

# Indentation Pressure in Ice/Vertical Structure Interaction

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## ABSTRACT

The relationship between the indentation pressure and indentation area is examined through field ice indentation tests. The local ice pressures obtained show intermittently sharp peaks and recessions, and moreover do not satisfy the assumption that ice pressure in an independent ice failure zone follows the log-normal distribution used by Kry (1978). The nature of the contact between ice sheet and structure during the indentation of structure into ice sheet is investigated statistically. This paper suggests that the indentation pressure can be expressed as a function of contact ratio, indentation area and ice strength.

## INTRODUCTION

The understanding of nonsimultaneous failure of an ice sheet at independent failure zones (IFZ) is important in the evaluation of indentation pressure on a wide structure in an ice-infested sea area. In general, the ice force, when the structure is narrow, indicates a maximum value (first peak force) at simultaneous failure of the ice sheet in front of the structure. After that, there is a subsequent force not exceeding the first peak force. Design ice force has been evaluated from first peak force. In contrast, when there is interaction of a wide structure with an ice sheet, failure of the ice sheet at the front of the structure is featured by nonsimultaneous failure and irregular contact between structure and ice sheet (Kry, 1978). Consequently, when the evaluation of ice force based on first peak force is applied directly to a wide structure, ice force will tend to be overestimated. Sodhi (1992) showed through laboratory tests that the contact area between the indenter and ice sheet during brittle flaking of ice was small by measuring pressure in different parts of the indenter, and then that the small contact leads to less effective pressure on the indenter. Riska (1991) measured spatial ice pressure distributions in laboratory and icebreaker tests, and the results showed that the local pressure decreased as pressure gauge area increased. Masterson and Frederking (1993) compiled a lot of data on local ice pressures and forces on structure and ship, and suggested design curves for local ice pressures on structures.

In this study, field indentation tests using freshwater lake ice were conducted to investigate failure characteristics of ice sheet, total ice force and local pressure. In turn, the relationship between indentation pressure and indentation area is investigated by considering especially the contact condition between ice sheet and indenter.

## INDENTATION TESTS

The ice indentation tests were conducted at Lake Shinotsu and

Lake Hakucho in Hokkaido. The natural ice had reached a thickness of more than about 30 cm at both lakes (freshwater). In tests, newly formed ice sheets of good quality were used to avoid any accumulated snow. The test conditions considered here are shown in Table 1. At the beginning of the indentation test, the contact condition of the leading edge of ice sheet with indenter is idealized (perfect) for Exp. 1, 3 and 7. For Cases 2, 3 and 4, the leading edge of the ice sheet is irregular, and first peak force did not occur. Total ice force was determined by measuring the pressure inside the hydraulic jack by pressure sensor and multiplying the pressure by hydraulic cross-sectional area. Local ice pressure was measured by pressure sensors attached to the front of the indenter. The arrangements of pressure sensors mounted at the surface of indentors are shown in Fig. 1. All sensors are set at central locations in ice thickness in each test. The diameters of two types of sensors are 8 and 14 mm. A standard-displacement transducer attached to the indenter was used to measure indentation velocity. Ice temperature ranged from 0 to -2°C during tests.

## TEST RESULTS

Typical total force data are plotted in Fig. 2 (Exp. 1) where initial contact of ice sheet with indenter is idealized. This shows that a first peak force due to simultaneous ice sheet failure occurs, and subsequent forces are due to nonsimultaneous failure based on irregular and imperfect contact. Examples of local ice pressures are shown in Fig. 3. (Exp.1). The time histories of ice pressure data show intermittently sharp peaks and recessions, and catastrophic properties are predominant through local failure of the ice sheet due to intermittent contact between ice sheet and indenter.

TEST	Ice Thickness <i>h</i> (cm)	Velocity <i>V</i> (cm/s)	Ice Strain Rate $*10^{-3} (d\epsilon/dt)$ $s^{-1}$	<i>W</i> (cm)	$\sigma_c$ (MPa)	Aspect Ratio (W/h)
Exp. 1	7.0	1.774	4.4	100	6.85	14.3
Exp. 3	7.0	1.171	3.0	100	6.85	14.3
Exp. 7	11.9	1.03	8.5	30	4.67	2.5
Case 2	6.5	1.08	2.7	100	4.88	15.4
Case 3	6.5	1.084	2.7	100	4.88	15.4
Case 4	6.5	1.111	2.8	100	4.88	15.4

Table 1 Test conditions

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KEY WORDS: Nonsimultaneous failure, indentation pressure, subsequent force, first peak force.