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Long-Period Harbor Oscillations in Gamcheon Harbor

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1. Introduction

Long-period wave oscillations in a harbor could create unacceptable vessel movements leading to the downtime of moored ships. It is practically very difficult to prevent long-period harbor oscillations, but extension of breakwaters at the harbor mouth could be a countermeasure in part. Narrowing a harbor mouth might give rise to increase in the energy loss due to flow separation near the mouth, which in turn makes resonant periods of the harbor become longer, especially for the first (or Helmholtz) resonant mode.

This study includes field measurements for short- and long-period waves, and the development of a finite element model based on the extended mild-slope equation, which incorporating the bottom frictional dissipation and the entrance loss due to flow separation. The model can handle an arbitrary shaped harbor with non-straight coastlines, and remove unwanted artificial resonance phenomena caused by the abrupt depth discontinuity at the interface boundary of near and far field regions discussed by Liu (1986) and Jeong and Park (1996).

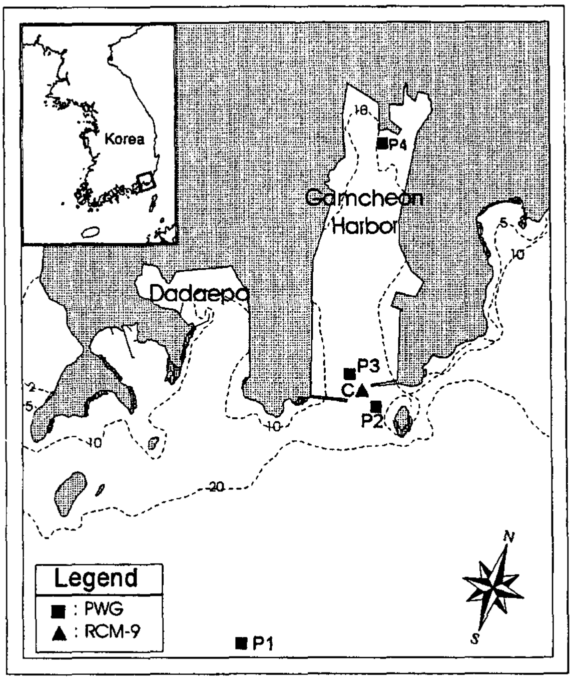

Fig. 1 Location map of field measurement stations.

2. Field Measurement

Field measurements for short- and long-period waves were performed around Gamcheon Harbor from November 27 to December 13 in 1997. In spite of narrow mouth, this commercial harbor located at the east-southern coast of Korea, is suffering from severe downtime problems in summer season. Four pressure-type wave gauges (PWG), and one Aanderaa RCM-9 current meter were deployed at locations shown in Fig. 1. Sampling intervals for pressures at P1 and P4 were set to 5 seconds, while pressure data at P2 and P3 were gathered in the interval of 1 second. Current velocities from RCM-9 were averaged over 1 minute.

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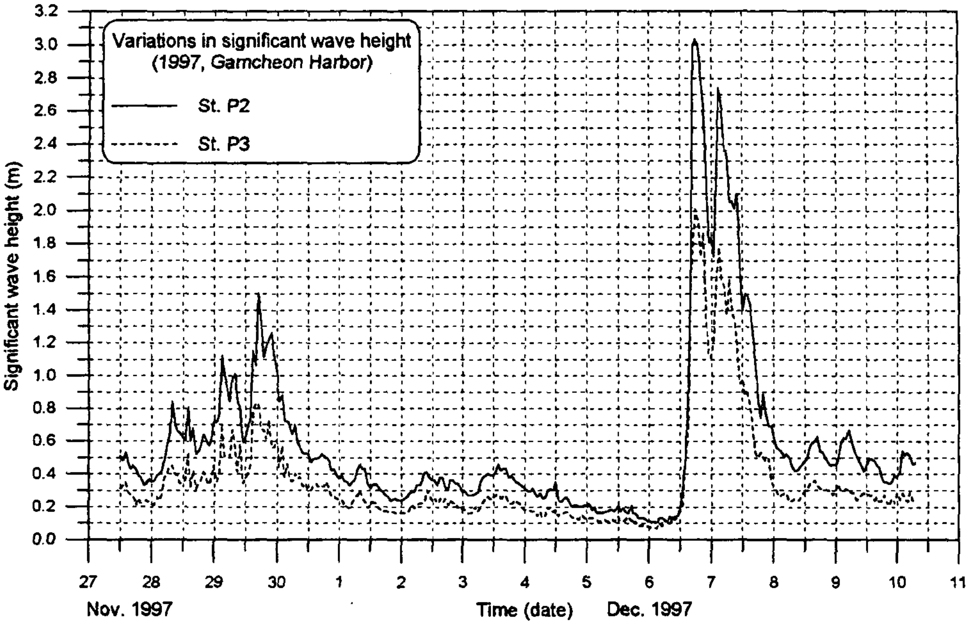

Fig. 2 Variation in significant wave heights at P2 and P3 (Nov. 27~Dec. 10).

To obtain short-period wave characteristics, the data obtained at P2 and P3 were analyzed by using a spectral method. Fig. 2 shows the variation of significant wave heights at P2 and P3 from November 27 to December 10. Two storm wave conditions were clearly observed at November 29 and December 6~7 with significant wave height of 1.2~1.5 and 2.7~3.0 m, respectively.

After filtering tidal components from pressure signals using a Butterworth high-pass filter in MATLAB, spectral analyses were performed 16 sets of filtered pressure data. Fig. 3 shows the power spectral densities of long-period wave data set no. 6 obtained at 4 stations. We can find

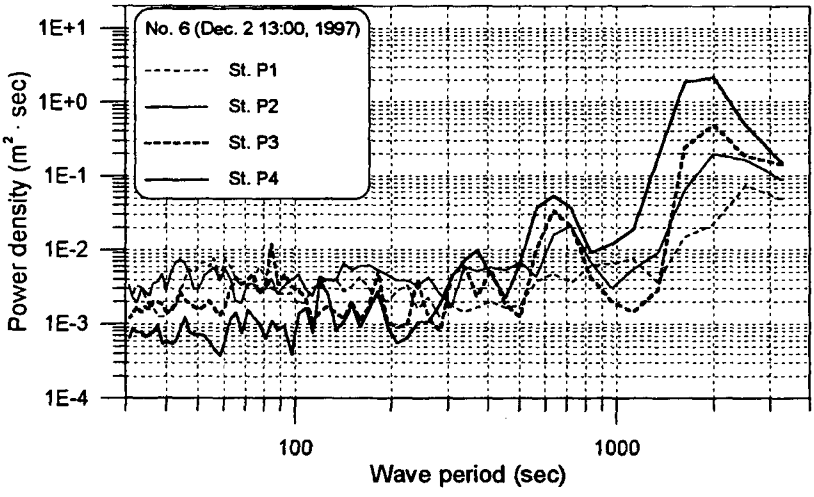

Fig. 3 Power spectral densities obtained at stations P1~P4.

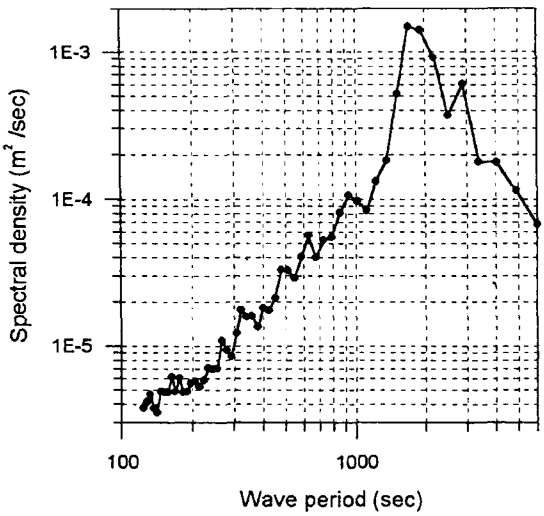

Fig. 4 Power spectral densities for observed velocity at the harbor mouth.

the first and second resonant modes appear near 2,000 seconds and 600 ~ 700 seconds, respectively. It is noted that the period of Helmholtz resonant mode of Gamcheon Harbor is 27.0 ~ 33.3 minutes and the amplification ratios are about 9 ~ 14 and the second and third resonant periods appear at 9.4 ~ 12.1 and 5.2 ~ 6.2 minutes respectively. Fig. 4 shows the power spectral densities of current velocity normal to the harbor mouth. It is noted that the maximum value appears around 28.2 ~ 31.9 minutes corresponding to the Helmholz mode.

3. Galerkin Finite Element Model

In this study, the extended mild slope equation with the bottom frictional dissipation derived using Galerkin eigen-function technique (Massel, 1992; Suh et al., 1997) has been used. For more detailed mathematical formulations, see Jeong et al. (1997). The domain in the model is divided into two regions as shown in Fig. 5: one is a near field region (Ω_1) that is modeled as conventional finite elements and the other is a far field region (Ω_2) that is represented as infinite elements of which shape functions satisfy the radiation condition at infinity.

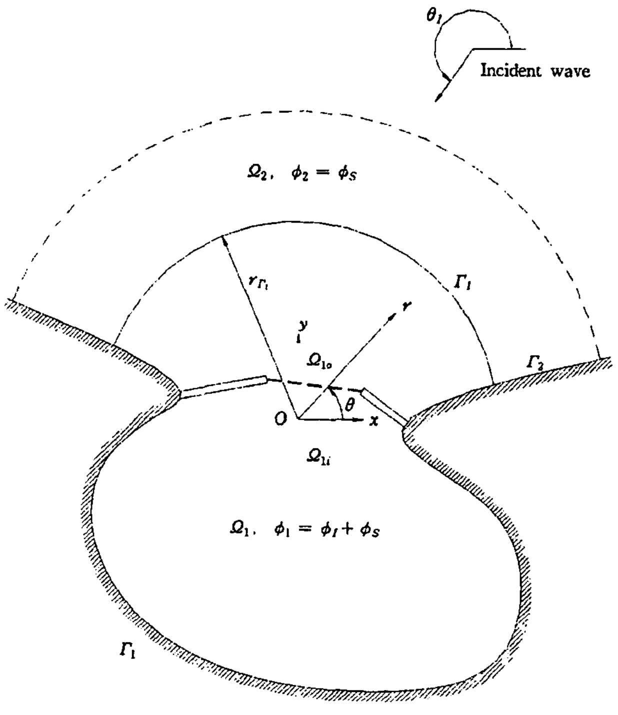

Fig. 5 Definition sketch for boundary value problem.

To take into account the entrance loss at the narrow harbor mouth, the near field region is again divided into two sub-regions, that is inner (Ω_{1i}) and outer regions (Ω_{1o}) of the harbor (see Fig. 5). Two matching conditions were introduced on the interface boundary of two sub-regions, i.e., velocity and pressure continuity conditions at the harbor mouth (Unluata and Mei, 1975).

For the entrance loss effects, the following matching conditions are introduced.

$$u_i = u_o$$

$$\frac{p_i}{\rho} = \frac{p_o}{\rho} + \frac{1}{2}\frac{f_e}{g}|u_o|u_o + \frac{l_j}{g}\frac{\partial u_o}{\partial t}$$

where, f_e is the loss coefficient and l_j is the jet length. The quadratic non-linear energy loss term was linearized by using Lorentz transformation and equating depth averaged power, that is,

$$\frac{1}{2}\frac{f_e}{g}|u_o|u_o = \frac{1}{2}\alpha\, u_o$$

where, the linearized loss coefficient α is given by

$$\alpha = \frac{8}{9\pi}\frac{f_e}{g}\overline{u_o}\tanh kh\,\frac{5+\cosh 2kh}{2kh+\sinh 2kh}$$

where, $\overline{u_o}$ indicates the wave mean velocity. In the above equations, f_e and l_j are determined by hydraulic experiments for various cross-sections. We used f_e based on inverse Strouhal number, $u_e/a\omega$ suggested by Lepelletier (1980). For the jet length, a simple formula suggested by Morse and Ingard (1968) is used.

The present finite element model can accommodate the non-straight coasts at the outside of the harbor, which poses considerable difficulty in the conventional HEM (Chen, 1986; Jeong and Park, 1996). The depth discontinuity between near and far field regions in HEM may induce unwanted phenomena such as additional resonances, amplifying responses, and so forth. To remove these problems, the effect of depth variations along circumferential interface boundary is included in the present model. Discussion on the influence of water depth discontinuity and the bottom frictional dissipation are, for brevity, omitted.

4. Numerical Experiments for Long-Period Harbor Oscillations

To verify the accuracy of present model, numerical experiments have been performed for a rectangular harbor used by Lepelletier (1980) in hydraulic experiments. Two types of rectangular harbor have been tested: one is a fully open harbor (a/b = 1.0, a is width of a harbor entrance, b is width of harbor) and the other is a partially open one (a/b = 0.2). In Fig. 6, numerical results without and with entrance losses are presented with the experimental results by Lepelletier (1980). The amplification ratio obtained without energy losses remains constant (with a far overestimated value) independent of incident wave heights. But numerical results with energy loss coincide with the experimental ones very well. Fig. 7 shows the results for a partially open harbor. In this case, the numerical results without considering energy loss are higher than those of the fully open harbor, explaining the famous "harbor paradox". But the amplification ratios are considerably reduced with increase in energy loss and jet length. The amplification ratios decrease with increase in incident wave heights.

Fig. 8 shows the comparison of measured data and calculated amplification ratios in Gamcheon Harbor. Hollow black circles are 13 measured data and black square are estimated results. Both results show good agreements in point of the resonant period and the amplification ratios. In the numerical calculation, 0.1 m of incident wave height was used for the entrance

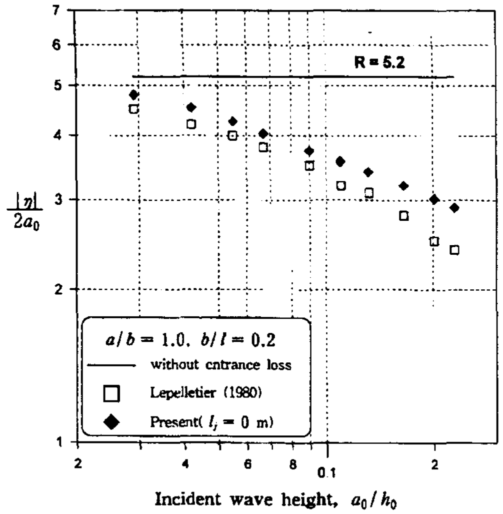

Fig. 6 Variation in amplification ratios wrt incident wave heights for a fully open rectangular harbor (a/b = 1.0).

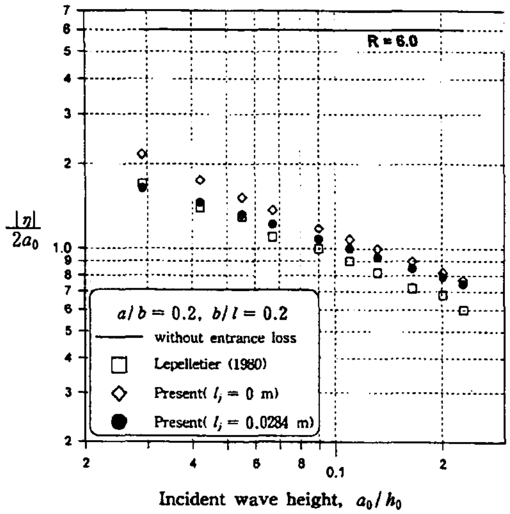

Fig. 7 Variation in amplification ratios wrt incident wave heights for a partially open rectangular harbor (a/b = 0.2).

losses. The measured long-period wave heights were in the range of 0.03~0.07 m.

5. Conclusion and Discussion

In the present study, a Galerkin finite element model based on the extended mild-slope equation with the bottom friction dissipation incorporating infinite elements has been developed.

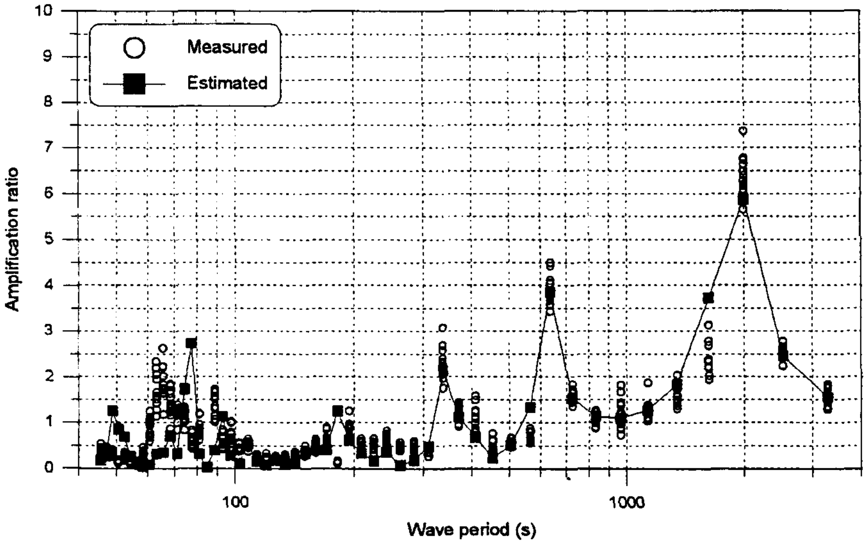

Fig. 8 Comparison of measured and calculated results for Gamcheon Harbor.

In addition, the present model was extended to include the entrance losses due to flow separation at harbor mouth, and was applied to the real harbor with narrow mouth, Gamcheon Harbor. Through the comparison with the hydraulic experiment and field data, the accuracy and applicability of present model has been proved. Although more informations on the input data including incident wave heights and direction as well as partial reflection coefficients at solid boundaries are required.

Acknowledgement

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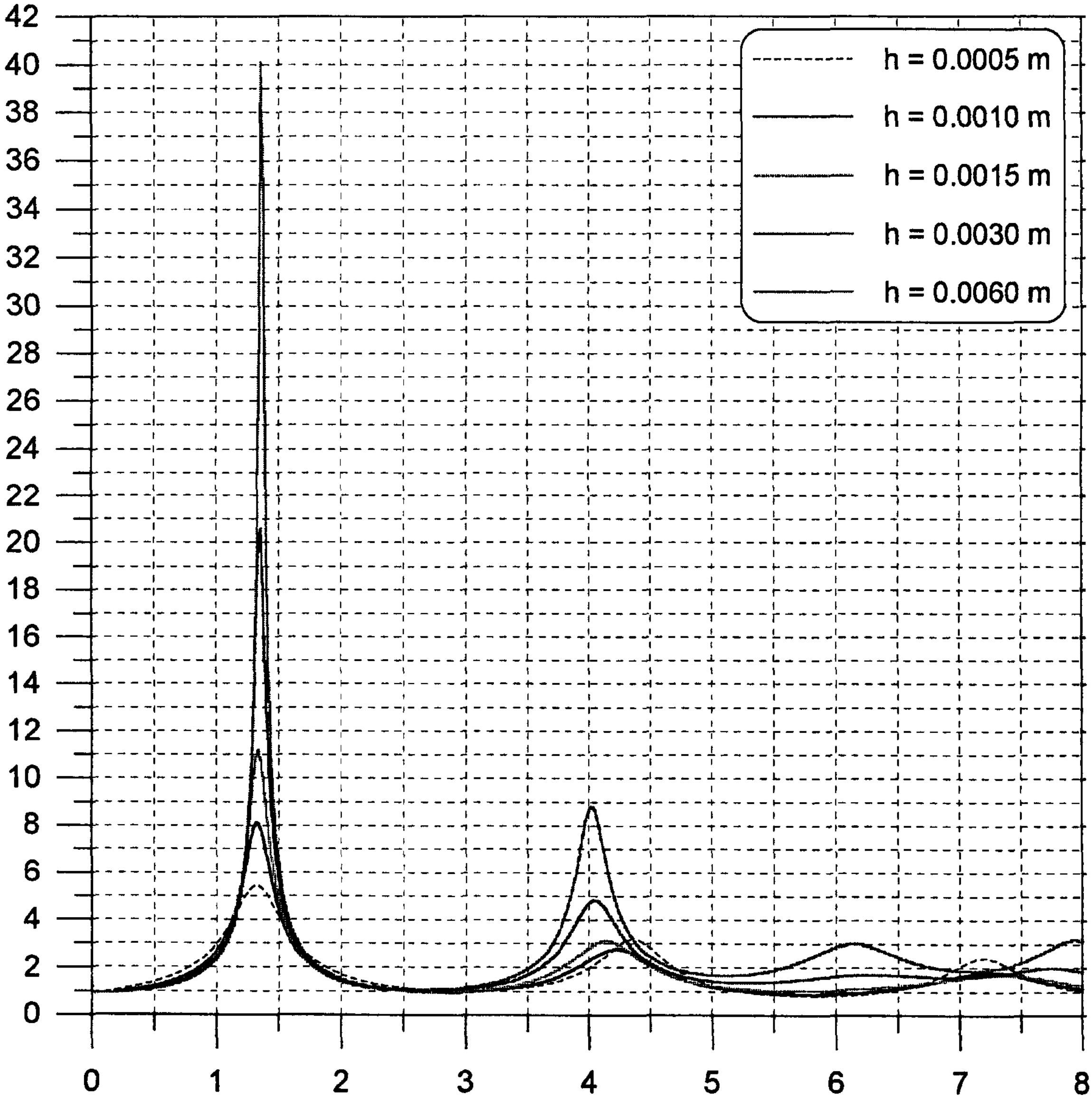
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