Experimental investigation on the wave decay characteristics along a long array of cylindrical legs

Hiroshi Kagemoto, Motohiko Murai and Masanobu Saito
Department of Environmental and Ocean Engineering
University of Tokyo, Japan

1.Introduction

As indicated by Maniar and Newman[1], Newman[2], regular monochromatic waves propagating along a long array of cylinders fixed in the waves with equal distance can, at least theoretically, induce large surface elevations among the cylinders at a certain resonant frequency range. Kagemoto[3] also showed numerically that, at higher frequeincies, waves decay monotonously along an array whereas, at lower frequencies, waves are enhanced rather than be decayed as they propagate toward the end of the array. The present study investigates experimentally these wave decay/enhancement characteristics along a long array of cylindrical legs fixed in waves. As will be shown, the measured surface elevations are much lower than the theoretically predicted ones at the resonant frequencies. A quasi-theoretical method is presented that can somehow rectify the observed discrepancies between the experimental results and the thoretical ones.

2.Experiment

2.1 In regular waves

An experiment was conducted in which 50 identical vertical truncated cylinders were fixed with equal distance in regular monochromatic waves as shown in Fig.1. Surface elevations were measured at 14 places among the array. Fig.2(a),(b),(c) show typical results of the spatial distributions of surface elevation amplitudes along the array in three different waves periods. The vertical axis represents the surface elevetion amplitude(ζ) divided by the incident wave amplitude(ζ_a). The experiments were conducted in three different wave height($2\zeta_a = 1cm, 2cm, 3cm$) as indicated in the legend to examine the linearity of the phenomena. The corresponding results predicted by the linear potential theory are also shown for the comparison. It is observed that, in short waves (Fig.2(a)), the surface elevations decay monotonously from the head of the array toward the end of the array and the theoretical predictions agree fairly well with the measued results. On the other hand, in long waves, the surface elevations are enhanced toward the end of the array, which is also well predicted by the linear theory. A distinguished feature is that, in the intermediate wavelength(Fig.2(b),(c)), the predicted surface elevations can be almost 6 times of the incident-wave amplitude while the experimental results are much lower than the predictions except at the head of the array. Another interesting fact is that the measured surface elevation amplitudes normalized by the incident wave amplitude is reproduced even if the incident wave amplitude is varied. This, in turn, implies the phenomena are linear, although the results of the linear theory differ significantly from the measured results. These characteristics are also observed in the experiments conducted with an array of composite truncated cylindrical legs.

2.2 In irregular waves

An experiment was also conducted in irregular waves. (The models used in this experiment are composite truncated cylindrical legs.) Fig.3(a) shows the measured spectrum of the incident wave used in the experiment. Fig.3(b),(c),(d),(e) show the spectra of the surface elevations measured among the array. The calculated results shown in the figures are obtained by multiplying the calculated RAO of the surface elevation with the measured spectrum of the incident wave. As observed in regular waves, the surface elevations are decayed in high frequencies while they are enhanced in low frequencies toward the end of the array. It is also consistent with the results in regular waves that the actual surface elevations are much lower than the calculated ones at the posterior region of the array.

3.Modification of the linear theory

In order to fill the gap between the experiments and the linear theory observed in the surface elevations at the resonant frequency range, the following modification was attempted in the linear potential theory.

We thought the fact that the linear potential theory agree well with the measured results except at the resonant frequencies may suggest a lack of certain damping forces on the fluid motion in the theory and therefore included an additional damping force $-N\tilde{v}$ in the equation of motion of a fluid particle(Euler's equation) as follows.

$$\frac{\partial \tilde{v}}{\partial t} + (\tilde{v} \cdot \mathrm{grad})\tilde{v} = \tilde{K} - \frac{1}{\rho}\mathrm{grad}p - N\tilde{v} \tag{1}$$

Here $\tilde{K}$ represents an external force vector per unit mass. Writing $q \equiv |\tilde{v}|$ and supposing $\tilde{v}, \tilde{K}$ are expressed as gradient of potential functions $\Phi, -gz$ respectively, the following modified Bernoulli's equation is obtained.

$$\frac{p}{\rho} = -\frac{\partial \Phi}{\partial t} - \frac{1}{2}q^2 - gz - N\phi \tag{2}$$

Assuming $\Phi(x,y,z,t) = \phi(x,y,z)e^{-i\omega t}$, the following linear free-surface condition is obtained.

$$\frac{\partial \phi}{\partial z} - \left(\frac{\omega^2}{g} + \frac{i\omega t}{g}\right)\phi = 0 \tag{3}$$

The corresponding dispersion relation is:

$$\frac{\omega}{g}(\omega + iN) = k \tanh kh \tag{4}$$

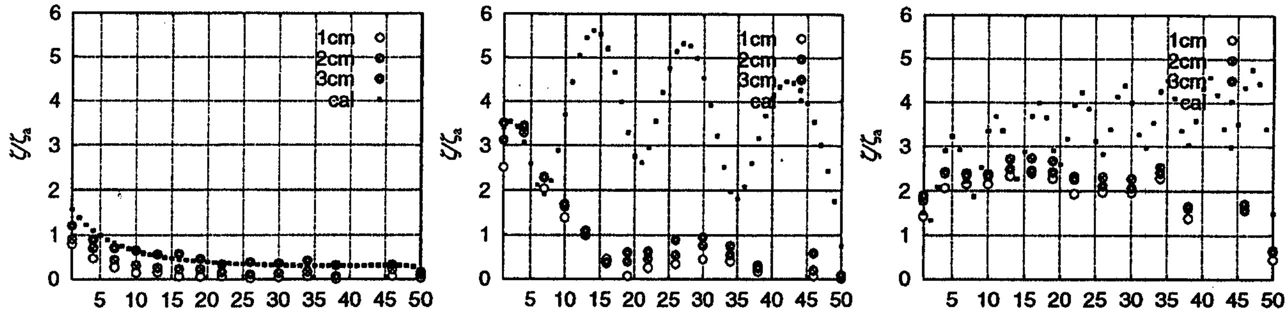
where h represents the water depth and k represents the wavenumber, which is now a complex number. This modification can be incorporated in the existing computer code fairly easily by replacing wavenumbers with the corresponding complex ones. The results corresponding to Fig.2(a),(b),(c) obtained in this manner are shown in Fig.4(a),(b),(c). The idea is similar to an additional damping force that is accounted for for the prediction of resonant motions in waves.

[1]H.D.Maniar and J.N.Newman: Wave diffraction by a long array of cylinders, *J. Fluid Mech.*, 339, 309-330, 1997.

[2]J.N.Newman: Resonant diffraction problems, Abstracts submitted to Georg Weinblum Special Meeting Lectures(In Proc.12th Intl.Workshop on Water Waves and Floating Bodies, 307-308, 1997.)

[3]H.Kagemoto: Wave decay characteristics along a long array of cylindrical legs, Proc.13th Intl. Workshop on Water Waves and Floating Bodies, 55-58, 1998.

Fig.1 An array of 50 vertical truncated cylinders fixed in waves.
(diameter:0.165m,draft:0.215m,distance between cylinders:0.330m,water depth:2.20m)



(a) T = 0.65 sec.
(b) T = 0.69 sec.
(c) T = 0.72 sec.

Fig.2 The distributions of surface elevation amplitudes along the array.

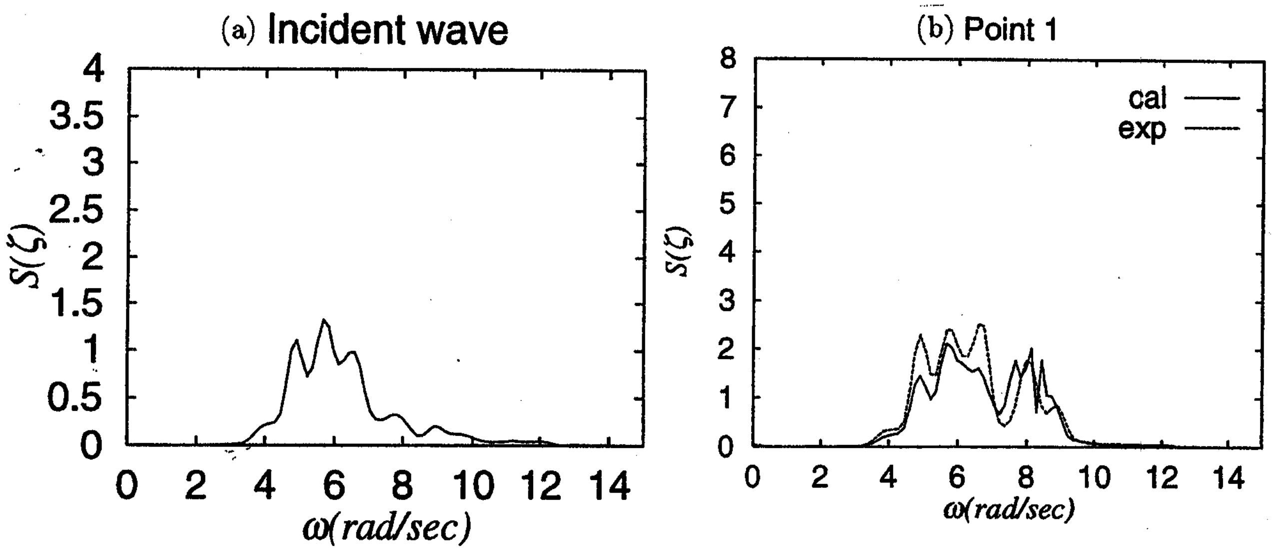


Fig.3 The spectra of surface elevations among the array in irregular waves.

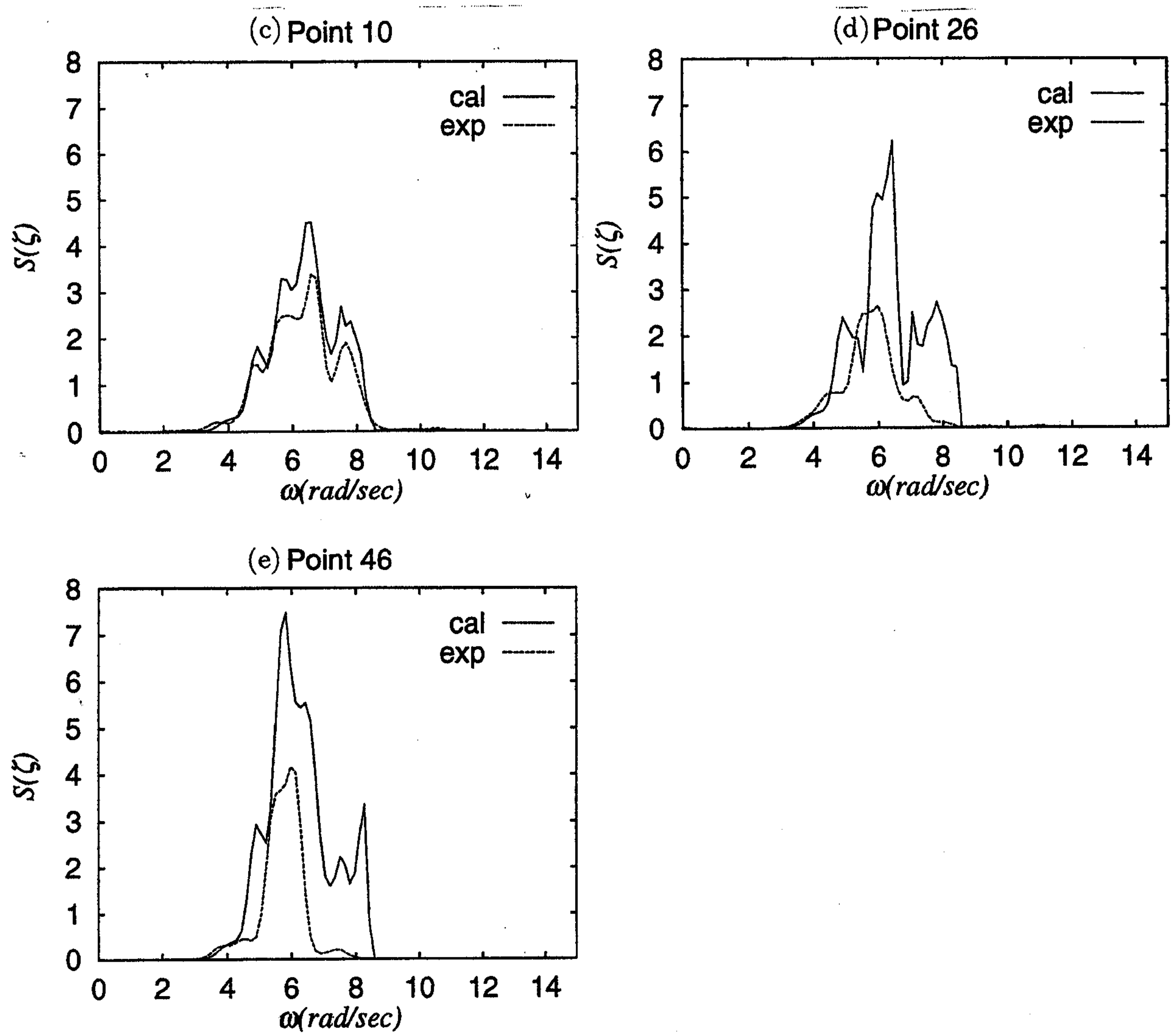
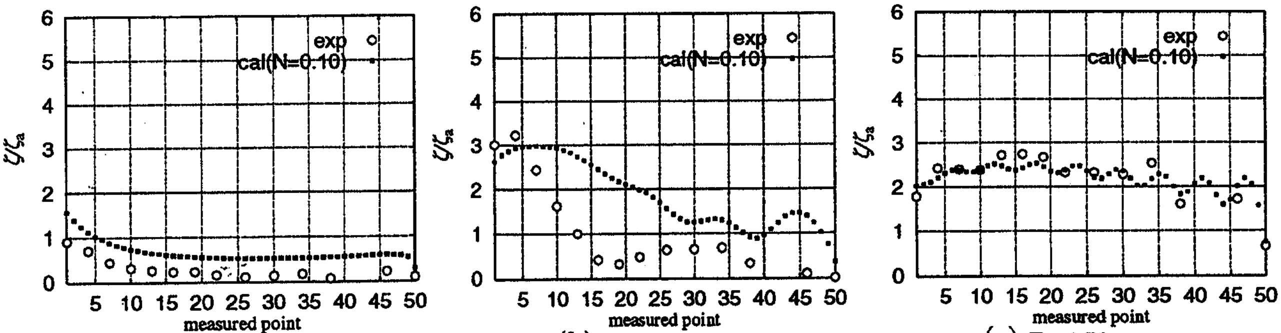


Fig.3 The spectra of surface elevations among the array in irregular waves.(continued)



(a) T = 0.65 sec. (b) T = 0.69 sec. (c) T = 0.72 sec.

Fig.4 The comparisons of the modified linear theory with experiments.