International Journal of Offshore and Polar Engineering
Vol. 6, No. 2, June 1996 (ISSN 1053-5381)

Modelling of Nonsimultaneous Ice Crushing as a Poisson Random Process

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ABSTRACT

A statistical model is developed to explain the scatter in measured ice crushing pressures with varying nominal contact areas. The statistical characteristics of the ice crushing pressure are determined by modelling the crushing as a compound Poisson process. This is done to develop a concept that can be used for definition of the statistical characteristics of the crushing pressure as a function of the nominal crushing area. The properties of the statistical variables used in the model are determined based on full-scale measurements onboard the icebreaker *Sampo* in the northern Baltic Sea. The obtained pressure-area curves are also compared with the available crushing test results from the Baltic ice.

INTRODUCTION

Ship interaction with level ice is initiated by crushing of the ice edge, and the crushing continues until the ice cover breaks due to the shear or bending failure. It is the ice crushing process at the contact between a structure and the ice edge that has caused most of the difficulties in the development of a reliable statistical model of ice loading. This is a common problem for both ice-strengthening of ships and designing of offshore structures to be used in ice-covered waters. The earliest and still widely used concept of the contact was developed by Korzhavin (1971) for vertical structures in level ice. He assumed that the contact pressure is related to the uniaxial compressive number of ice and that the effects of structural shape, contact length, and number of the contact spots can be taken into account by empirical coefficients. Therefore, in his approach, the statistical aspects are buried in the empirical coefficients. This nominal contact pressure formulation was developed further by Varsta (1983) and Riska and Frederking (1987) for the multiaxial stress state in ice.

The first analytical models to explain the statistical nature of the ice failure process were based on the concept of independent, nonsimultaneous failure zones (Kry, 1978). These were later developed by Ashby et al. (1986). This model was based on the assumption that the contact width in level ice can be divided into a number of statistically independent zones. The width of these zones should be at least four times the ice thickness (Kry, 1980). Each zone was assumed to apply some nominal pressure to the structure and fail independently into ice when the failure pressure of ice is reached. With these assumptions and by applying simple probability theories, a mean value and standard deviation for the total load as a function of the contact area were obtained. When the contact area increases, the probability of having all the zones in contact decreases. Therefore, the maximum pressure as a function of contact area decreases. The contact length parameters and nominal contact pressure are arbitrary constants as no criteria for these were given (Sanderson, 1988). The nonsimultaneuous failure concept has recently been extended to a more rigorous statistical basis by applying the so-called shot noise model (Takeuchi and Saeki, 1994) to generate time series of ice-induced pressure peaks and to study the spatial distribution of compressive strength of ice. In addition, detailed surveys and statistical analyses of the measured data of local pressures induced by ice on structures have been given by Masterson and Frederking (1992) and Jordaan et al. (1993).

Recent research results have indicated that the brittle failure process of ice can result in a line-like contact between a structure and ice (Joensuu and Riska, 1989; Fransson et al., 1991; Tuhkuri, 1993). The orientation of the line-like contact is sensitive to the orientation of the columnar grains in ice (Tuhkuri, 1993). The physical background for the line-like contact has not been thoroughly explained even though a process model of the contact was presented by Daley (1991), who described the brittle ice failure as a sequence of through-body shear cracks that occur when the gross stresses on the failure plane reach critical values. The failure process was found to behave chaotically. Recent attempts to model the statistical nature of the contact also include the application of fractal concepts (Bhat, 1990). Fractals offer new possibilities to formulate the contact characteristics, but these models are at present mainly qualitative.

In this paper, a statistical model is developed to explain the scatter in the measured ice crushing pressures with varying nominal contact areas (Kujala, 1994). The crushing is described as a random Poisson process. The aim is to develop a concept that can be used to define the statistical characteristics of the crushing pressure as a function of the nominal crushing area. The properties of the statistical variables used in the crushing pressure model are determined based on the full-scale PVDF measurements onboard the IB *Sampo* in the northern Baltic Sea. Here, PVDF means small load sensitive polyvinylidene fluoride film pressure gauges (Joensuu and Riska, 1989).

ANALYSIS OF CRUSHING PROCESS

The strength of any solid is related to the statistical characteristics of a number of primary elements, each of which is to some degree responsible for the strength of the solid as a whole. For polycrystalline, natural ice, the grains and contact surfaces among them form the primary elements. Grains can differ in size, orientation, elasticity and strength. The failure of this type of material under compression with brittle behaviour is a complex process. In addition to the large variation of failure geometries, this complexity is caused by the interaction of the primary elements during the failure process (Bolotin, 1969).

Crushing is used here as a general term for ice failure under compression. Crushing is described by defining the contact pres-

Received August 2, 1995: revised manuscript received by the editors October 20, 1995. The original version was submitted directly to the Journal on August 2, 1995.
KEY WORDS: Ice pressure, ice load, nonsimultaneous ice crushing, Poisson process.