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Long-Term Predictions of Vertical and Horizontal Accelerations for a Ship in Ocean Waves*

by

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Introduction

Many computer programs are now available for the purpose of analysing the hull structure strength including the local, transverse and longitudinal strength. In view of the general importance of local and transverse strength analysis for large oil tankers, ore carriers and bulk carriers, accurate informations are required about the local and transverse internal loads on the hull structure due to bulk cargo such as oil, ore and grain as well as the external hydrodynamic loads on the hull surface, which are both induced by the ship motions in waves. As the first stage of evaluating the internal dynamic loads due to oil, ore and grain, the magnitude of vertical and horizontal accelerations induced by the ship motions is a matter which requires very close analysis.

Recently, in Japan, the systematic research works on the local and transverse loads including external and internal loads, which are induced on transverse ship sections, have been continued by the Research Committee SR-131 under the sponsorship of "The Shipbuilding Research Association of Japan". As a part of those research works, the long-term predictions of vertical and horizontal accelerations have been made for an ore carrier of 247 meters length and 117,570 tons deadweight. Important results of the predictions are presented here.

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Predicting Methods

a) Response Functions of Vertical and Horizontal Accelerations

By the aid of the modified strip theory, the heave, pitch, sway, yaw and roll motions of a ship in regular oblique waves can be obtained as follows [1],

$$\left.\begin{aligned}
\zeta &= \zeta_o\cos(\omega_e t-\varepsilon_\zeta) = \zeta_c\cos\omega_e t + \zeta_s\sin\omega_e t \\
\phi &= \phi_o\cos(\omega_e t-\varepsilon_\phi) = \phi_c\cos\omega_e t + \phi_s\sin\omega_e t \\
\eta &= \eta_o\cos(\omega_e t-\varepsilon_\eta) = \eta_c\cos\omega_e t + \eta_s\sin\omega_e t \\
\psi &= \psi_o\cos(\omega_e t-\varepsilon_\psi) = \psi_c\cos\omega_e t + \psi_s\sin\omega_e t \\
\theta &= \theta_o\cos(\omega_e t-\varepsilon_\theta) = \theta_c\cos\omega_e t + \theta_s\sin\omega_e t
\end{aligned}\right\} \quad (1)$$

By using the solutions of ship motions in the form of (1), the vertical and horizontal displacements of a point p(x,y,z) can be obtained as follows,

$$\begin{aligned} Z &= \zeta - (x-x_G)\phi + y\theta \\ &= Z_o\cos(\omega_e t-\varepsilon_Z) = Z_c\cos\omega_e t + Z_s\sin\omega_e t \end{aligned} \quad (2)$$

$$\begin{aligned} Y &= \eta + (x-x_G)\psi - z\theta \\ &= Y_o\cos(\omega_e t-\varepsilon_Y) = Y_c\cos\omega_e t + Y_s\sin\omega_e t \end{aligned} \quad (3)$$

Accordingly, the vertical and horizontal velocities and also the vertical and horizontal accelerations of a point (x,y, z) can be obtained as follows, by ignoring the component of the gravity acceleration,

$$\dot{Z} = \omega_e Z_o\cos(\omega_e t - \varepsilon_Z + \pi/2) \quad (4)$$

$$\dot{Y} = \omega_e Y_o\cos(\omega_e t - \varepsilon_Y + \pi/2) \quad (5)$$

$$\ddot{Z} = \omega_e^2 Z_o\cos(\omega_e t - \varepsilon_Z + \pi) \quad (6)$$

$$\ddot{Y} = \omega_e^2 Y_o\cos(\omega_e t - \varepsilon_Y + \pi) \quad (7)$$

where the coordinate system as defined in [1] is adapted.

b) Predictions of Vertical and Horizontal Accelerations in Short-Term Seaways

By using the calculated response amplitudes of vertical or horizontal acceleration together with the I.S.S.C. wave spectrum adapted to the short-term sea condition, the variance of vertical or horizontal acceleration can be evaluated based upon the linear superposition theory. It follows that

$$R^2 = (2/\pi)\int_{-\pi/2}^{\pi/2}\int_0^{\infty}[f(\omega)]^2[A(\omega,\delta+\gamma)]^2\cos^2\gamma d\omega d\gamma \tag{8}$$

$$[f(\omega)]^2 = 0.11H^2\omega_T^{-1}(\omega/\omega_T)^{-5}\exp[-0.44(\omega/\omega_T)^{-4}] \tag{9}$$

where

$[A(\omega,\delta+\gamma)]$: response amplitude of acceleration

ω : circular frequency of a component wave

δ : average heading angle against the average wave direction

γ : angle between the average wave direction and a component wave direction

H : average wave height estimated visually

$\omega_T = 2\pi/T$, T : average wave period estimated visually

c) Long-Term Predictions of Vertical and Horizontal Accelerations

The expected long-term probability that the peak value of vertical or horizontal acceleration exceeds a certain level α_1 can be evaluated by assuming that the ship navigates always with a constant heading angle δ in a sea route and by considering all heading angles with equal probability in that sea route. It follows that, respectively,

$$Q(\delta) = \int_0^{\infty}\int_0^{\infty}\exp[-\alpha_1^2/2R^2]p(H,T)dHdT \tag{10}$$

$$Q = (1/2\pi)\int_0^{2\pi}Q(\delta)d\delta \tag{11}$$

where

$p(H,T)$: long-term probability of occurence for the sea condition of the average wave height H and the average wave period T

Predicted Results

Short- and long-term predictions of vertical and horizontal accelerations have been carried out for the ore carrier "KASAGISAN-MARU" (247 meters length, 117,570 tons deadweight). Important results of the predictions are illustrated in Figs. 1 ∿ 4. Those illustrations show the predicted results of vertical and horizontal accelerations induced on the longitudinal axis through the ship's centre of gravity, which are produced by the heave, pitch, sway and yaw motions but not by the roll motion. The wave statistics of the North Atlantic Ocean summarized by Walden [2] are utilized for the long-term predictions.

According to the predicted results, there were found the following trends of vertical and horizontal accelerations.

1) Generally the vertical accelerations are larger than the horizontal accelerations.

2) The vertical accelerations induced on the ore carrier "KASAGISAN-MARU" are found to be very large in seaways of the average wave period of 10 ∿ 12 seconds, and the horizontal accelerations are found to be considerablly large in seaways of the average wave period of 6 ∿ 8 seconds.

3) The vertical and horizontal accelerations are found to be largest at the fore and after ends and to be smallest at midship. Magnitude of the vertical or horizontal acceleration is almost equivalent at the fore and after ends.

4) The vertical accelerations are found to be largest in head sea conditions and to be smallest in following sea conditions. They decrease with decreasing of ship speed in head and bow sea conditions but increase with decreasing of ship speed in following and quartering sea conditions.

5) The horizontal accelerations are found to be largest in beam sea conditions and to be smaalest in head and following sea conditions. They decrease a little with decreasing of ship speed.

Further investigations on the vertical and horizontal accelerations will be continued in order to make clear the influences of the roll motion and of the gravity acceleration.

References

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[2] H. Walden : "Die Eigenschaften der Meereswellen im Nordatlantischen Ozean" Einzerveröffentlichungen Nr. 41, Hamburg, 1964.

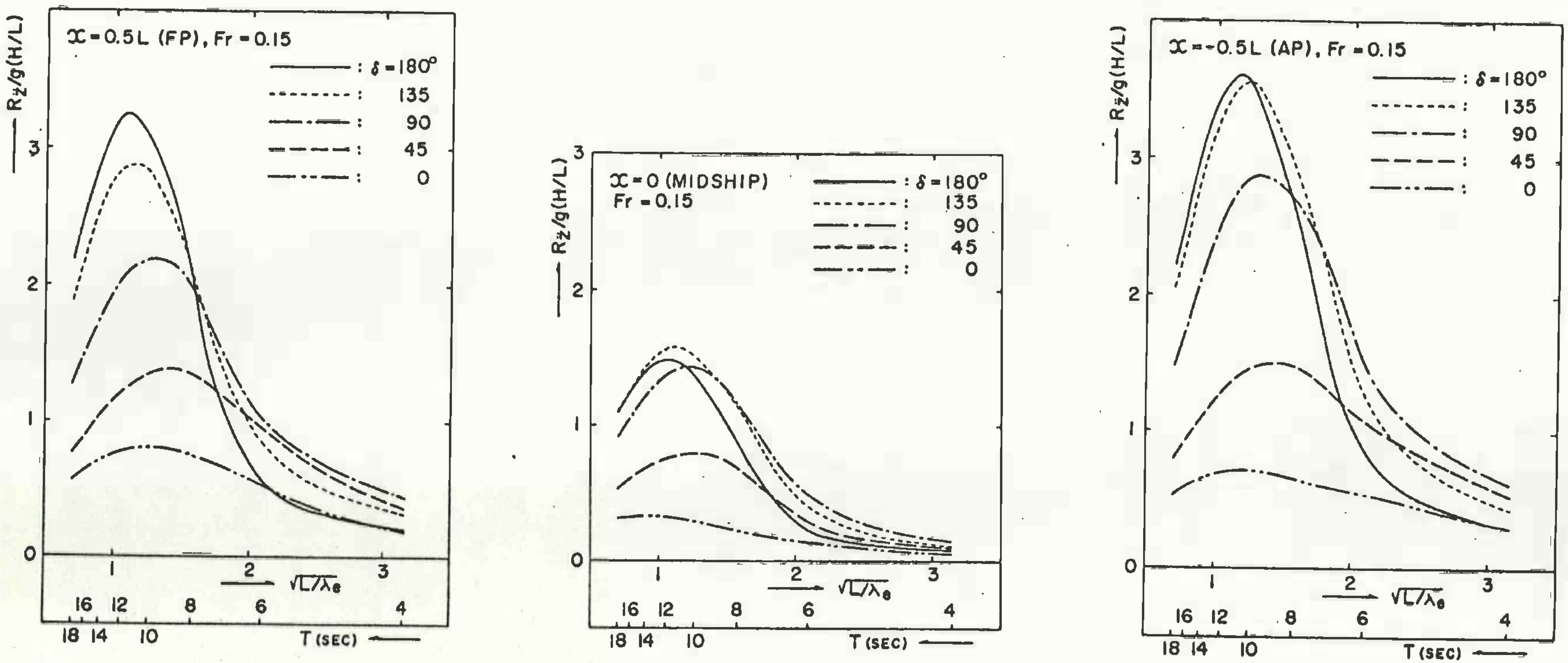

Fig. 1 Standard Deviations of Vertical Acceleration Induced on the Ship in Short Crested Irregular Seas

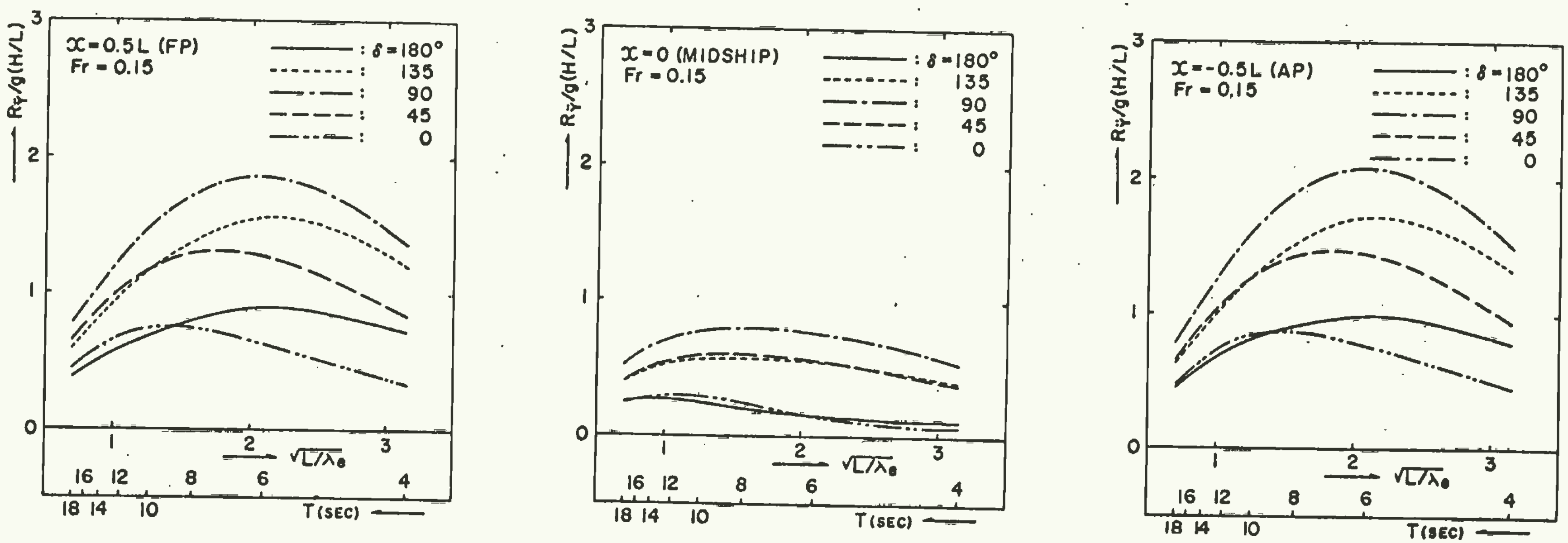

Fig. 2 Standard Deviations of Horizontal Acceleration Induced on the Ship in Short Crested Irregular Seas

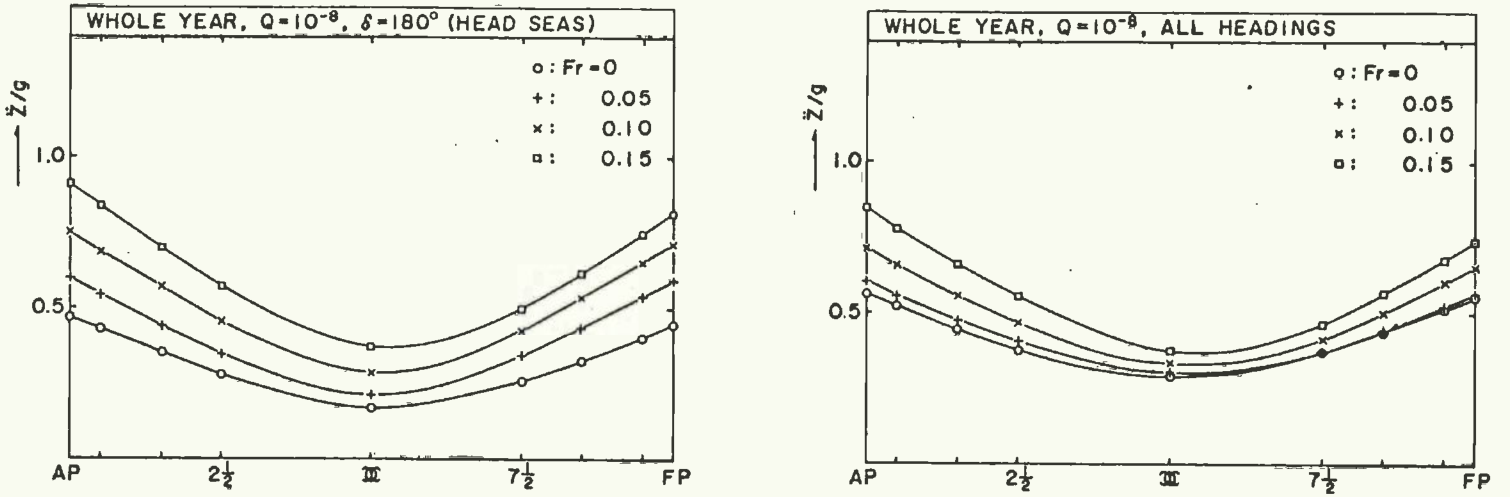

Fig. 3 Vertical Accelerations Predicted with the Exceeding Probability of 10^{-8} in the North Atlantic Ocean for Head Sea Condition and for All Headings

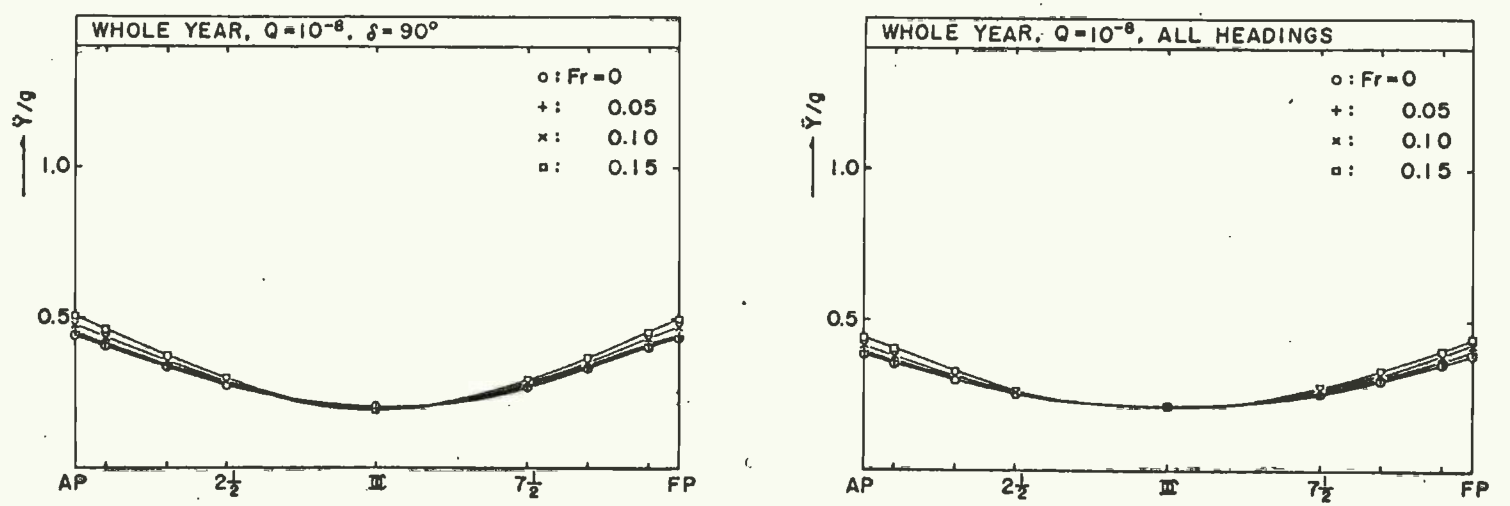

Fig. 4 Horizontal Accelerations Predicted with the Exceeding Probability of 10^{-8} in the North Atlantic Ocean for Beam Sea Condition and for All Headings