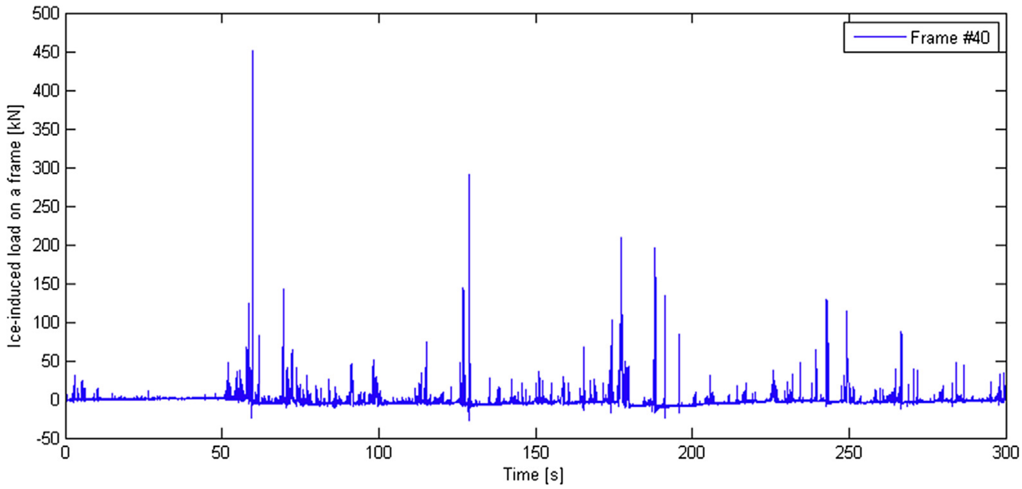

Fig. 2. The ice-induced load time history measured at the aft shoulder frame of S.A. Agulhas II in the Baltic Sea.

collected on ships and offshore structures have shown a decreasing trend of the pressure as a function of the area for both global and local pressures; see e.g. Ref. [11–15]. However, the extent of global contact area and exposure time can increase the local pressures even though the average global contact pressure decreases [11,16,17].

Riska et al. [18] and later e.g. Taylor and Richard [19] observed from full-scale measurements that the ice-induced pressure is line-like in the first-year ice conditions. This allows the use of load length rather than the area. In this paper, the load length refers to the horizontal length of the contact area. The assumption is also implemented in the Finnish-Swedish Ice Class Rules (FSICR) [20] in the dimensioning of frames. The line load can be obtained by measuring the shear strains on the web of the frame to obtain the force acting on the frame in full-scale and dividing the force by the frame spacing. The line load has also been determined from the observed damage by employing the plastic limit load approach and ice damage; see e.g. Ref. [21]. In FSICR, the magnitude of the line load as a function of the load length is embedded in a coefficient, c_a, which takes into account the probability that the full length of the area under consideration will be under loading. The coefficient has been defined on the basis of a set of measurements on board ships in the Arctic and Baltic; see Refs. [2,21,22] for the measurements and [23] for