R4816-000
ICE FORCE STUDIES
IN THE BOTHNIAN BAY
Phase 2 1989-94

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FOREWORD

The second phase of the project ICE FORCES AGAINST OFFSHORE STRUCTURES was initiated in 1989 as an extension of the first phase of the study, conducted between 1985 and -88. The 2nd phase has been sponsored by

* **MOBIL Research and Development Corporation, USA**

* **Canadian Marine Drilling Ltd. (CANMAR), Canada**

* **The Swedish National Maritime Administration (NMA)**

Experience from the 1st phase of the study has been summarized in a series of five reports and, as an introduction, in the present report in which the achievements during the 2nd phase are then accounted for.

VBB VIAK has been responsible for the management of project. The main part of the field work has been carried out by **NMA**. Hamburgische Schiffbau-Versuchsanstalt **HSVA** has been responsible for the testing and operation of the Ice Force Sensing Panel System with assistance of the NMA staff.

The essence of our findings during the two phases of the project is presented in Chapter 9 in the form of a generalized model for numerical characterization of ice force time-histories and observations concerning important physical features of the ice-structure interaction, whether periodical or of a more chaotic character.

Stockholm March 21, 1994
VBB VIAK

Alf Engelbrektson

LIST OF SYMBOLS ETC

Units

SI units are generally used in this study

Symbols

h: ice thickness
b: instantaneous width of ice-structure contact area
d: diameter of a cylindrical indentor

f_u: uniaxial strength of the ice (compressive if not otherwise stated)

f_{um}: "mean uniaxial strength", averaged over the contact area (compressive if not otherwise stated)

p: contact pressure between the ice and the structure

p_{eff}: "mean effective ice pressure", the unidirectional ice pressure averaged over a defined gross contact area, normally h x b, i.e.

$$p_{eff} = \frac{F}{h \times b}$$

F: "global ice force" i.e. the total unidirectional ice force on a structure, instantaneous or averaged over a certain period of time

F_{max}: the "peak global ice force" during a certain period of global ice force variations (in our studies the "peak force" is in fact also averaged, since it is related to the measured response of a structure, but it is normally averaged over a very small fraction of the period of the most significant mode of structural vibrations)

ΔF: amplitude of ice force fluctuation around the mean global ice force averaged during a certain period of time or determined as a low-frequency (filtered) load.

k_S: "shape factor", the ratio between global ice loads on e.g. cylindrical and plane indentors

k_I: "indentation factor", for factoring the ice load with respect to the aspect ration b/h

k_C: "contact factor", for factoring the ice load with respect to imperfect contact between the ice and the structure

$k = \frac{p_{eff}}{f_{um}}$ a common factor, accounting for all the abovementioned and other factors for transformation of the uniaxial ice strength to effective ice pressure on a structure

v: ice drift velocity

v_R: velocity of indentation or relative velocity between the moving ice and a vibrating or otherwise moving structure

v_S: velocity of the contact surface of the structure in the ice drift direction

$K_\phi = \frac{F\ Z_F}{\phi}$ rotational stiffness factor

ϕ: inclination of the lighthouse (above ice level and for static ice loads if not otherwise indicated)

Z_F: distance between the resultant ice force and the base of the structure

x_1, x_2, x_3, x_4 displacements corresponding to instruments Nos 1-4 (locations) and directions given in the text

x (t), $\dot{x}$ (t) $\ddot{x}$ (t) time functions of the parameters of motion in horizontal direction

$\ddot{x}_R$ (t) time functions of the recorded acceleration

$\ddot{x}_\phi$ (t) time function of the fraction of gravity caused by the inclination of the structure

$\bar{x}$, $\bar{\dot{x}}$, x etc. dashed symbols indicate mean values or low-frequent components of motion

F (f) Fourier wave amplitudes

θ (f) phase angle of a component wave

$\alpha = \frac{\ddot{x}}{x}\phi$ ratio between "tilt acceleration" and displacement

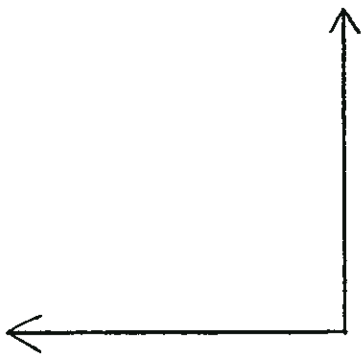
Symbols used in the computer calculations and plotted diagrams

A1, A2	Structural acceleration and signal No. (Signals 1 and 2 are relating to the upper instrument level.)
V1, V2	Structural velocity and signal No.
D1, D2	Structural displacement and signal No.
I3, I4	Inclinometer signals.
T3, T4	Tilt angles corresponding to I3, I4.
F1, F2	Ice force components in directions Nos 1 and 2.
Fres	Resultant ice force.
Fdir	Direction of resultant ice force

KEY TO COORDINATE SYSTEMS, SCALES AND TRANSFORMATION OF UNITS

Norströmsgrund lighthouse

N Direction x_1 (accelerometers)



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Direction x_2 (acc.)

ϕ_4 and x_4 (incl.)

Instrument reading units:

- Accelerometers u_1, u_2

- Inclinometers u_3, u_4

Transformation of instrument reading units to units used in calculations:

- Accelerometers $\ddot{x}_R 1 = - u_1 \cdot 0.00191\ m/s^2$

$\ddot{x}_R 2 = u_2 \cdot 0.00191\ m/s^2$

- Inclinometers

$$\phi_3 = u_3 \cdot 2.564 \cdot 10^{-7} \text{ radians } *$$

$$\phi_4 = u_4 \cdot 2.564 \cdot 10^{-7} \text{ radians } *$$

$$x_3 = \phi_3 \cdot g/\alpha_f$$

$$x_4 = \phi 4 \cdot g/\alpha_f$$

$$\alpha_f = 0.315 \quad **$$

$$k = \frac{M}{\phi} = 7.378 \cdot 10^{11} \text{ Nm/radians}$$

$$F = M/z_F$$

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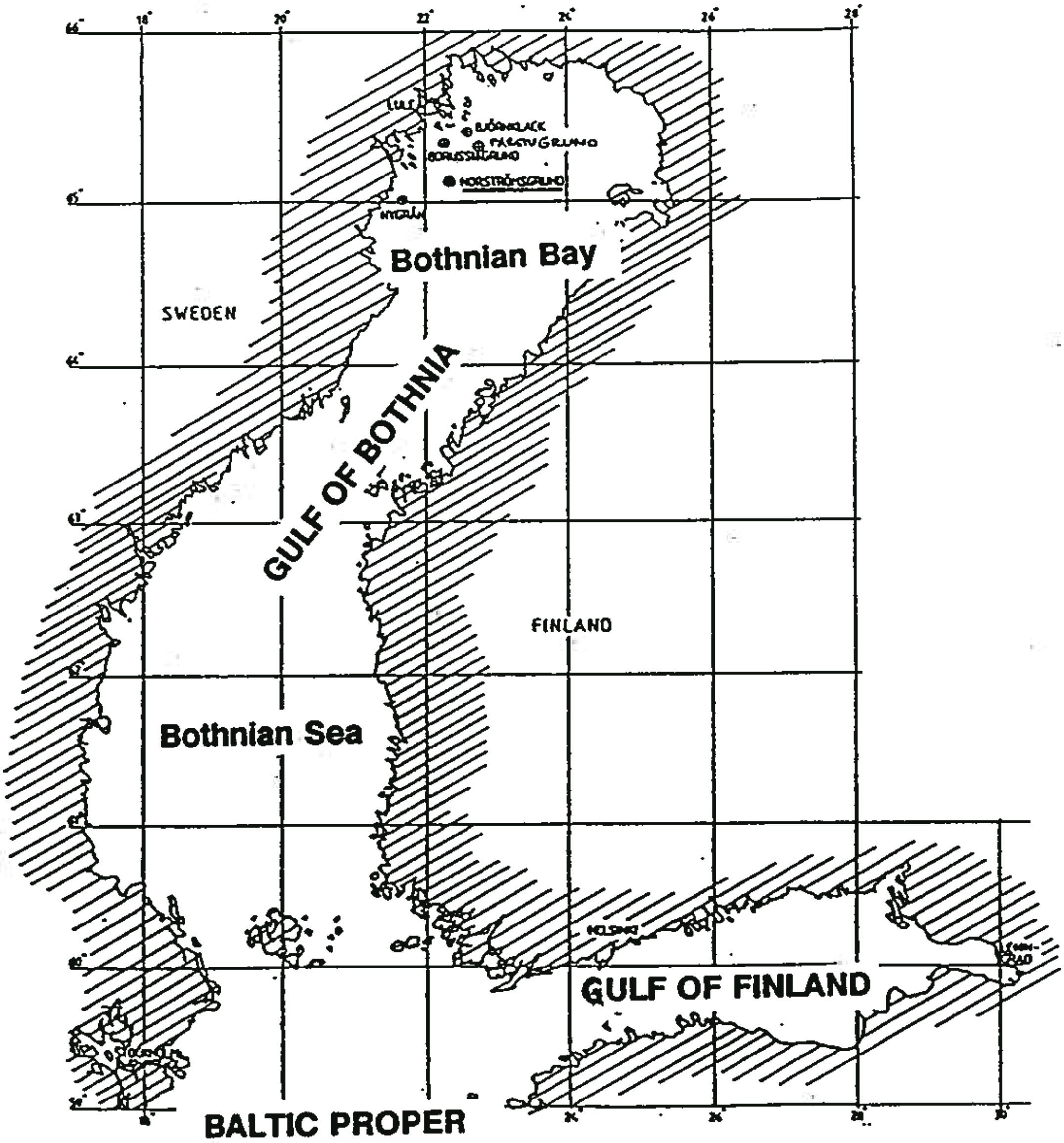
* u_3 and u_4 are filtered and calculated after the isolation of the horizontal acceleration component form the gravity component

** Determined by pull tests in July, 1988



Bothnian Bay
SWEDEN
GULF OF BOTHNIA
FINLAND
Bothnian Sea
GULF OF FINLAND
BALTIC PROPER