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Effects of a sea bottom step on wave drift force

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1 Introduction

A joint research project named “On the drifting prevention of disabled ships in rough waves” is conducted by Ship Research Institute, Maritime Safety Agency, Osaka University, Kyushu University, rope manufactures and a salvage company. In this project, a prototype onboard towing support system for rescue ships is expected to be developed as a final output. As a part of this project, the authors are studying wave drift force and drift motion of a freely floating body under various conditions. Bottom shape of the sea is one of the important condition. When a disabled ship is drifting to coast and be in danger of running aground, accurate estimation of required power for rescue ships as well as estimation of drifting speed and course is very important to avoid disaster. The bottom shape effect should be considered to estimate accurate drift force at the shallow seas.

Wave drift force is one of the old topics in marine hydrodynamics. In the early years of the research, Maruo (1960) investigated the mechanism of drift force from the conservation law of energy and momentum of wave field around a floating body. Nojiri and Murayama (1975) extended Maruo’s theory to shallow water and validated it by two dimensional experiment. Kudo and Kobayashi (1977,1978) studied the drift force on sphere and spheroid. After these works, many researchers and engineers applied these theories to ships and ocean structures. Following these study, the authors selected a step as the simplest sea bottom shape and studied its effect on wave drift force theoretically, experimentally and numerically. For this basic study, a two dimensional Lewis form body is used as an example of floating objects. At the previous symposium, the authors (Tanizawa and Minami,1998) applied our fully nonlinear simulation method and showed the estimated drift force is almost identical to the linear theoretical value of Nojiri et al.(1975). Consequently, in this paper, the authors used a linear simulation method for parameter study.

2 Theoretical relation among waves and wave drift force

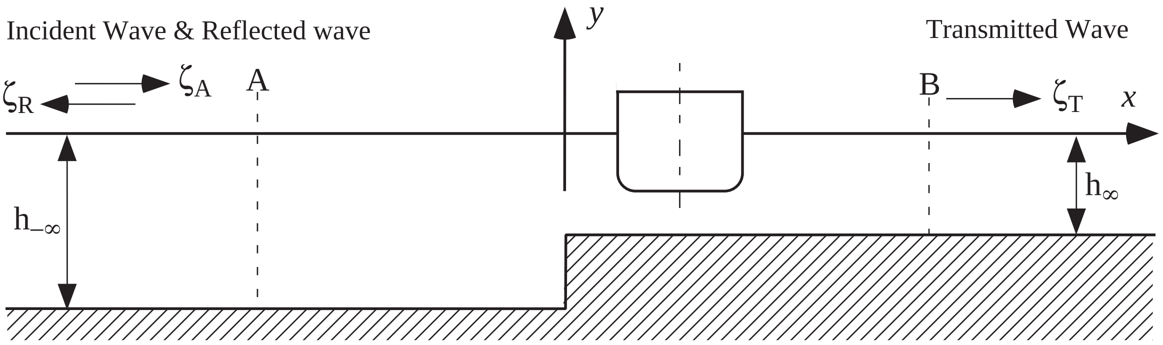

Fig.1 Wave flume with a bottom step

Fig.1 shows a two dimensional wave flume with a bottom step at $x = 0$. The depth of the flume at each sides of the step are $h_{-\infty}$ and h_∞ respectively. Incident wave travels from $x = -\infty$ to ∞. Part of wave energy is reflected by step and floating body and the rest is transmitted to $x = \infty$. In this theoretical study, we assume ideal fluid and no energy dissipation by floating body. The wave field is also assumed to be periodically steady. Therefore, the height of incident wave : ζ_A, reflected wave : ζ_R and transmitted wave : ζ_T are constant in time and space. Then, from the balance of energy flux at the control surface A and B, we have following relation

$$\frac{n_{-\infty}}{k_{-\infty}}(\zeta_A^2 - \zeta_R^2) = \frac{n_\infty}{k_\infty}\zeta_T^2 \ , \tag{1}$$

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where $k_{\pm\infty}$ and $n_{\pm\infty}$ are wave number and ratio between group velocity and phase velocity at $x = \pm\infty$ respectively. $n_{\pm\infty}$ can be written as

$$n_{\pm\infty} = \frac{1}{2}\left(1 + \frac{2k_{\pm\infty}h_{\pm\infty}}{\sinh 2k_{\pm\infty}h_{\pm\infty}}\right) . \tag{2}$$

The theoretical expression of wave drift force is also obtained from the balance of energy flux as

$$\frac{F_D}{\frac{1}{2}\rho g \zeta_A^2} = 2n_{-\infty}\left(\frac{\zeta_R}{\zeta_A}\right)^2 = n_{-\infty}\left\{1 + \left(\frac{\zeta_R}{\zeta_A}\right)^2\right\} - n_{\infty}\frac{k_{-\infty}}{k_{\infty}}\left(\frac{\zeta_T}{\zeta_A}\right)^2 . \tag{3}$$

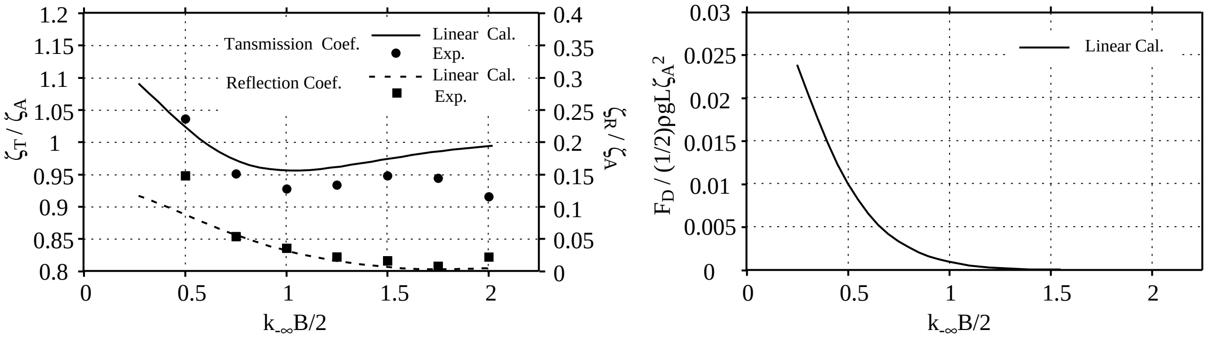
3 Linear calculation method of wave field and floating body motions

To calculate wave drift force using the above theory, one needs to solve radiation and diffraction problem of the floating body. For this purpose, we used a linear time domain direct simulation method. This linear simulation method is a subset of fully nonlinear simulation method (Tanizawa,1997). Also in the linear simulation, both the velocity and the acceleration fields are solved. Simulation is started from the calm condition and continued until body motions and wave field are converged to the periodically steady state. The linear simulation is much faster than fully nonlinear simulation and convergence is quite well. This linear simulation method is as accurate as frequency domain methods, at the same time more flexible to apply various linear problems.

4 Experiment

4.1 2-D Wave Flume

Experiment was conducted at our shallow two dimensional wave flume (Length=26m, Width=0.5m). An absorbing wave maker is equipped at the left end and a beach is equipped at the right end. On the right half of the bottom, a rigid raised floor was installed to form a bottom step. The depth of water was set to 0.5m at the left half part and 0.3m at the right half part. The end of raised floor was covered so that no wave energy travels under the raised floor. Wave was measured by electric capacity type wave probes. Incident wave and reflected wave were decomposed by Goda's method. Fig.2(a) shows measured and calculated transmission and reflection coefficients by this step. Horizontal axis is nondimensional wave number $k_{-\infty}B/2$, where wave number at the left part of flume $k_{-\infty}$ and a half of the floating body width $B/2$ are used as the principle wave number and the principle length. At long wave range ($k_{-\infty}B/2 < 0.5$), wave transmission coefficient exceeds 1.0. If water depth is uniform, this can not be happen. However as eq.(1) means, if water depth is different at $x_{\pm\infty}$, wave transmission coefficient can be larger than one. The result of linear calculation exactly satisfies eq.(1) and also shows good agreement with measured data. Fig.2(b) shows an estimation of wave drift force by eq.(3) and linear calculation. The wave drift force on the bottom step is very small even in long wave range.



(a) Tansmission and Reflection Coef. of bottom step

(b) Wave Drift Force acts on the bottom step

Fig.2 Wave reflection, transmission and drift force by the bottom step itself

4.2 Wave Drift Force on a Floating Body

A Lewis form 2-D model was used for the experiment. Table 1 and Fig.3 show its principle dimensions and section shape, respectively. The body was attached to a motion measuring equipment and moored by weak spring only in horizontal direction. Free motions, wave field and drift force were measured.

Table 1 Principle Dimensions

Breadth	B	0.40	m
Draft	d	0.20	m
Lewis form parameter	H_0	1.00	
	σ	1.00	
Metacenter height	GM	0.055	m
Displacement/Length	W	80.0	kg/m
Radius of gyration	$\sqrt{I_{yy}/W}$	0.13	m
Natural roll period	T_r	1.23	sec

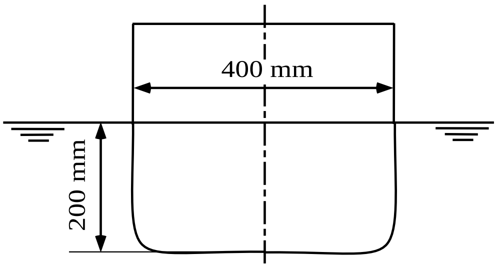
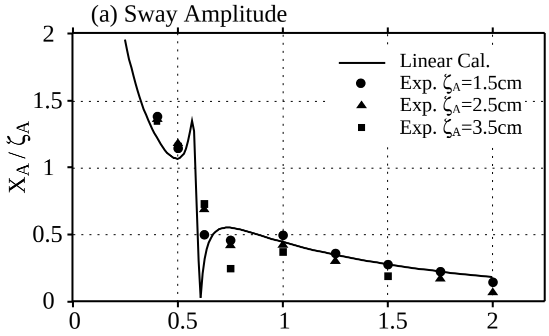


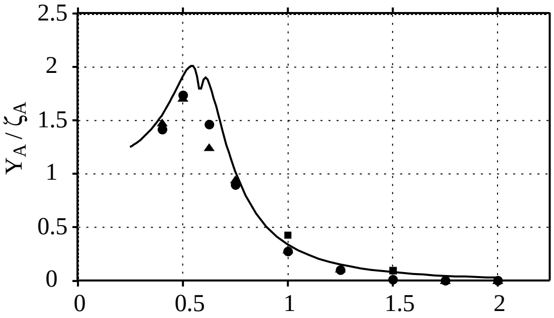
Fig.3 Shape of the floating body

Fig.4 shows comparison between measured data and linear calculation. Mean position of the center-line of the body was roughly kept just above the bottom step in the measurement. Overall, calculated motions well agree with measured motions. Fig.4(d,e) shows reflection and transmission coefficients. In the short wave range, calculated reflection coefficient is larger than measured value. This is due to weak wave breaking near the intersection line of free-surface and body surface at the weather side. On the other hand, calculated transmission coefficient well agrees with measured value. Fig.4(f) shows the wave drift force acts on the body. Calculated value is obtained from the total drift force by subtracting the drift force acts on the bottom step itself. Measured drift force was directly obtained by a load cell attached between heaving-rod and gimbal of the measuring equipment. Agreement between calculated and measured wave drift force seems to be insufficient. We are now taking a second look at the measured drift force.

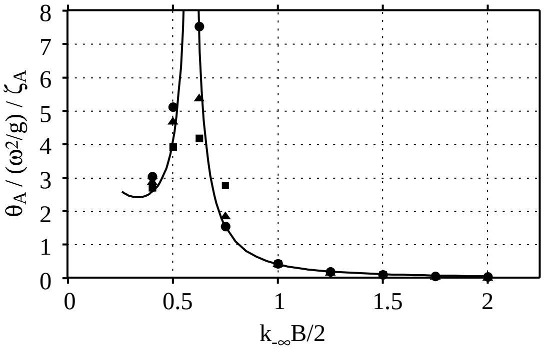
(a) Sway Amplitude



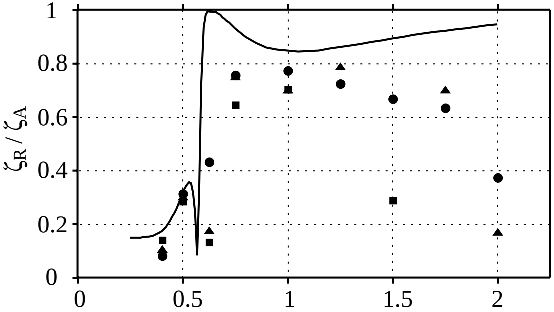
(b) Heave Amplitude



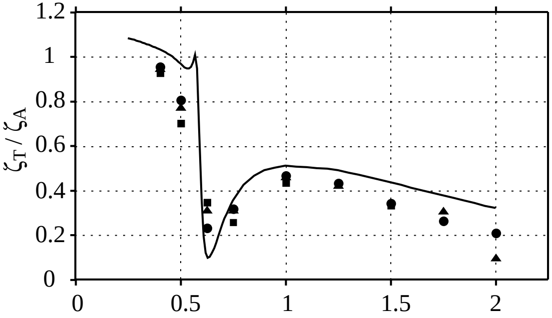
(c) Roll Amplitude



(d) Reflection Coefficient



(e) Transmission Coefficient



(f) Wave drift Force acts on the body

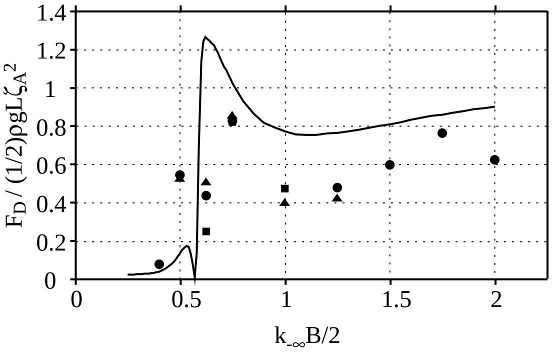


Fig.4 Floating body motions, wave reflection and transmission coefficients and wave drift force

At the present stage, we consider that the calculated wave drift force is reliable and useful to study the effect of bottom step on wave drift force. Fig.5 shows the calculated wave drift force acts on the body as a function of the location. The horizontal axis is distance between the center line of the body and the bottom step. Its range is $\lambda_{-\infty} \leq x \leq \lambda_{\infty}$, where $\lambda_{\pm\infty}$ are wave lengths at the both side of the bottom step. In case of the wave frequency $\omega = 4.772$ rad/sec, wave drift force significantly increases when the body enters to the shallower area. Oscillation of wave drift force is also observed. The lengths of this oscillation are equal to $\lambda_{\pm\infty}/2$. This oscillation results from body-step interaction. On the other hand, in case of the wave frequency $\omega = 5.345$, rad/sec, change and oscillation of the drift force are not so significant. Detail of the bottom step effects will presented in future.

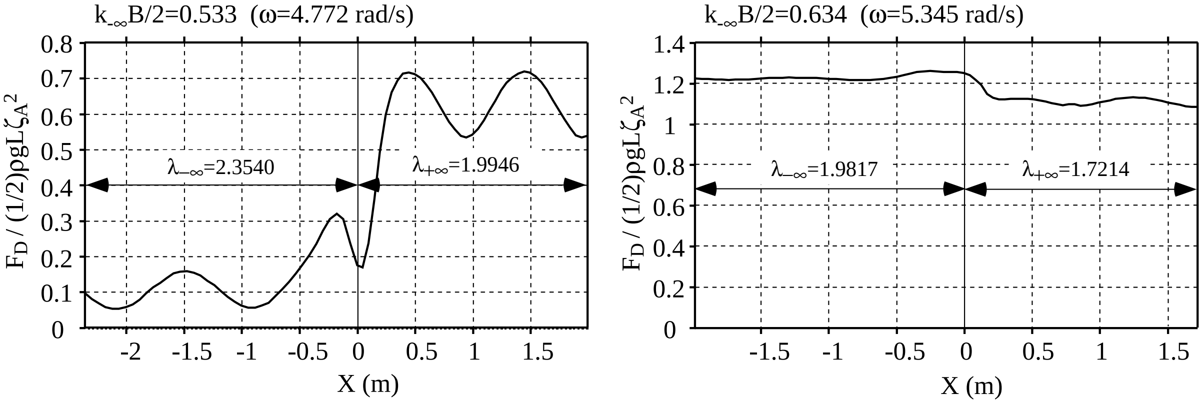


Fig.5 Wave drift force as a function of relative body position to the bottom step

5 Conclusion

Effects of bottom step to wave drift force are studied theoretically, experimentally and numerically. So far, following items are conclusions of this on going study.

1. The theoretical relations among incident wave, reflected wave, transmission wave and wave drift force are given.
2. To calculate reflected and transmitted waves, radiation-diffraction problem is solved by the linear time domain simulation method.
3. Simulated motions and waves well agree with measured values in overall.
4. Agreement between calculated and measured wave drift forces is insufficient.
5. Wave drift force calculated as a function of location jumps at the step and oscillates at the both sides of the step. Such a jump and oscillation depend on wave frequency.

The authors are now studying more detail of the bottom step effects and intend to publish complete reports, hopefully.

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