Available online at www.sciencedirect.com
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Publishing Services by Elsevier
International Journal of Naval Architecture and Ocean Engineering 8 (2016) 301−311
http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/

Determination of global ice loads on the ship using the measured full-scale motion data

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Received 22 September 2014; revised 19 November 2014; accepted 24 February 2016
Available online 13 June 2016

Abstract

This paper describes the whole procedures to determine ice-induced global loads on the ship using measured full-scale data in accordance with the method proposed by the Canadian Hydraulics Centre of the National Research Council of Canada. Ship motions of 6 degrees of freedom (dof) are found by processing the commercial sensor signals named Motion Pak II under the assumption of rigid body motion. Linear accelerations as well as angular rates were measured by Motion Pak II data. To eliminate the noise of the measured data and the staircase signals due to the resolution of the sensor, a band pass filter that passes frequencies between 0.001 and 0.6 Hz and cubic spline interpolation resampling had been applied. 6 dof motions were computed by the integrating and/or differentiating the filtered signals. Added mass and damping force of the ship had been computed by the 3-dimensional panel method under the assumption of zero frequency. Once the coefficients of hydrodynamic and hydrostatic data as well as all the 6 dof motion data had been obtained, global ice loads can be computed by solving the fully coupled 6 dof equations of motion.

Full-scale data were acquired while the ARAON rammed old ice floes in the high Arctic. Estimated ice impact forces for two representative events showed 7−15 MN when ship operated in heavy ice conditions.

Keywords: Global ice load; Ship motions of 6 degrees of freedom; Motion Pak II; GPS; Band pass filter; Resampling

1. Introduction

Traditionally, global ice impact forces on ships have been measured by strain gauging the structure. That approach involves treating the ship as an elastically deformable structure. Its structural deformations are measured by strain gauging strategic hull-girder beams throughout the ship. Measuring structural strains can be an effective method for measuring global loads, however installing the gauges can be a time-consuming (and expensive) process.

Recently, a novel approach for determining global loads on ships was put forward by the Canadian Hydraulics Centre of the National Research Council of Canada (NRC-CHC). The method assumes the ship is a rigid body and uses its whole-ship motions to determine external ice forces. The whole ship motions in six-degrees of freedom are measured using an instrument called the MOTAN. Specially developed MOTAN software is used to process those motions and calculate global impact loads. To date, the MOTAN has been used on three icebreakers with satisfaction (Johnston et al., 2003).

Following the method proposed by the NRC-CHC, an algorithm and an analysis tool (hereinafter "program") to estimate global ice load based on the ship motion data were developed. The analysis program was used to calculate the

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Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2016.03.006

global ice load on the ship that processes the measured ship motion signals, linear accelerations and angular rates by a commercial sensor, Motion Pak II (Motion Pak II User's Guide).

This paper describes the whole procedures to compute the global ice loads of a ship. Linear velocities were computed by the measured linear acceleration by Motion Pak II and the linear displacements were obtained by the integration of the linear velocities without drift. Angular accelerations and the angles were computed by the differentiation and the integration of the measured angular rates using Motion Pak II during the full scale sea trials of Korean research vessel ARAON rammed ice floes in the high Arctic. To eliminate the noise of the measured signals, a band pass filter (Vegte, 2001) that passes between 0.001 and 0.6 Hz were developed and the cubic spline interpolations were applied to resample the measured data. The measuring rates were 100 Hz, however, the time interval of the resample data were 0.005 s to get more accurate 6 dof motions without any drift during the integration of the signals. Linear velocities were obtained by the integration of the measured Motion Pak II data and the linear displacements were obtained by integration of the computed linear velocities. Angular accelerations as well as angular displacements were obtained by the differentiation and the integration of the filtered angular rates. Hydrostatic coefficients were computed by the hull form data and the hydrodynamic data, added mass and damping coefficients, were computed by the three-dimensional panel method under the assumption of zero-frequency. Once the 6 dof motion data and all the coefficients of the equations of the motion were found, global ice loads were computed in a straightforward way using the developed program.

When a ship rams in the ice floes, ship motions must be affected by the ice loads acting on the ship. When a ship collides with the large and hard ice floes, the ship motions should be varied significantly than that of small and soft ice floes. In order to calculate the effect of load by ice on ship, an ice load analysis algorithm was developed using an obtained ship motion data as well as the computed hydrodynamic forces of a ship. An ice load analysis program based on LabVIEW using the ship motion data during a full-scale ice-breaking test was then developed.

2. Equations of motion to determine global ice loads

The ice-breaking vessel considered in this study operates at a low speed when breaking ice. The global ice loads can be computed as follows.

$$\mathrm{F}^{Ice} = \{\mathrm{M}\}\ddot{\eta} + \{B\}\dot{\eta} + \{C\}\eta \tag{1}$$

Where

$$\mathrm{F}^{Ice} = \left[F_x\, F_y\, F_z\, M_x\, M_y\, M_z\right]^2$$

$$\eta = [x\, y\, z\, \Phi\, \theta\, \psi]^2$$

$$\{\mathrm{M}\} = \begin{bmatrix} m - X_{\dot{u}} & 0 & -X_{\dot{w}} & 0 & mz_G - X_{\dot{q}} & 0 \\ 0 & m - Y_{\dot{v}} & 0 & -mz_G - Y_{\dot{p}} & 0 & mx_G - Y_{\dot{r}} \\ -Z_{\dot{u}} & 0 & m - Z_{\dot{w}} & 0 & -mx_G - Z_{\dot{q}} & 0 \\ 0 & -mz_G - K_{\dot{v}} & 0 & I_x - K_{\dot{p}} & 0 & -I_{xz} - K_{\dot{r}} \\ mz_G - M_{\dot{u}} & 0 & -mx_G - M_{\dot{w}} & 0 & I_y - M_{\dot{q}} & 0 \\ 0 & mx_G - N_{\dot{v}} & 0 & -I_{zx} - N_{\dot{p}} & 0 & I_z - N_r \end{bmatrix}$$

$$\{\mathrm{B}\} = \begin{bmatrix} X_u & 0 & X_w & 0 & X_q & 0 \\ 0 & Y_v & 0 & Y_p & 0 & Y_r \\ Z_u & 0 & Z_w & 0 & Z_q & 0 \\ 0 & K_v & 0 & K_p & 0 & K_r \\ M_u & 0 & M_w & 0 & M_q & 0 \\ 0 & N_v & 0 & N_p & 0 & N_r \end{bmatrix}$$

$$\{\mathrm{B}\} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_z & 0 & Z_\theta & 0 \\ 0 & 0 & 0 & K_\Phi & 0 & 0 \\ 0 & 0 & M_z & 0 & M_\theta & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$Z_Z = -\rho_w g A_{WP}$$

$$Z_\theta = \mathrm{M}_Z = \rho_w g \iint_{A_{WP}} x dA$$

$$K_\Phi = -\rho_w g \nabla (z_G - z_B) - \rho_w g \iint_{A_{WP}} y^2 dA = -\rho_w g V GM_T$$

$$M_\theta = -\rho_w g \nabla (z_G - z_B) - \rho_w g \iint_{A_{WP}} x^2 dA = -\rho_w g V GM_L$$

The hydrostatic restoring force and moment coefficient matrix (C) can be obtained from the given ship characteristics, while the hydrodynamic added mass and the damping coefficients ($\mathrm{X}_{\dot{u}}$ and X_u etc. in M and B) are computed by the three-dimensional panel method assuming a motion of frequency of zero.