

# A CASE STUDY ON HARBOR OSCILLATIONS BY INFRAGRAVITY WAVES

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In this study, the minimization of harbor oscillation using permeable breakwater was applied to the actual harbor and investigated a reduction effect by computer simulation in order to take into account the water quality problems and measures of harbor oscillation by infragravity waves at the same time. The study site is Mukho harbor located at east coast of Korea. The infragravity waves which obtained by analyzing the field data for five years focused on the distribution between wave periods of 40s and 70s and wave heights in less than 0.1m was 94% of analyzing data. The target wave periods for minimization of harbor oscillation was 68s. The most effective method of minimization of harbor oscillation by infragravity waves was to install a detached permeable breakwater with transmission coefficient of 0.3 on the outside harbor and replace some area of the vertical wall with wave energy dissipating structure to achieve a reflectivity of 0.9 or less in a harbor. The reduction rate of amplitude shown in 27.4% in this method

*Keywords : infragravity waves, harbor oscillation, minimization, permeable breakwater, long-term field data, Boussinesq wave model*

## INTRODUCTION

Infragravity waves are surface waves with a lower frequency than short period waves produced by the wind. The short period wave has a frequency of 0.04Hz to 1Hz, while the infragravity waves are at a frequency of 0.004Hz to 0.04Hz. Infragravity waves was first observed by Munk(1949), and the theory that the principle of generation is bound wave theory(Biel, 1952; Longuit-Higgins and Stewart, 1962) and the other theory is caused by changing the location of the wave breaking points in shallow water depth(Symonds et al., 1982).

When infragravity waves close to the natural resonant frequency of a harbor are propagated into a harbor, the harbor oscillation is further developed by resonance phenomenon. In particular, infragravity waves within a minute of periods are similar to the natural frequency of medium and large ships.

In recent years, more harbors have been using permeable breakwater to improve water quality and promote sea exchange. Although it may not be appropriate for long period wave measures as the transmission rate increases as the wave period is extended, in this study the minimization method of using the permeable breakwater to simultaneously consider water quality problems and measures for harbor oscillation is investigated numerically. The study site is Mukho harbor located in east coast of Korea. This harbor has been occurred harbor oscillation frequently. Here, infragravity wave periods and heights figured out by analyze the observation field data for five years. The analyzed field data used as inputs for the computer simulation of Mukho harbor. And the response curves were analyzed at various points in the harbor before measures to select the target wave period for minimization of harbor oscillation. In addition, various methods of minimization including permeable breakwater applied to Mukho harbor and the reduction effect of harbor oscillations were reviewed by comparing the response curves before and after the countermeasures and reduction rate of amplitude.

## LONG-TERM FIELD DATA

The research area has been observed wave periods and heights by installing a pressure type wave gauge from fifteen years ago. In this study, the long-term wave observation data for five years from August 2013 to January 2018 were analyzed and the infragravity wave components at Mukho area were extracted.

The infragravity waves are as shown in Figure 1 which expressed in time series during the analysis period. In the figure, the black solid line is the infragravity wave heights( $H_{ig}$ ) with a range of 0.01m to 0.70m and shows a relatively large wave heights in winter season. The largest wave height in the analysis data was 0.7m observed in the winter of 2013. And the blue solid line is a infragravity wave periods( $T_{ig}$ ) that ranges from 40s to 130s. Figure 2 is the scatter diagram of infragravity waves during the analysis period. The infragravity wave periods are concentrated between 40s and 70s, and the wave heights are mainly distributed below 0.1m.

The wave directions in the Mukho area are unable to obtain data because of a pressure type wave gauge. Therefore, we refer to the data on the waves of Gangneung, which is closest to Mukho. The

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waves propagated in seven directions of N, NNE, NE, ENE, E, ESE and SE, and the direction with a highest rate of appearance accounted for 22% of the total waves in the NE direction(Jeong et al., 2016).

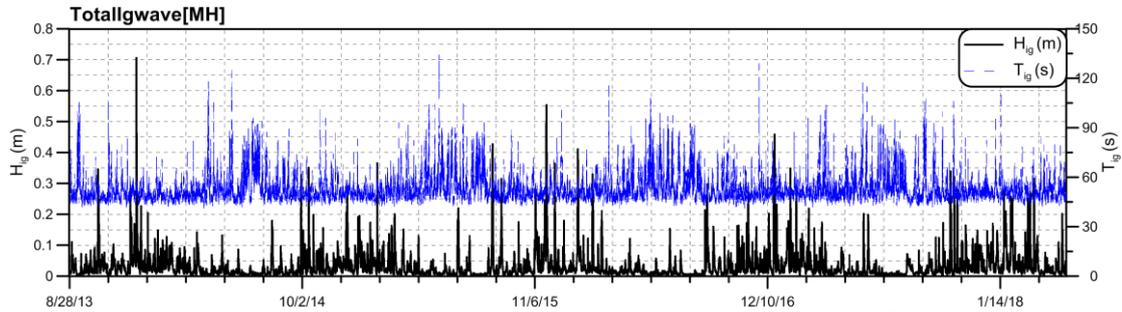


Figure 1. Five-year time series of infragravity waves at Mukho[MH].

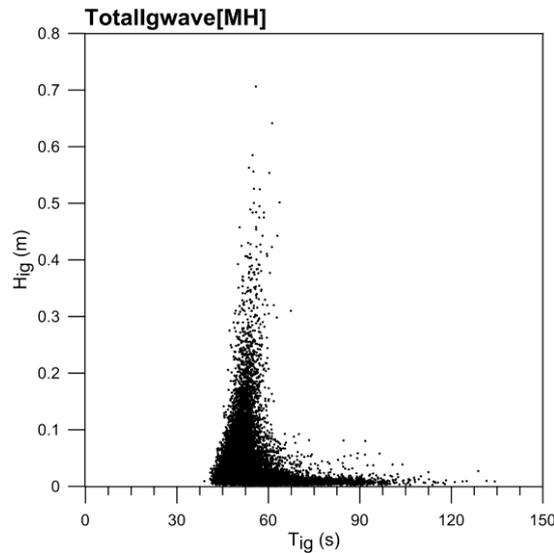


Figure 2. Scatter diagram of infragravity waves at Mukho[MH].

### COMPUTER SIMULATION OF HARBOR OSCILLATION

The wave model used in this study is the Boussinesq wave model of MKE21 BW with improved dispersion characteristics, with a simulated maximum depth of  $1/2(h/L_0 \approx 0.5)$  of deep water wavelength. The model equations have been extended to take into account of wave breaking and moving shoreline as described in Madsen et al.(1997) and Sørensen et al (2004).

The BW model solves the enhanced Boussinesq equations by an implicit finite difference technique with variables defined on a space-staggered rectangular grid. The model is capable of reproducing the combined effects of most wave of interest in port, harbor and coastal engineering. These include shoaling, refraction, diffraction, wave breaking, bottom friction, moving shoreline, partial reflection and transmission, non-linear wave-wave interaction, frequency spreading and directional spreading.

Phenomena, such as wave grouping, surf beats, generation of bound sub-harmonics and super-harmonics and near-resonant triad interactions, can also be modelled using the BW model. Thus, details like the generation and release of low-frequency oscillation due to primary wave transformation are well described in the model. This is of significant important for harbor resonance, seiche and coastal processes(MIKE BY DHI, 2009).

Mukho harbor has a narrow and long rectangular shape with a harbor length of 1,500 meters and a width of 400 meters. The berth facility include cement carriers, ferries, fishing boats and Coast Guard rescue boats. The computer simulation domain was 2,680m in the north-south direction and 2,600m in the east-west direction with a grid spacing of 4m, which consisted of  $670 \times 650$  meshes. The water depth in the simulation domain is 25m for the incident region and  $4 \sim 8$ m for in the harbor basin, and the

reflectivity of the structures is set at vertical wall 0.99, dissipating block 0.98, and natural coast 0.97 (Figure 3).

In this study, the infragravity wave components extracted from the long-term continuous wave observation data of five years were used as the incident wave conditions in computer simulation. For each wave direction, the incident wave periods are set at 64 cases in the range of 30s to 125s, and the wave height is set at 0.1m. The wave direction considered in N, NNE, NE, ENE, E, ESE and SE directions. The BW model is an unsteady model for simulating time domain, and the Courant number varies depending on the grid spacing, time interval and wave celerity. The time interval was applied with 0.25s and 0.4s according to the incident wave periods, and the Courant number used with the condition of  $Cr \leq 0.9$  and 1.4. In addition, the total simulation time for each case was applied to be 20 periods so that standing waves could develop sufficiently in the harbor.

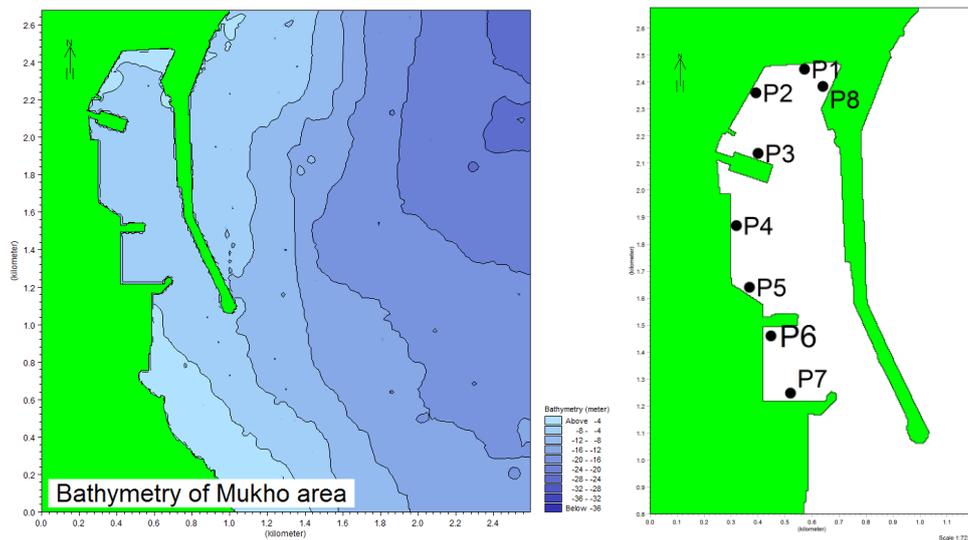


Figure 3. Computer simulation domain and bottom topography(left) and location of comparison points(right)

When a long period waves propagated in a harbor with a rectangular shape, it is difficult for the wave energy of the multi-reflected waves to be scattered out of a harbor, and generated superposed waves with the incident wave, resulting in harbor oscillation with standing wave motion. The computer simulation results obtained the amplitude response curves at eight points in the harbor as shown in Figure 3. Amplitude response curves make it easy to figure out the harbor oscillation in a harbor according to the incident wave periods and wave directions.

Figure 4 show the amplitude response curves with the incident wave periods at the comparison points before the measures. The horizontal axis is the incident wave periods, and the vertical axis is amplification factor that divides the wave height of the comparison point in the harbor by the incident wave height. Figure 4(a) is the response curve of P1 point located in the inner harbor, with the amplitude of the incident wave increasing 4.7 times on the peak period of 36s. Figure 4(b) shows the response curve of P2 point, with an amplitude factor of 4.5 on peak at 38s. Figure 4(c) shows the response curves of P4 point with the peaks at 37s, 50s, 70s and 92s, and the amplification factor simulated in 3.0, 2.7, 3.1 and 2.8 respectively. Figure 4(d) shows the response curves of P6 point located in near harbor entrance, with peaks of 32s, 55s, 68s, 78s and 110s, and the amplification factor simulated in 4.7, 3.3, 5.3, 3.0 and 4.1, respectively. This is due to the large increasing of harbor oscillation in the basin with a rectangular shape at the harbor entrance by diffracted waves at the end of breakwater and the reflected waves from the southern shore protection of the harbor.

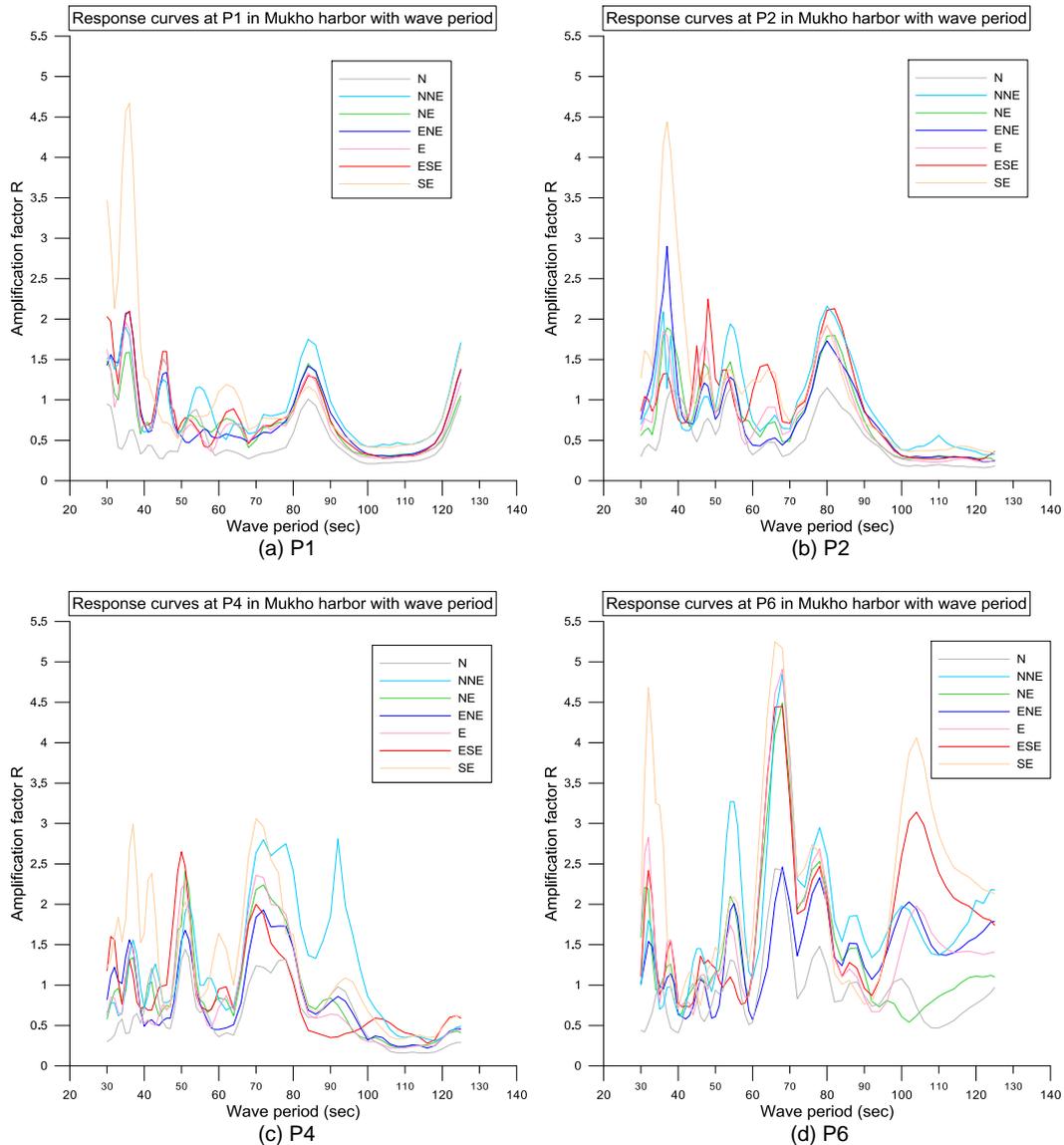


Figure 4. Response curves with wave periods before measures.

#### COMPARISON OF REDUCTION EFFECT

The measures of harbor oscillation by infragravity waves assume five cases as Figure 5. Case 1 and 2 are the method of installing a permeable detached breakwater with a length of 120m and a transmission coefficient of 0.3 on the outside of the harbor. Case 4 and 5 are the method of installing a permeable breakwater with a length of 200m and transmission coefficient of 0.13. Case 2, 3 and 4 are the method of replacing the vertical wall with a low reflective structure of less than reflectivity 0.9 on the inside of the harbor.

Figure 6 show the comparison of the amplitude response curves according to the measures at P6 when the infragravity waves is propagated in the direction of NE. In the figure, the black line is the results before the measures and the colored lines are the results after the measures.

The reduction effect shown distinctly at peak periods 32s and 68s. In particular, all cases showed a reduction effect in periods of 68s, and the most effective case was Case 2 which expressed in the blue line.

Meanwhile, Case5 was increased amplitude on 90s to 120s in comparison with before the measures were applied. This is because Case 5 has increased the characteristic length of the harbor by installing the permeable breakwater parallel to the main breakwater.

Case 2 clearly showed reduction effects of harbor oscillation for all considering wave direction as Figure 7. For NNE, NE, E, ESE and SE directions with multiple peak periods, the amplitudes before the measures were significantly reduced.

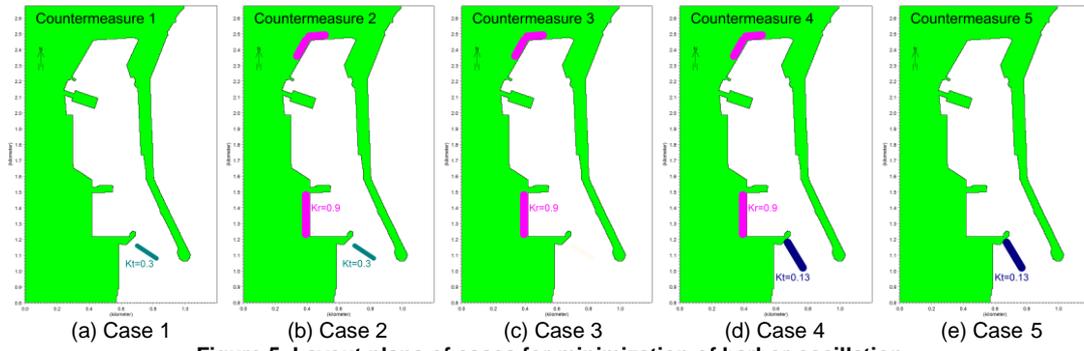


Figure 5. Layout plans of cases for minimization of harbor oscillation.

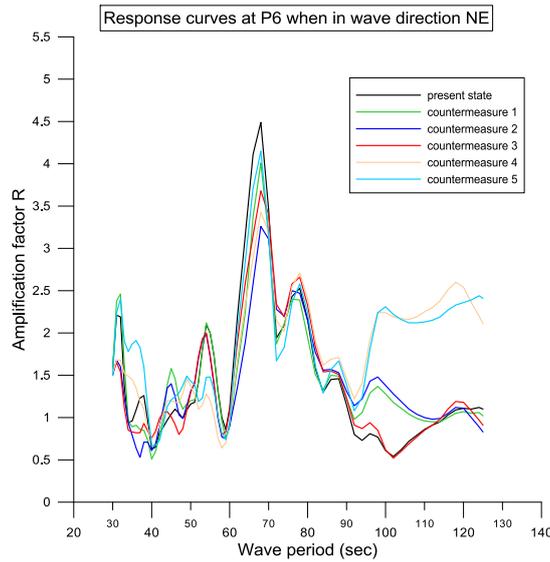


Figure 6. Comparison of response curves at P6 after measures.

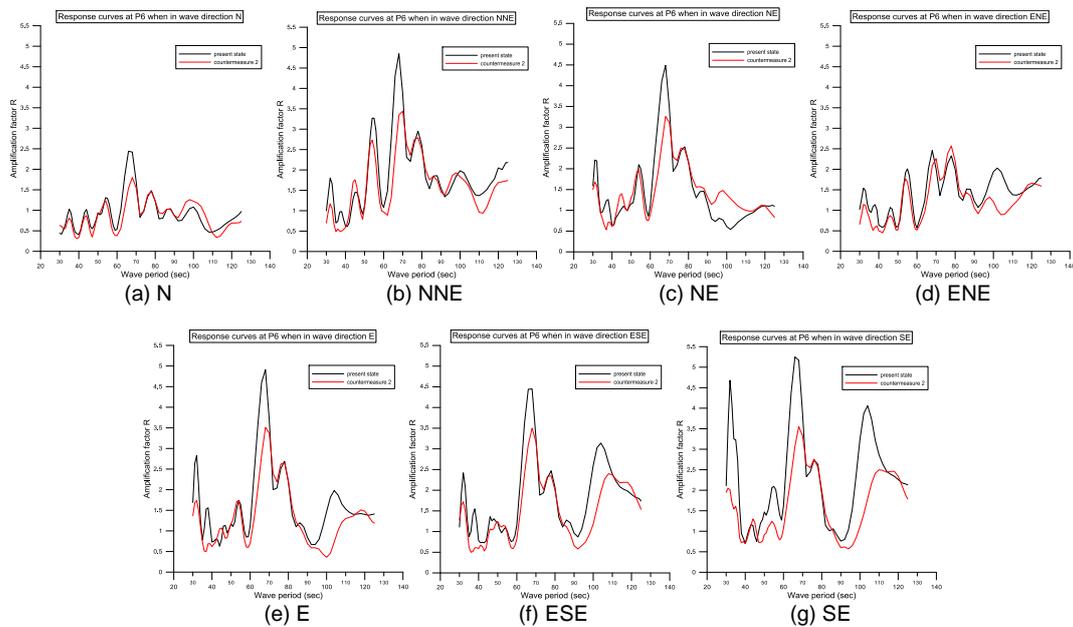


Figure 7. Comparison of response curves at P6 with different wave direction.

In particular, at peak period 68s with the largest amplification factor, the decrease in amplitude was even greater, and SE direction was shown to significantly reduce amplitude at peak periods of 32s, 68s and 110s.

Table 1 is a comparison of the reduction rate of amplitude according to the measures at P6 when waves propagated in NE direction. Case 2 was the most effective method of reduction with a reduction rate of 27.4% as the amplification factor was reduced from 4.49 to 3.26. The following was a reduction rate of 23.6% as Case 4, and Case 3 was 18%.

Meanwhile, Case 1 and 5 had 10.9% and 7.6% reduction rates, and measures to install only permeable breakwaters on the outside harbor has a small reduction effect.

Cases	Minimization		Reduction rate(%)	Remarks
	Before(R)	After(R)		
1	4.49	4.00	10.90	permeable breakwater( $K_T=0.3$ )
2	4.49	3.26	27.40	permeable breakwater( $K_T=0.3$ ) + wave energy dissipating( $K_R=0.9$ )
3	4.49	3.68	18.00	wave energy dissipating( $K_R=0.9$ )
4	4.49	3.43	23.60	permeable breakwater( $K_T=0.13$ ) + wave energy dissipating( $K_R=0.9$ )
5	4.49	4.15	7.60	permeable breakwater( $K_T=0.13$ )

## CONCLUSION

This study applied the reduction measures of harbor oscillation by infragravity waves to Mukho harbor and investigated reduction effect numerically using the Boussinesq wave model. From the long-term continuous wave observation data, the infragravity waves of Mukho area was found to be concentrated between 40s and 70s, and the wave height was 94 % at less than 0.1m. The most effective method to reduce harbor oscillation in this harbor by infragravity waves was to install a permeable detached breakwater with a transmission coefficient of 0.3 on the outside harbor and replace vertical wall with a low reflective structure with reflectivity of 0.9 on some area in the harbor. Meanwhile, the method of installing only permeable breakwater on the outside harbor did not have a significant effect of reducing harbor oscillation by infragravity waves.

## ACKNOWLEDGEMENT

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