

## Ice Load Equation for Level Ice Sheet

Takahiro Takeuchi  
 Hachinohe Institute of Technology, Hachinohe, Japan

Satoshi Akagawa and Hiroshi Saeki\*  
 Hokkaido University, Sapporo, Japan

Naoki Nakazawa  
 Systems Engineering Associates Inc., Tokyo, Japan

Ken-ichi Hirayama  
 Iwate University, Morioka, Japan

### ABSTRACT

A series of Medium Scale Field Indentation tests (MSFIT) has been performed as part of the JOIA project, and the influence of model structure width ( $W$ ), ice thickness ( $h$ ), indentation speed ( $V$ ) and uniaxial compressive strength ( $\sigma_c$ ) on ice load have been examined. The global ice load ( $F_i$ ) equation for level ice is derived from MSFIT data and factors incorporated into the equation are determined based on the main parameters ( $V$ ), ( $h$ ), ( $W$ ) and ( $\sigma_c$ ).

### INTRODUCTION

As a part of the project, a lot of local as well as global ice load data has been obtained since 1996 from medium-scale field indentation tests (MSFIT) under various test conditions of indentation velocity  $\{V\}$ , ice thickness  $\{h\}$ , and model structure width  $\{W\}$  with a rectangular face. A 2-dimensional panel sensor that can measure pressures at many points over a small area was also used to determine the ice failure pattern in addition to local ice pressures. These results were reported in Akagawa et al., 1999, 2000; Nakazawa et al., 1999; Saeki et al., 1998; Sodhi et al., 1998; and Takeuchi et al., 1997, 1998, 1999, 2000, 2001. Two types of ice deformation and failure are observed depending on  $\{V/h\}$ . The boundary between these types is located at  $3 \times 10^{-3}$  (1/s) of  $\{V/h\}$ . Multi-failure of an ice sheet occurs under the condition of  $\{V/h\} > 3 \times 10^{-3}$  (1/s), called the brittle range, and nonsimultaneous transmission of the ice force on a structure at different positions predominates. On the other hand, under the condition  $\{V/h\} < 3 \times 10^{-3}$  (1/s), called the ductile range, ice deforms simultaneously even at the irregular leading edge of an ice sheet; simultaneous transmission of the ice force predominates over the structure. In this paper, an equation is proposed for estimating the global ice force in both the ductile and brittle ranges, and a process is performed for determining factors incorporated into the global ice force equations in both ranges.

### ICE/STRUCTURE INTERACTION MODEL

When an ice sheet with an irregular leading edge interacts with a structure (Fig. 1), 2 types of deformation and failure occur,

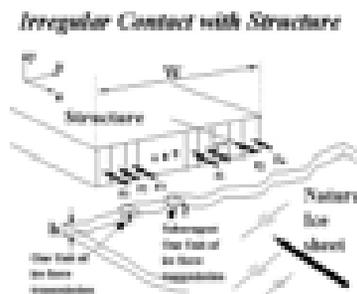


Fig. 1 Ice/structure interaction

depending on  $\{V/h\}$ . When  $\{V/h\}$  is larger than  $3 \times 10^{-3}$  (1/s), ice fails in a nonsimultaneous manner with increasing  $\{V/h\}$  (Figs. 1 and 2a). A unit of interaction between ice and structure transmits a force to a structure at salient parts of the leading edge of an ice sheet, and the shape irregularity makes force transmission nonsimultaneous at different interaction areas. The size of a unit of interaction has a range of values and is approximately  $\{h \times h\}$  from the correlation coefficient between ice forces (Takeuchi et al., 1999). Thus, the total number  $n$  of unit interactions over the structure is:

$$n = \frac{W \times h}{h \times h} = \frac{W}{h} \quad (1)$$

The global instantaneous ice force acting on a structure is given by:

$$F_i(t) = \sum_{i=1}^{n_e} F_i(t) \quad (2)$$

where  $F_i(t)$  is the instantaneous local force acting on the contact zone  $A_f$  and  $n_e$  is the number of contact zones interacting with the structure. The local force  $F_i(t)$  is written as:

$$F_i(t) = P_i(t)A_f \quad (3)$$

\*ISOPE Member.

Received September 17, 2001; revised manuscript received by the editors April 9, 2002. The original version (prior to the final revised manuscript) was presented at the 11th International Offshore and Polar Engineering Conference (ISOPE-2001), Stavanger, Norway, June 17–22, 2001.

KEY WORDS: Ice load, sea ice, panel sensor.