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Safe Speeds of Navigation in Ice as Criteria of Operational Risk

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ABSTRACT

Safety of ships operating in ice-choked waters depends, among other factors, on operational aspects (first of all, speed) and on the structural capability of the ship. Generally, ice class is the primary but rather vague criterion characterizing ship's operational limits and her structural strength. A better assessment of ship's safety and operational limits can be obtained from safe speed analysis for the ship in question. Solving a structural response problem with regard to the speed of ship/ice impact can yield the ship's speed limits in given ice conditions and corresponding to the chosen strength criteria. The main ice-related parameters and ship/ice impact scenario characteristics are treated statistically. This in conjunction with a wide range of structural strength criteria (including plastic deformations up to the ultimate plastic state of local side structures) made it possible to provide a probabilistic interpretation of the safe speed, e.g. via risk levels of ice-induced damage versus ship speed in ice. The paper outlines the concept of safe speed definition, describes the nature and the model of speed-dependent ship/ice impact loading, presents a range of damage criteria up to the ultimate load-bearing capacity in plastic stage, explains the probability-based approach and shows the role of safe speed analysis for different ice classes.

CONCEPT

Ice class assigned by a classification standard requires a minimum level of ice strengthening of hull structures. This level is assumed to be sufficient for normal operations of ships in the ice conditions associated with the ice class. But these ice conditions are defined very vaguely at best and the operational modes in ice are not specified at all. In reality, ice class ships operate in ice according mainly to accumulated experience and established traditions within the limits of governmental regulations wherever they exist. Classification standards of ice strengthening usually do not include speed as a parameter in selecting the ice class and in determining the design ice loads on hull structures. But the hierarchy of ice classes expressed via a hierarchy of design ice loads and other requirements implies that ships of higher ice classes are capable of operating not only in more severe ice conditions but also at higher speeds than ships of lower ice classes. This common perception is vague, however, and needs to be quantified for specific situations.

As ice impact loads on hull structures are inherently speed-dependent, the structural redundancy or safety margin built in in the rules can diminish and disappear with an increase in operational speed. Assessment of safety and operational limits for each individual ship can be obtained from safe speed analysis. It is the minimal value of all maximum speeds satisfying a set of expressions equating the speed-dependent ice loads due to possible ship/ice impacts and the load-bearing capacity of the structure affected, solved for every ice-loaded structural member or grillage (Tunik, 1986), i.e.:

$$V_{safe} = \min(V^j_{\max}) \qquad P_j(V) \le P_j(\sigma_a, \varepsilon_a) \qquad (1)$$

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where $P_j(V)$ is the speed-dependent ice impact load on the j^{th} ship structure (element); $P_j(\sigma_a, \varepsilon_a)$ is the load-bearing capacity of the j^{th} ship structure with respect to allowable criteria for stress-strain $(\sigma_a, \varepsilon_a)$ state; $V^j_{\max}$ is the maximum ship speed satisfying conditions (Eq. 1) for the j^{th} structural member (grillage); and V is the ship speed.

The safe speed has nothing to do with propulsion capabilities. It is a stand-alone criterion characterizing the limits of hull structures to absorb impact ice loads. In reality ice-going ships very seldom experience problems in propulsion and structural strength simultaneously. When ice conditions are sufficiently severe for a ship to propel, her speed is low and impact loads are relatively low as well. When the ship encounters moderate or no ice resistance and is sailing relatively fast in leads, polynyas, or thin ice with immediately adjacent strong ice features, she can hit the features resulting in high impact loads and damages. This is the scenario for a great majority of speed-related damage. It is the basic scenario in the safe speed concept that applies to all modes of independent navigation, as well as to many but not all modes of moving in a channel behind a leading icebreaker. As a result, the safe speeds are not related directly to ice thickness, but rather to the probabilities of encountering strong and massive ice features. The resulting safe speeds are expressed either as probabilistic (or return period) curves in probabilistic analysis or as discrete values for simplified discrete calculations.

It should be noted that the safe speed concept discussed in this paper is different from the concept adopted currently in the Russian "ice passport" system. Historically the safe speed concept was first introduced by D. Kheisin and V. Kurdyumov in the late 1970s as a by-product of their analytical model of ship impact against ice (Kurdyumov and Kheisin, 1976). This became possible because their model was the first and only one where the resulting ice load parameters (force, pressure, etc.) were analytically derived as functions of velocities, masses, geometries and mechanical properties of colliding ship and ice feature. Unfortunately, the authors did not publish any papers on safe speed, nor did they mention safe speeds in their other works on structural strength of ships under ice loads. Gradually, safe speeds had been incorporated into the ice passport system, very vaguely in the early 1980s (Maxutov and Popov, 1981) and then coupled with