EFFECT OF SHALLOW WATER ON THE NATURAL PERIOD OF HEAVE

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EFFECT OF SHALLOW WATER ON THE NATURAL PERIOD OF HEAVE

By

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The paper deals with the natural period of pure heaving motion of a ship in shallow water.

Methods of the theoretical calculation and the model experiments are described.

It was shown that the natural heaving period of a ship in shallow water became longer than in deep water, and then comparison of theory and experiments for the natural period showed good agreement.

1. Introduction

Y. S. Yu and F. Ursell [1] calculated the hydrodynamic forces on the two-dimensional circular cylinder that oscillates on water of finite depth and then measured the amplitude of progressive wave generated by the heaving motion of the circular cylinder laid in the 100 ft. channel.

In this case, the results from experiment show good accord when for the wave amplitude they are compared with those from theory, the former being a few percents lower than the latter.

Hydrodynamic forces and moments acting on the Lewis-form cylinders that oscillate on the surface of shallow water have been lately calculated by one of the authors [2].

From these theoretical calculations, it is inferred that the natural heaving period of a ship in shallow water is generally longer than that in deep water.

In order to confirm this inference, we measured the natural heaving periods of three ship models in a shallow water tank and compared the results with the theoretical calculations.

2. Measurement of Natural Period of Heave

Experiments were carried out in the shallow water tank at TSUYAZAKI Sea Disaster Laboratory of Research Institute for Applied Mechanics, which

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is an annex of Kyushu University [3].

The shallow water tank is 25 m long, whose rectangular section is 5 m wide and 0.4 m deep. (See Fig. 1)

The ship models used in the experiments are shown in particulars in Table 1.

The natural heaving period of a ship model was measured by the accelerometer.

In the analysis of the experiments, we omitted the oscillogram record of the first half cycle and took the mean period of the following two cycles as the natural period of heave.

3. Theoretical Determination of Natural Period of Heave

The natural period of pure heaving motion of a ship is given by the formula

$$\tau_z = \frac{4\pi\,(m_z'' + m)}{\sqrt{4\,(m_z'' + m)\,\rho\, g\, A_w - N_z^2}} \tag{1}$$

, where m_z'' = added mass in heaving,
m = ship's mass,
A_w = waterplane area,
N_z = damping coefficient.

The period of exciting force i. e. the period of shallow water wave in our case, is obtained by

$$\tau = \sqrt{\frac{2\pi\lambda}{g}\;\frac{1}{\tanh\,(2\pi\, H/\lambda)}} \tag{2}$$

, where λ = wave length,
H = water depth.

For our convenience we introduce here a term of true natural period for the required natural period of heave and represent it by T_z.

This true natural period will be determined by the following four steps:

First we assume several exciting periods or frequencies by giving them some values of water depth H and wave length λ in accordance with the formula (2).

Secondly, we determine added mass and damping coefficient m_z'' and N_z that correspond to the exciting frequencies assumed above by the strip method.

Thirdly, we calculate the natural frequencies of heave τ_z which corresponds to the exciting frequencies assumed in the first step, by substituting the values of m_z'' and N_z obtained in the second step, into the equation (1).

Finally we plot both exciting and natural frequencies τ and τ_z as functions of the wave length λ and obtain the point of intersections, which provides the true natural period T_z.

The calculation of added mass and damping coefficient of a ship is carried

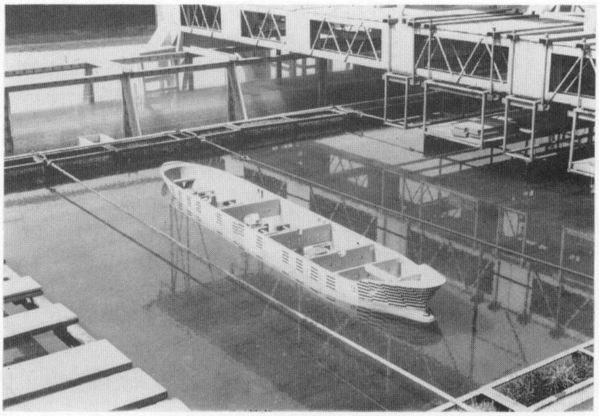

Fig. 1. The shallow water tank and a tanker model

(Facing p. 224)

out as usual: The ship length is equally divided into 10 cross-sections and the values of added mass and damping coefficient for each cross-section are obtained by two-dimensional theory [2]. Added mass and damping coefficient of a ship are obtained by integrating these two-dimensional values.

In our calculation of T_z, 3 meter long Todd 60 series models of $C_B = 0.6$ and 0.7 are adopted. The parameters of depth H/d were ∞, 10, 3, 2.5, 2, 1.75 and 1.5 for each model.

Computed results of virtual mass coefficient and damping coefficient for the model of $C_B = 0.7$ are shown in Fig. 2 and 3.

The ratio of period $T_z/T_{z\infty}$ to depth parameter H/d is given in Table 2 and also illustrated in Fig. 4.

The calculated value of the natural period $T_{z\infty}$ for the model of $C_B = 0.7$ was 1.05 and experimental value was 1.03 sec.

4. Discussion

Theoretical calculation showed good agreement with the result of experiments for $H/d > 1.5$.

It was found in this calculation that, at the depth of 1.3d, the theoretical solution to determine the added mass and damping coefficient did not converge. We were therefore obliged to break our calculation for the depth less than 1.5d.

It was attemped, however, to figure out roughly the values of virtual mass and damping coefficients i.e. $(m_z'' + m)/m$ and $N_z\sqrt{Lpp/g}/m$ for $H/d = 1.1$ by extrapolation. The extrapolated curves are shown in Fig. 2 and 3.

By making use of the curves we obtained the period ratio $T_z/T_{z\infty} = 1.5$ for the depth parameter $H/d = 1.1$, which is compared with the corresponding experimental point in Fig. 2.

References

1) Y.S. Yu and F. Ursell: "Surface waves generated by an oscillating circular cylinder on water of finite depth", Fluid Mechanics, 11, 1961.
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Table 1

Main Particulars of Ship Models						
	CB	Lpp (m)	B(m)	d(m)	L/B	B/d
Todd 60 Series	0.600	3.0	0.400	0.160	7.5	2.5
	0.700	3.0	0.428	0.171	7.0	2.5
Full Tanker	0.815	3.0	0.500	0.169	6.0	2.973

Table 2

	H/d	1.5	1.75	2.0	2.5	3.0	10.0	∞
$T_z/T_{z\infty}$	CB=0.60	1.14	1.06	1.03	1.0	1.0	1.0	1.0
	CB=0.70	1.21	1.09	1.04	1.01	1.0	1.0	1.0

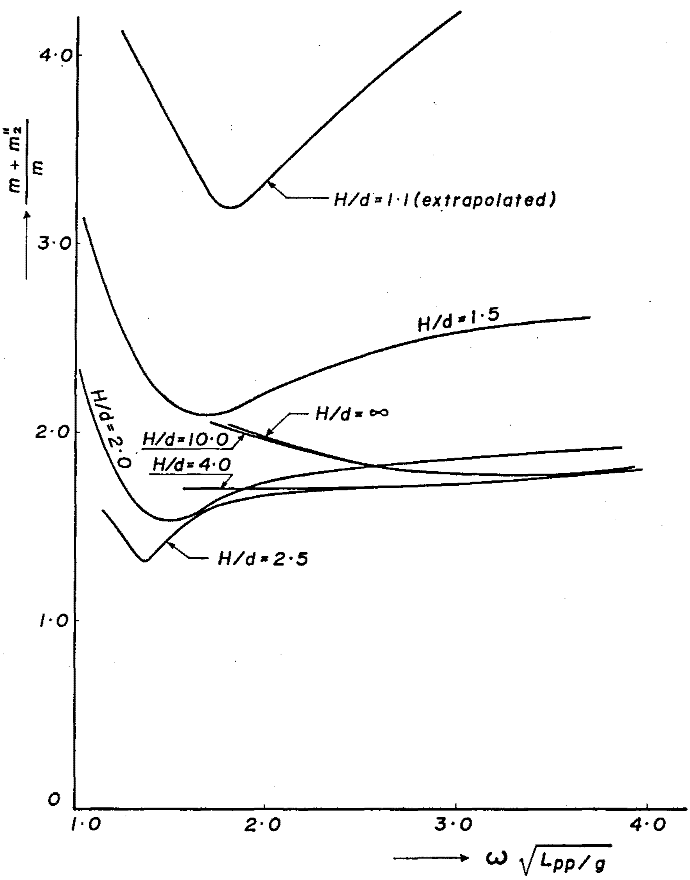

Fig. 2. Virtual mass coefficient $(m_z''+m)/m$ for the Todd 60 series model of $C_B=0.7$ at $Fn=0.0$

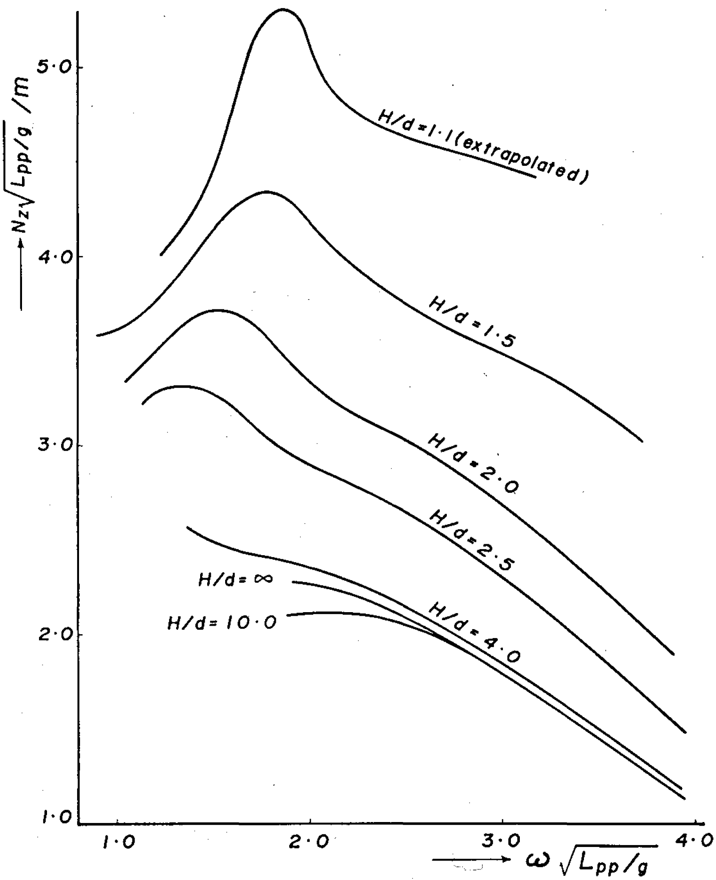

Fig. 3. Damping coefficient $\frac{N_z\sqrt{Lpp/g}}{m}$ for the Todd 60 series model of $C_B=0.7$ at $Fn=0.0$

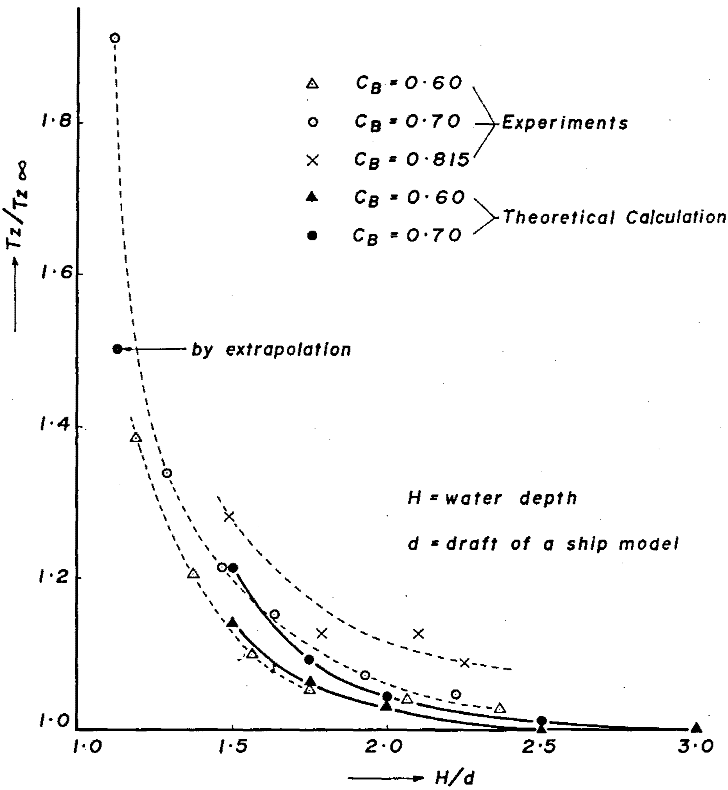

Fig. 4. Comparison of theoretical calculation and experimental results for the shallow water effect of natural heaving period