Journal of
Ship&Ocean
Technology
©MARCH 2003

SOTECH Vol. 7, No. 1, pp. 13~18, 2003

Adaptive Re-reflecting Wave Control In Plunger Type Wave Maker System: Experiments In Two Dimensional Wave Basin

Gun-Il Park[1], Ki-Jung Kim[1], Jae-Woong Choi[1] and Jin-Ho Lee[1]

[1]Shipbuilding/plant Research Institute, Samsung Heavy Industries, 530, Jangpyung-ri, Sinhyun-up, Goje-shi, Kyungnam, Korea; E-mail: jaewng.choi@samsung.com

Abstract

The control performances for active re-reflecting wave control suggested in the previous paper have been verified in cases of regular and irregular waves in a real two dimensional wave basin. For regular waves, the control performances are investigated in terms of reflection coefficients, expected amplitudes of propagating waves and wave absorbing capabilities after cessation of wave generation, compared with those of no-control cases.

For irregular waves, similar verification procedures were adopted. Though there are certain constraints due to the geometrical non-linearity of wave maker and certain nonlinear characteristics due to the near field and gravity waves, these experiments show that the control logic could be useful in realizing re-reflecting wave control in conditions of real wave basin.

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

1 Introduction

Re-reflecting waves are generated by reflection waves from experimental object, wave absorber and other obstacles in wave basin (Naito et al 1984, Hirakuchi et al 1990). At small wave basin and in long-time experiments, these waves could be easily generated and, therefore, should be controlled to obtain boundary condition like that of real sea.

In the previous paper by authors (Choi et al 2003), the control logic has been suggested and verified as useful in a numerical wave basin for regular and irregular waves. Henceforth, this paper is prepared to demonstrate experimental verification of the control logic in real wave basin. The experiments in regular and irregular waves have showed reasonable performances in control cases of re-reflecting waves and wave absorption after cessation of wave generation.

This paper will describe measured signals without detailed description of experimental setup, for the purpose of brevity.

2 Wave basin and its impulse response function

Figure 1 shows the wave basin with plunger-type wave maker, wave absorber and an arrangement of wave meters.

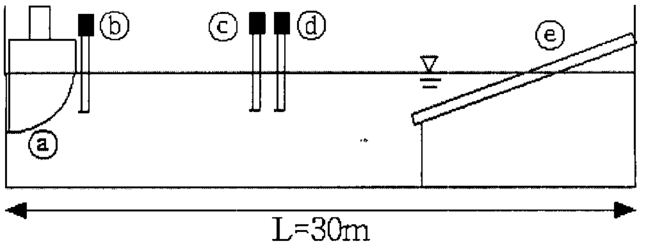

Figure 1: General terms of two Dimensional wave basin (ⓐ: Plunger of the wave maker, ⓑ: a wave height gauge for measuring the reflecting waves, ⓒⓓ: wave height gauges for wave decomposition, ⓔ: passive wave absorber)

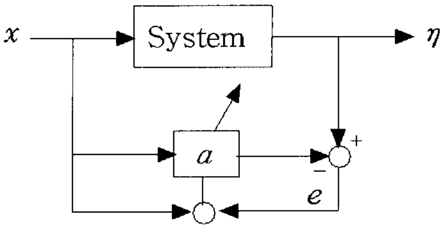

Figure 2: An example of system modeling using Filtered-X LMS algorithm

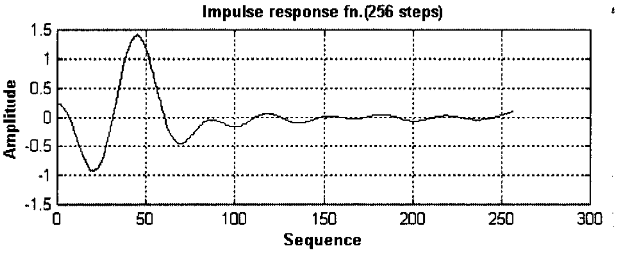

Figure 3: Estimated impulse response function between wave meter near and control input for wave maker.

The relation between the control input to wave maker, ⓐ, and the wave height near to wave meter, ⓑ, can be described by impulse response function. Though it can be estimated by theoretical derivation, it is hard to consider the shape of the wave maker, ⓐ, and other nonlinear behaviors, such as dispersion relation and near field effects, etc. Henceforth, this paper uses experimental approach, based on FIR (Finite Impulse Response) filter illustrated in Figure 2. That is, wave meter, wave maker and analog filter to reduce certain unwanted noise are used to obtain the FIR filter model. Equation (1) describes governing equation of the impulse response function.

$$\eta(t) = \sum_{i=0}^{\infty} a_i x(t - i\triangle t) \tag{1}$$

Here, $\eta(t)$ and $x(t)$ stand for the wave height at wave meter, ⓑ, and the control input to the wave maker, respectively. The a_i represents the related FIR coefficient (Nelson and Elliott 1992).

Figure 3 illustrates the estimated impulse response function coefficients for propagating wave-only, based on careful experimentation to reduce the effects of reflection from the wave absorber, ⓔ.

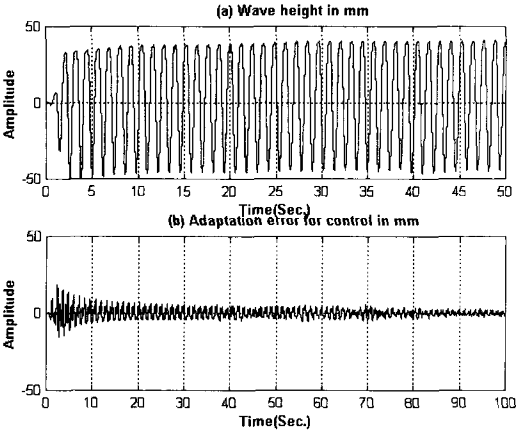

Figure 4: Wave height and adaptation error signals in re-reflecting wave control.

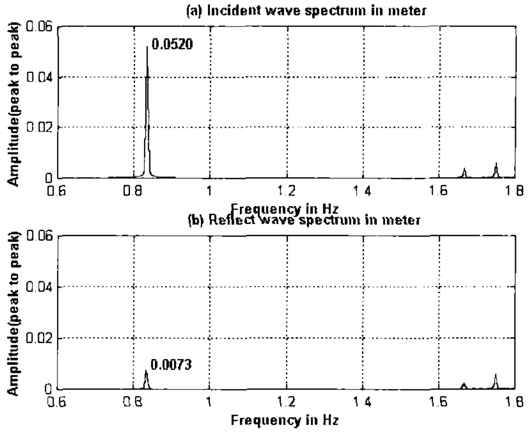

Figure 5: Wave decomposition in case of without control.

3 Experimental results for regular wave

3.1 Performance of re-reflecting wave control

The wave decomposition method by Seybert (1988) can be used as a useful tool to check the performance in case of two dimensional wave superposition. In this experiment, the wave period was 1.2 sec. and the displacement of wave maker was 4.3 cm.

A steady-state wave field in the experimental model could be obtained after round-trip time of approximately 55 seconds that corresponds to the length of wave basin. Figure 4 illustrates error signals in control logic and wave height signals near to wave maker from the beginning of the control. Though reflection waves are added at near 55 seconds, the adaptation error shows smoothly decreasing pattern at near 55 seconds. However, one has to consider time signals over 55 seconds to model the impulse response function, since this is strongly connected to the amount of reflecting waves.

Figure 5 and Figure 6 illustrate the results of wave decomposition in cases of no-control and active re-reflecting wave control, respectively. The reflection coefficient due to wave absorber can be estimated at about 14 % and 12 %, respectively.

Now, let us investigate the coefficients' relations by assuming that the reflection coefficient by the wave maker is 100 % and the reflection coefficient by the wave absorber in no-control case is r. In addition, the amplitudes of propagating and reflecting waves are defined as A_I and A_R, respectively. The reflection coefficient of wave absorber and the initial amplitude of desirable propagating wave can, thereby, be derived by the following.

$$A_I = \frac{a}{1-r}, \quad A_R = \frac{ar}{1-r} \tag{2}$$

$$r = \frac{A_R}{A_I}, \quad a = A_I(1-r) \tag{3}$$

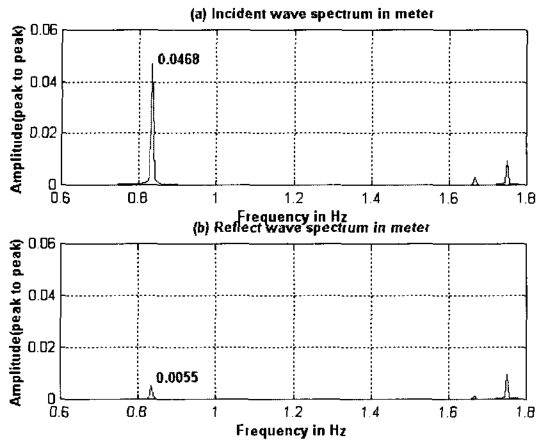

Figure 6: Wave decomposition in case of active re-reflecting wave control.

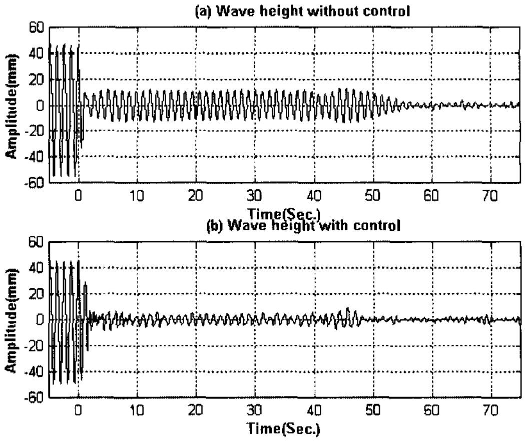

Figure 7: Wave height behaviors after cessation of wave generation.

These equations are derived by the superposition of infinite series of propagating, reflecting and re-reflecting waves. Based on this, in case of Figure 5, the reflection coefficient r of wave absorber becomes about 0.14 and the initial amplitude a becomes about 0.0446 m and therefore, the reflection component will be 0.0063 m upon completion of wave control. These values are slightly different from those in Figure 6, that is, approximately 5 % and 11 % differences, respectively, for propagating and reflecting wave components, respectively.

Finally, the control logic could be used for re-reflecting wave control with marginal errors.

3.2 Performance of active wave absorption

Given physical considerations, the wave amplitude in case of active re-reflecting wave control will become half of that in the case of no-control, unless the reflection by wave maker is assumed to be 100 %.

Figure 7 illustrates the wave signals between from -5 sec. to 75 sec. when the wave generation ceases at about 0 sec. followed by deceleration of 2 seconds in both cases. In this figure, one can assess about half amplitude in the case of control, compared to that in case of no-control, in a physical sense. This can be investigated by the following standard deviation during the wave absorbing period.

$$\sigma = \sqrt{\frac{1}{T}\int_0^T [\eta(\tau) - \bar{\eta}]d\tau} \qquad (4)$$

By applying the equation to Figure 7, 0.48 mm and 0.74 mm are obtained in cases of control and no-control respectively. That is, the control makes about 68 % of wave height compared to that in the case of no-control. The figure also shows some small amplitude at about 55 seconds representing the round-trip time of generated wave by wave maker.

Besides, the wave has slightly distorted from the pure sinusoidal wave due to the geometrical nonlinearity of wave maker, near field effects and the dispersion relation by gravitational water

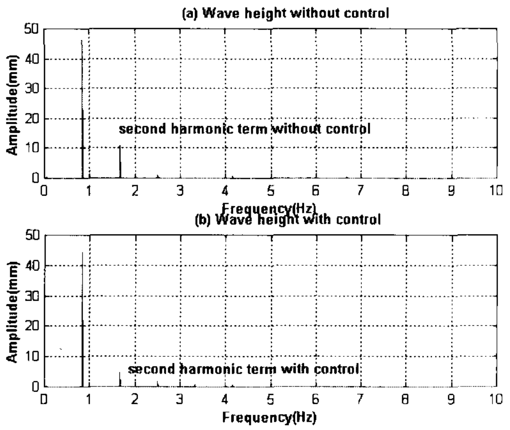

Figure 8: Wave behaviors in frequency domain near wave meter in cases of with control and without control, respectively.

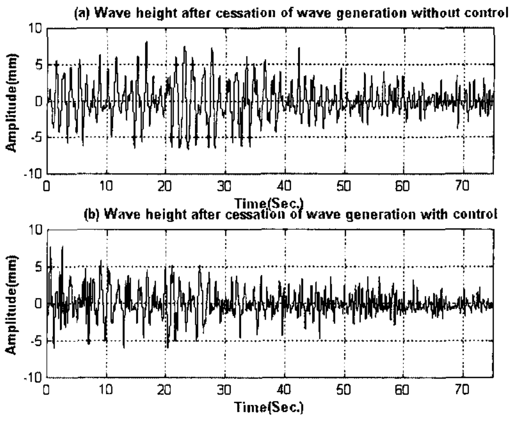

Figure 10: Comparisons of wave height after cessation of wave generation.

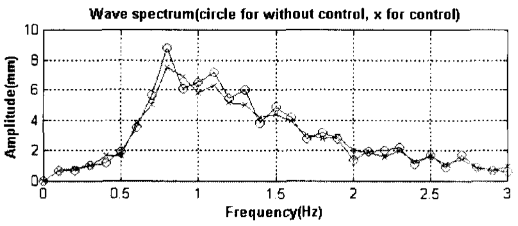

Figure 9: Comparisons of wave spectrum near to wave maker (circle for without control, x for with control).

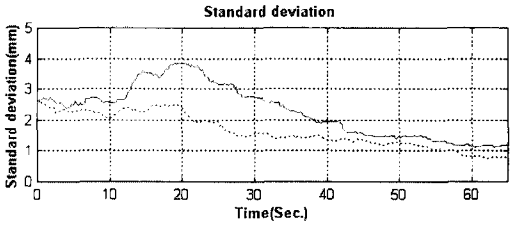

Figure 11: Variations of standard deviation of figure 10 (solid line for control and dotted line for no-control).

wave etc. Figure 8 illustrates this as a second harmonic term in frequency domain. However, the control causes some alleviation of the second harmonic term because the control logic considers the term as noise to suppress.

4 Experimental results for irregular wave

4.1 Performance of re-reflecting wave control

Figure 9 shows the spectra for wave height near to wave maker in frequency domain in both cases of control and no-control. The rough pattern in no-control case comes from the superposition of many wave components, such as propagating, reflecting, and re-reflecting waves, etc. However, these irregular patterns are alleviated by the active re-reflecting wave control, since the target spectrum possesses a smooth shape in frequency domain.

4.2 Performance of active wave absorption

The wave behaviors after cessation of wave generation are illustrated in Figure 10. The global patterns of amplitude show about half-wave amplitude in case of control such as that of regular wave. This can be investigated using patterns of standard deviation in terms of time marching; that is, calculation of standard deviation in certain intervals.

Figure 11 shows this standard deviation patterns by calculating in every 10 second intervals without overlap for the data in Figure 10. Though there are some significant fluctuating levels in no-control case, on the contrary, one can see constantly decreasing patterns of the level in that of control case.

5 Conclusion

The control performances of newly suggested active re-reflecting wave control logic, verified by the numerical wave basin in the previous paper by the authors, are investigated now in real wave basin. Based on these experimental works, the following is concluded.

The control logic gives good convergence after the round-trip period of waves. The performances of propagating wave in regular wave have been verified by using wave decomposition method and showed very reasonable performances. The wave-absorbing performance have also been represented as about half of that in no-control, quite similar to a physical sense. For the irregular waves, these verification procedures were also applied and illustrated quite similar performances.

Based on these observations, the active re-reflecting control logic has been verified as useful logic in real situations.

References

CHOI, J.W., LEE, J.H., PARK, G.I. AND KIM K.J. 2003 Adaptive Re-reflecting Wave Control In Plunger Type Wave Maker System: Theory. J. of SNAK, Accepted for publication

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

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

NELSON, P.A. AND ELLIOTT, 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