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Adaptive Re-reflecting Wave Control in Plunger Type Wave Maker System: Theory

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Abstract

Active control has been partly applied to suppress the re-reflecting waves in wave basin with plunger-type wave maker to obtain desirable waves. This limitation comes from the non-confirmable theoretical background to the control algorithm. This paper proposes control logic to overcome this drawback, based on the impulse response function for propagating waves between control input and the wave height. The performances have been verified as reasonable in practical application by comparing with the propagating wave components in numerical wave basin, using wave decomposition method. Moreover, the control logic can also give useful wave-absorbing performance after cessation of wave generation.

Keywords: plunger-type wave maker, re-reflecting wave control, active wave absorption, wave decomposition, Filtered-XLMS algorithm

1 Introduction

A wave basin consisting of wave maker and wave absorber has been used to simulate a situation of desirable waves. Here, this wave maker could re-reflect the reflected waves by the object and the wave absorber located at the opposite side. Henceforth, a reduction of re-reflecting waves is an essential problem toward obtaining desirable waves.

For a piston-type wave maker, Hiraguchi et al(1990) proposed a method based on a theoretical solution and obtained good control performance. For a plunger-type wave maker, Naito et al(1984, 1987, 1989) proposed theoretical approaches in the cases of regular and irregular waves. However, these cannot be applied to the plunger-type wave maker with arbitrary shape, since the effects of plunger shape could not be exclusively included in the theoretical description.

By the lack of theoretical solution for general plunger-type wave generation mechanism, Lee et al(2000) have applied a numerical approach: it could be possible when the control signal is defined before control action is applied. However, this cannot happen in a real situation because reflected signal is changing in terms of time.

This paper introduces a control logic to overcome these drawbacks. The logic is based on the pre-estimated transfer function between control input and wave height by the wave maker. The performance has been verified using the wave decomposition method by Seybert(1988). The ability of suppression of re-reflecting wave has been represented a good performance for regular and irregular wave generation, and reasonable wave absorbing performance after cessation of wave

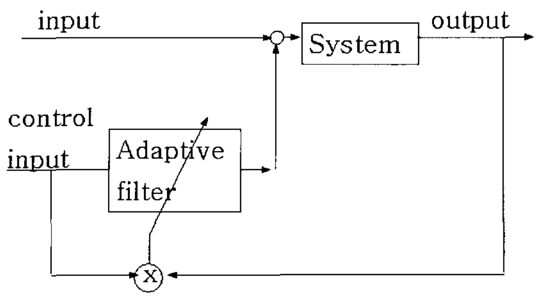


Figure 1: An active control model

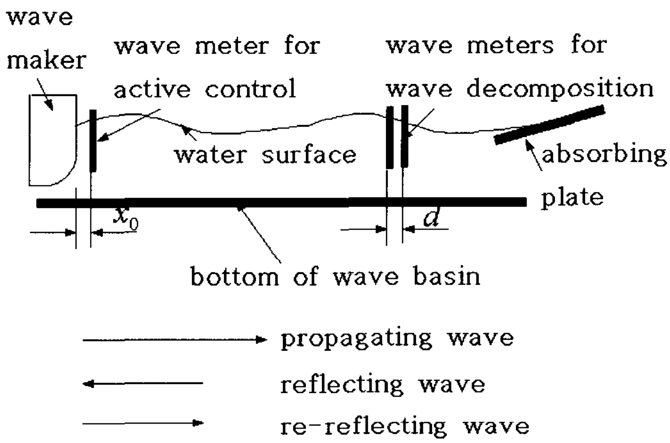


Figure 2: Schematic diagram for two dimensional wave basin and an arrangement for active re-reflecting wave control

generation as well. This paper will describe theoretical contents based on numerical simulation. The experimental works showing quite similar results will be presented in the following paper, including detailed experimental works. Finally, this approach could be applied to the other types of wave makers and could be expected to produce a reasonable performance.

2 Active control logic

Active control has been a well-known topic in noise and vibration fields toward suppressing some target signals. Therefore, explicit definition of control targets is an essential preparation for control. Many related logics can be found in the book on active control of sound by Nelson and Elliot(1992). Figure 1 illustrates a typical example of active control to make zero output.

In case of two dimensional wave basin, wave-generating mechanism could be simplified as shown in Figure 2. That is, the propagating waves consist of object waves, reflecting waves from the wave-absorbing facility and experimental models, and re-reflecting waves by the wave maker. Henceforth, the suppression of re-reflecting waves is an essential problem to obtain desirable waves that have been assumed to give negligible reflection effect on the ship motion. Based on

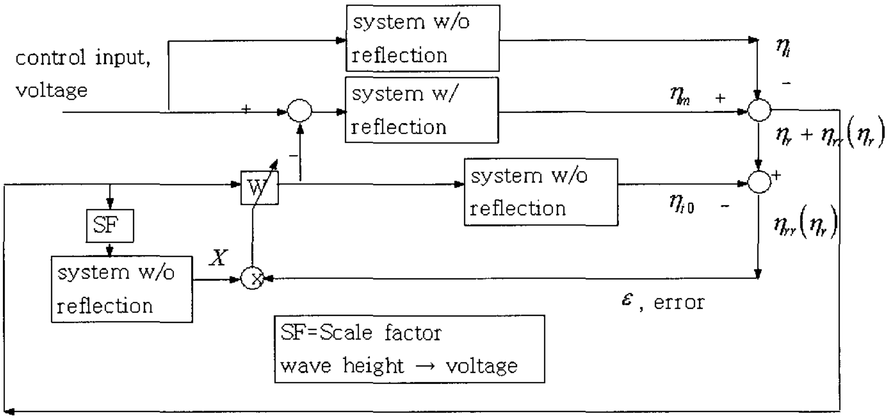


Figure 3: Schematic diagram for re-reflecting wave control

these observations, we introduce the control logic illustrated in Figure 3. Here, the system w/o reflection stands for the impulse response function that is estimated in case of no reflection and the W stands for the adaptation filter. The adaptation signal, $\eta_r + \eta_{rr}(\eta_r)$, comes from subtracting the desired propagating waves, η_i, from the measured waves, η_m. This renders good performance of wave absorption after cessation of wave generation. Here, η_r stands for the reflecting waves due to experimental object. The re-reflecting waves, $\eta_{rr}(\eta_r)$, becomes zero when the reflecting waves are completely absorbed by the controlled waves, η_{i0}. Based on these physical interpretations, the adaptation filter can be defined as the following.

$$W = W + \mu\varepsilon X \tag{1}$$

Here, is a scale factor that results to convergence speed, stands for signal vector for the Filtered-XLMS algorithm, and represents the adaptation error that corresponds to the re-reflecting waves, $\eta_{rr}(\eta_r)$.

The next chapter will describe the applicability by numerical simulations.

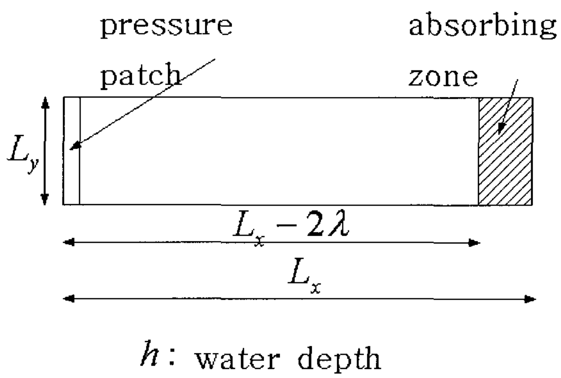
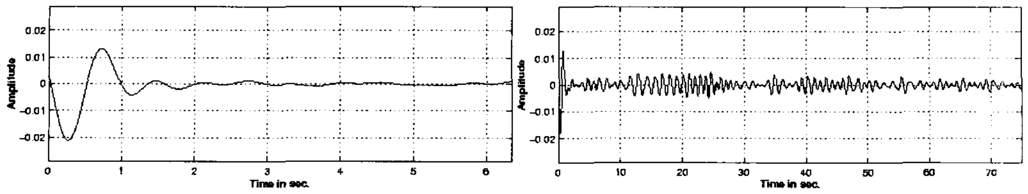


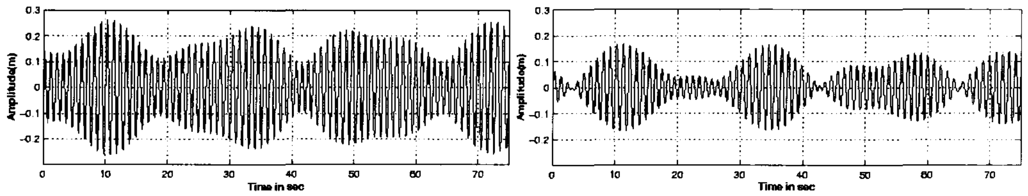
Figure 4: Geometry of two-dimensional wave basin for numerical simulation



(a) Impulse response fn.(128 time steps) for propagating wave only

(b) Impulse response fn.(1500 time steps) for wave basin

Figure 5: Impulse response functions between control input and wave meter near to wave maker (sampling frequency: 20Hz)



(a) Wave height without control in operating

(b) Wave height with control in operating

Figure 6: Wave behavior during operation (frequency range: 0.9Hz - 1.0Hz, sampling frequency: 20Hz)

3 Numerical wave basin for simulation

A numerical wave basin illustrated in Figure 4 was adopted for verification of the proposed control logic. Principal dimension of the wave basin is $(L_x, L_y, h) = (8m, 2m, 1m)$.

Lee and Chun(2000) have introduced the unsteady inviscid waves using the integration of ordinary differential equation derived from fully nonlinear kinematic and dynamic free surface boundary condition at each time step. In that governing equation, a damping layer is deployed in the region of absorbing zone to decrease wave reflection. This paper uses the above solution to obtain waves in time domain, and then, the impulse response function is estimated by typical Filtered-XLMS algorithm(Nelson and Elliot 1992).

Figure 5 illustrates the impulse response function between the pressure fluctuation and the wave height. Figure 5(a) shows the impulse response function for propagating wave only and Figure 5(b) shows the response including propagating, reflecting and re-reflecting waves for the basin. As shown in the figure, it can easily be modeled by 128 time steps in the case of only propagating wave. However, 1500 time steps are required for the whole basin, due to the reflecting and re-reflecting terms. Additionally, two more impulse response functions in the basin were estimated to verify the performance of the control logic using the wave decomposition method. However, these results are omitted in this paper, as the results are quite similar to Figure 5(b).

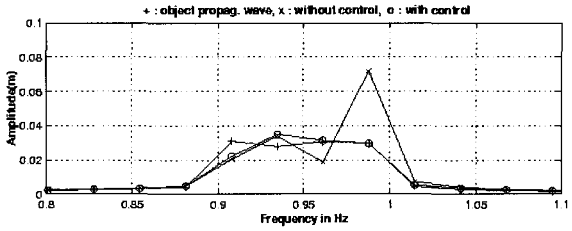
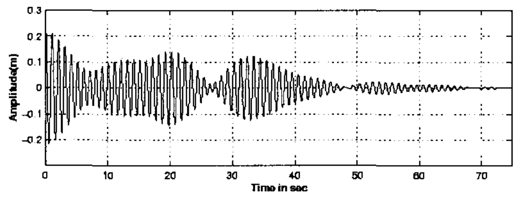
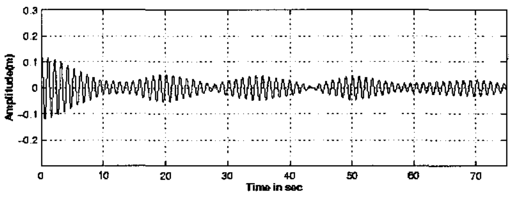


Figure 7: Frequency characteristics of propagating waves using wave decomposition method (+: for object wave, o: with control, x: without control)



(a) Wave height without control after cessation of wave generation



(b) Wave height with control after cessation of wave generation

Figure 8: Wave behavior after cessation of wave generation

4 Numerical Simulation

Many simulations for regular wave generations were performed using the control logic and the results showed acceptable performance. For an irregular wave generation, Figure 6 shows propagating time signals according to the before and after and control by using the wave decomposition method. The amplitude of signal after control shows a signal lower than that prior to control, as the superposition of re-reflecting waves is minimized by the control. In this paper, the wave decomposition method by Seybert(1988) has been used to decompose propagating and reflecting waves using the signals at two additional wave meters located at mid positions(Figure 2) in the basin. Figure 7 illustrates the results in frequency domain: that is, the propagating waves before control are the stronger than those of object waves, and the waves after control are the quite similar to those of object waves.

Figure 8 shows a performance after cessation of wave generation. The upper figure illustrates the more irregular behavior than that of bottom figure, due to the active absorbing function of the control logic. However, the controller could find it difficult to establish an equilibrium state since this control logic will continue until zero response. To solve this problem, the adaptation logic should have a criterion whether the control will be stopped or not.

5 Conclusion

This paper introduces a control logic for suppression of re-reflecting waves in two dimensional numerical wave basin. The performances were verified by comparing to the propagating wave components using wave decomposition method. The control logic also demonstrates wave absorbing function after the cessation of wave generation and, subsequently makes the more stable stopping procedure of wave maker.

Finally, the control performance represents very reasonable for both regular and irregular wave cases. Hence, it could be applied to the real wave basin and the following paper will present these performances in real two dimensional wave basin.

References

HIRAKUCHI, H., KAJIMA, R. AND KAWAGUCHI, T. 1990 Application of a piston-type absorbing wave maker to irregular wave experiments. Coastal Engineering in Japan, **33**, **1**, pp. 11-23

LEE, J.H. AND CHUN, H.H. 2000 Numerical Simulation of Unsteady Inviscid Waves by Spectral Method. Proc. of the Society of Ocean Engineering of Korea, May, pp. 140-145

LEE, J.H., PARK, G.I. AND HA, M.K. 2000 Certification of Pneumatic Absorbing Wave Maker based on Numerical Wave Tank. Proc. of the Society of Naval Architects of Korea, Nov., p. 9

NAITO, S., NAKAMURA, S. AND FURUKAWA, H. 1984 Wave Energy Absorption Of Irregular Waves. J. of the Kansai Society of Naval Architects, **194**, Sep., pp. 25-31

NAITO, S., HUANG J. AND NAKAMURA S. 1987 Research on Perfect Absorption of Regular Wave with the Terminal Device. J. of the Kansai Society of Naval Architects, **205**, May., pp. 29-36

NAITO, S., HUANG J. AND NAKAMURA S. 1989 Research on the Absorb-Making of Irregular Waves with the Terminal Device. J. of the Kansai Society of Naval Architects, **207**, Dec., pp. 25-32

NELSON, P.A. AND ELLIOT, S.J. 1992 Active Control of Sound. Academic Press

SEYBERT, A.F. 1988 Two-Sensor Method for the Measurement of Sound Intensity and Acoustic Properties in Ducts. J. Acoust. Soc. Am., **83**, **6**, pp. 22-33