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Marina Development Impact on the Tranquility of Small Coast Harbor

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Abstract : *Due to the increased demand for safety and security requirements on the port infrastructure, the harbor tranquility is one of the important parameter in the mooring basin of harbor. It relates keenly to berthing/unberthing and cargo handling works but also it is an important indicator to get the minimum water area as the safe refuge. Hupo harbor is a national coastal harbor located in east coast of Korea and a development plan for a new marina near the entrance is being carried out including berth layouts, breakwater extensions, 300m marina berths, dredging and land reclamation works. The new plan will impact on calmness of the existing port. Therefore, it is necessary to analyze in complex the variation of wave height and direction caused by wave refraction, diffraction, shoaling and reflection from the incident waves from outside the harbor. In order to check the calmness inside a harbor, the numerical models are being used currently need fundamental reviews according to the difference of results which depend on their respective features. In this study, hence, it was introduced the validity of numerical models by comparing the computational results with the hydraulic model experiment. The current investigations contribute to the existing development recommendations and provide further solutions for port planning.*

Key words : *Harbor tranquility, Mooring basin, Marina, Hydraulic model test, Numerical model*

1. Background and Object

Due to the increased demand for safety and security requirements on the port infrastructure, the harbor tranquility is one of the important parameter in the mooring basin of harbor. It relates keenly to berthing/unberthing and cargo handling works but also it is an important indicator to get the minimum water area as the safe refuge. Hupo harbor is a national coastal harbor located in east coast of Korea and a development plan for a new marina near the entrance is being carried out including berth layouts, breakwater extensions, 300m marina berths, dredging and land reclamation works. The new plan will impact on calmness of the existing port. Therefore, it is necessary to analyze in complex the variation of wave height and direction caused by wave refraction, diffraction, shoaling and reflection from the incident waves from outside the harbor. In order to check the calmness inside a harbor, the numerical models are being used currently need fundamental reviews according to the difference of results which depend on their respective features. In this study, hence, it was introduced

Fig. 1 Location map for Hupo port with a marina plan

Fig. 2 View of the existing Hupo port

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the validity of numerical models by comparing the computational results with the hydraulic model experiment. The current investigations contribute to the existing development recommendations and provide further solutions for port planning. Fig.1 and Fig.2 show the location map and marina plan and view of Hupo port. Maintenance dredging plan would be included for the passenger terminal and turning basin as shown in Fig.4. The water depth for the berth and turning basin(D=330m) are scheduled to dredge up to (-)7.5m and the approaching and entrance channels are deep enough as present state. The size of basin for this port has 600m long and 660m wide. Existing counter facilities are the west breakwater (607m) and the east breakwater(1,312m), and 1,347m berthing facilities, such as quays(260m), wharves(1,030m), and the coast guard wharf(60m). However, there are extension of berthing facility to 180m and the east breakwater to 150m, the coast guard wharf to 110m, 250m of wave breakers together with 45m extension to the ferry terminal as shown in Fig. 3.

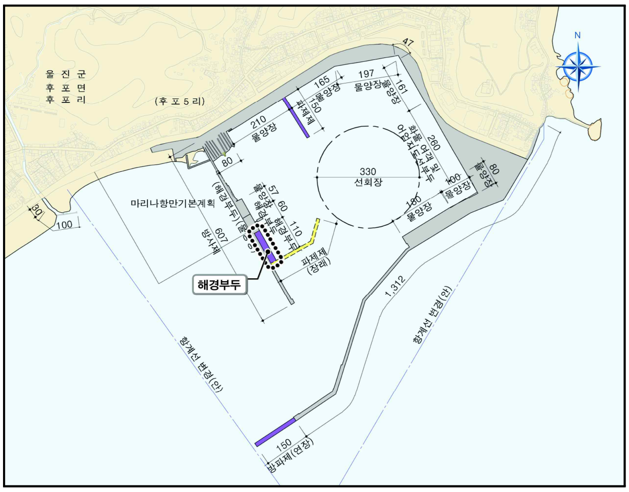


Fig. 3 Modified master plan at Hupo port

2. Review of Theoretical Basis for Numerical Model

Solving the wave problems numerically for the analysis of harbor tranquility may be the most time-consuming stage because the wave equations are being solved iteratively in all grid cells. Selecting appropriate wave equations and numerical schemes are also important. Numerous research works have been done for harbor tranquility previously, and especially, Lee (1989), Lee and Kim(1991), and Kim and Hur(2003) had used the extended mild-slope equation for Korean ports and shown good discussions. In this study two types of equation are adopted such as the wave action balance equation and the time dependent mild slope equation for simulating nearshore waves as follows. The difference of two equations from the response analysis of the shore structures will be discussed.

2.1 Wave action balance equation model (model1)

In order to analyze the wave deformation at the study area, WABE model was used by various conditions. This has been developed and validated specifically in coastal and inland waters. In nearshore zones, finite depth effects such as bottom friction, shoaling, refraction, depth induced breaking, and modified wave-wave interaction become important. Governing equation for the numerical model based on the spectral wave action balance equation is defined as Equation (1). Each of representing the spatial propagation speeds, c_x, c_y is in the equation (2) and (3), respectively, c_σ , c_θ in equation (5)and(6) are the propagation speeds in terms of frequency and directional domains.

$$\frac{\partial N}{\partial t}+\frac{\partial c_x N}{\partial x}+\frac{\partial c_y N}{\partial y}+\frac{\partial c_\sigma N}{\partial \sigma}+\frac{\partial c_\theta N}{\partial \theta}=\frac{S}{\sigma} \tag{1}$$

$$c_x=\frac{dx}{dt}=\frac{1}{2}\left[1+\frac{2kd}{\sinh 2kd}\right]\frac{\sigma k_x}{k^2}+U_x \tag{2}$$

$$c_y=\frac{dy}{dt}=\frac{1}{2}\left[1+\frac{2kd}{\sinh 2kd}\right]\frac{\sigma k_y}{k^2}+U_y \tag{3}$$

$$c_\sigma=\frac{d\sigma}{dt}=-\frac{\partial \sigma}{\partial d}\left[\frac{\partial d}{\partial t}+\vec{U}\cdot\nabla d\right]-c_g\vec{k}\cdot\frac{\partial \vec{U}}{\partial S} \tag{4}$$

$$c_\theta=\frac{d\theta}{dt}=-\frac{1}{k}\left[\frac{\partial \sigma}{\partial m}\frac{\partial d}{\partial m}+\vec{k}\cdot\frac{\partial \vec{U}}{\partial m}\right] \tag{5}$$

where, σ Is the equivalent relative frequency, θ is the wave direction, N is the wave action density spectrum, k is the wave number, d is the depth, m is a coordinate in the θ direction, U is the stream velocity vector, and $S=S(\sigma,\theta)$ are expressed the energy source of generation, dissipation, transfer. Also it is includes inflow of the wind energy, energy dissipation, nonlinear interaction. More general and detain introductions on this model are given by Booij et al (1999), Ris et al (1999), and Lee et al (2009).

2.2 Time dependent mild slope equation model (model2)

A time-dependent mild slope equation is applied to simulate the deformation of irregular waves due to refraction, reflection, diffraction, and breaking. It is based on Berkhoff's mild slope equation(1972) with modified boundary conditions by Copeland (1985) and Maruyama and Kajima (1985), and the resulting model is capable of simulating the time evolution of irregular wave profiles. The validity of the model is verified through comparisons with experimental data in a wave flume. In this study, it was applied like the bellow equation (6).

$$\frac{\partial Q_x}{\partial t} + C^2 \frac{\partial \eta}{\partial x} + f_D Q_x = 0 \tag{6}$$

$$\frac{\partial Q_y}{\partial t} + C^2 \frac{\partial \eta}{\partial y} + f_D Q_y = 0 \tag{7}$$

$$\frac{\partial \eta}{\partial t} + \frac{1}{n}\left[\frac{\partial}{\partial x}\left(nQ_x\right) + \frac{\partial}{\partial y}\left(nQ_y\right)\right] = 0 \tag{8}$$

where, x, y are the horizontal perpendicular coordinate, η is the water surface displacement, C is the wave velocity, t is the time, Q_x, Q_y are the vertically integrated particle velocity fluxes in x, y direction, n is the ratio of group velocity and wave velocity, $(=C_g/C)$ and f_D is the energy attenuation coefficient.

3. The formulation of the models

3.1 Covered area of model study

Two numerical models were configured to simulate the Hupo harbor original shape as shown in Fig.1 and 4.Those numbers of Fig.4(a) are the stations of wave measurements at the hydraulic model. Ninety two stations are enlisted here. Simulation cases are focused to the two design waves, SE and SSE. Fig.4(b) also shows the cross sections of in and out of water basin for comparison of wave responses for different cases.

This measurement would be compared with case 1 of numerical model test result. The mesh used was 276cells long by 233cells wide in the numerical model. Four cases were simulated with the present water depth but after case 3 of dredging plan, same dredged condition was imposed to case 4 of marina plan as listed in Table 1.

3.2 Numerical model simulation cases

In this section, numerical calculations are presented in order to check the significance of the port development to calmness of port sea surface. The layouts of port and shore boundary for the simulation is shown in Table 1. Initial attempts are to simulate the wave responses with adopted openings to both the east and west breakwaters but the marina plan removed the opening to the west breakwater.

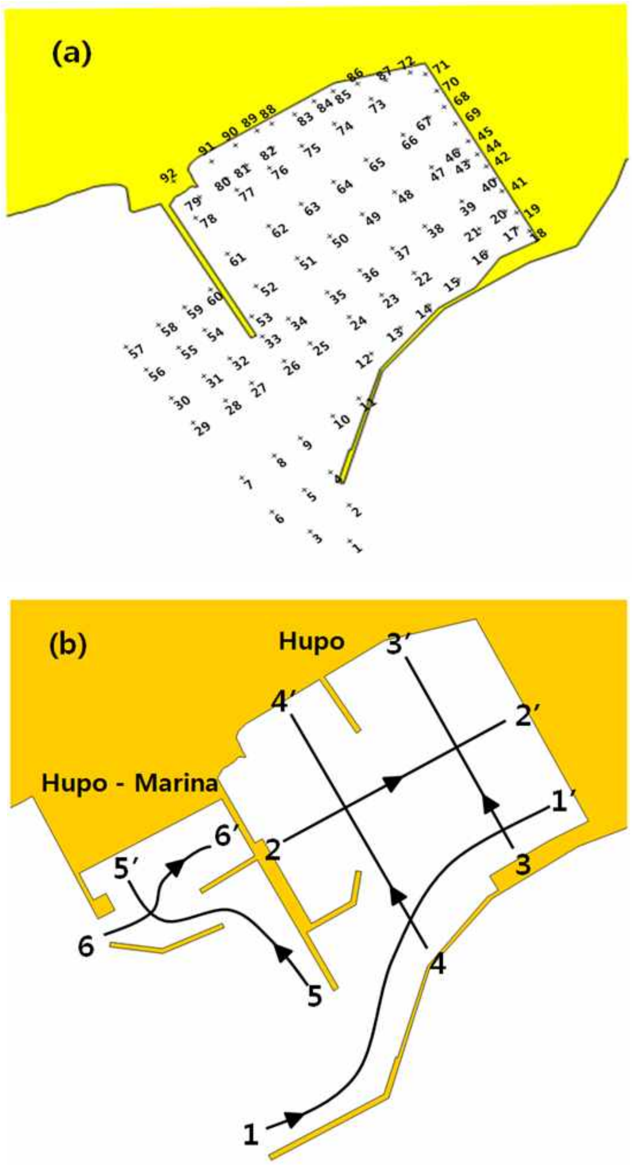
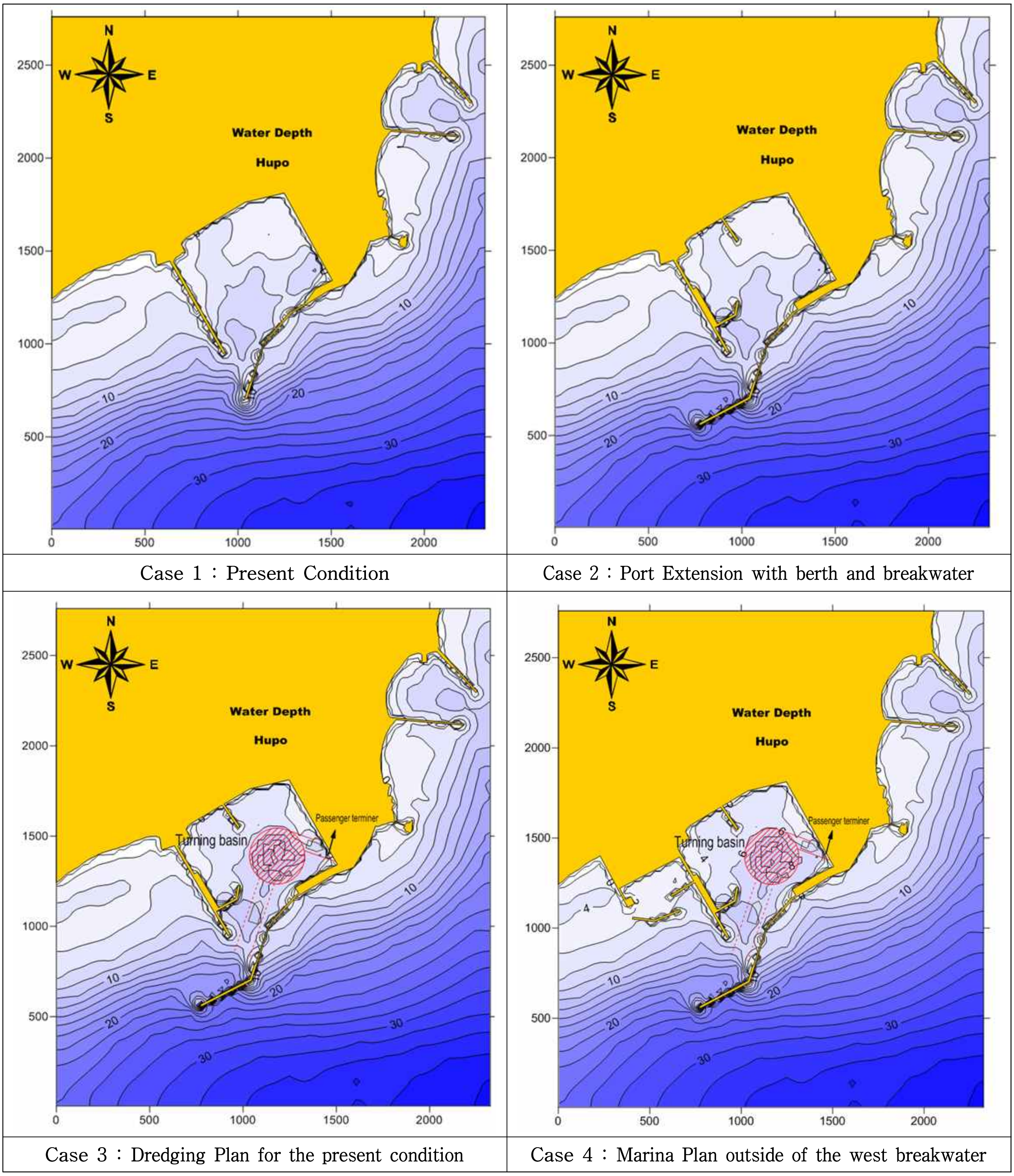


Fig 4 Wave measurement and comparison stations (a) for hydraulic and cross sections (b) for numerical models

The water depths are varying from (-)40m of offshore to (-)4.5m of harbor and (-)1.2m of shore boundary. Case 2 is applying the master plan of Hupo harbor which was adopted in 2011 under the 3rd national port master plan amendment (MOMAF, 2011).As this port has two main design incident waves from SE and SSE directions. In order to protect them it is necessary to extend the



Case 1 : Present Condition

Case 2 : Port Extension with berth and breakwater

Case 3 : Dredging Plan for the present condition

Case 4 : Marina Plan outside of the west breakwater

Fig. 5 Water depth for 4 model test cases at Hupo port waters

entrance breakwater as shown at Fig.5(case 2). Considering the trend of cargo ship and passenger ships under servicing, it is necessary to dredge the inner water area of berth as shown in Fig.5 (case3). An additional simulation was performed to illustrate the effect of the marina port development for harbor tranquility analysis (case 4) by adding the dredging plan adopted in the case 3. Two simulations for each case were performed with each model as described in section 2.

3.3 Numerical model verification from the results of the physical model

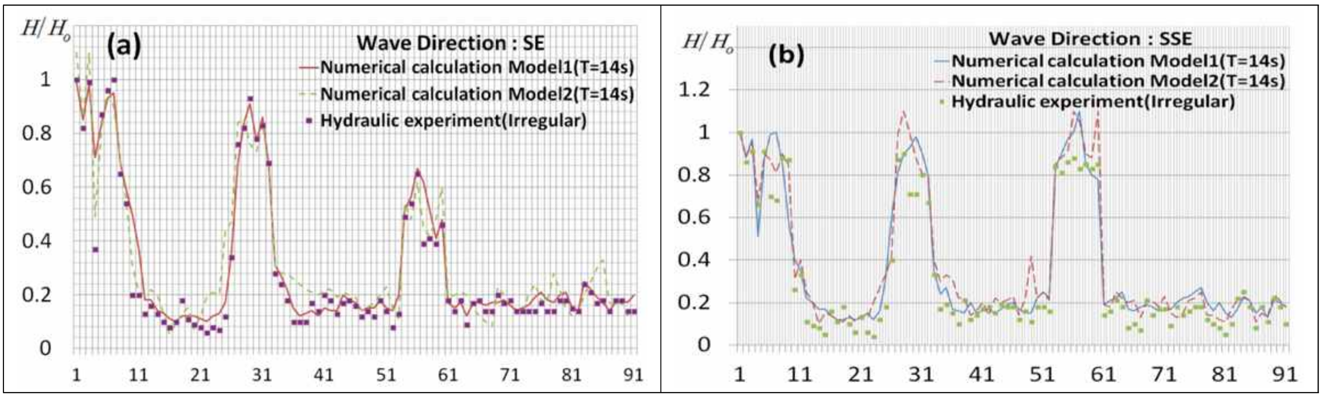


Fig. 6 Verification of numerical model for case 1 with the hydraulic model experiment results (a: SE wave, b: SSE wave).

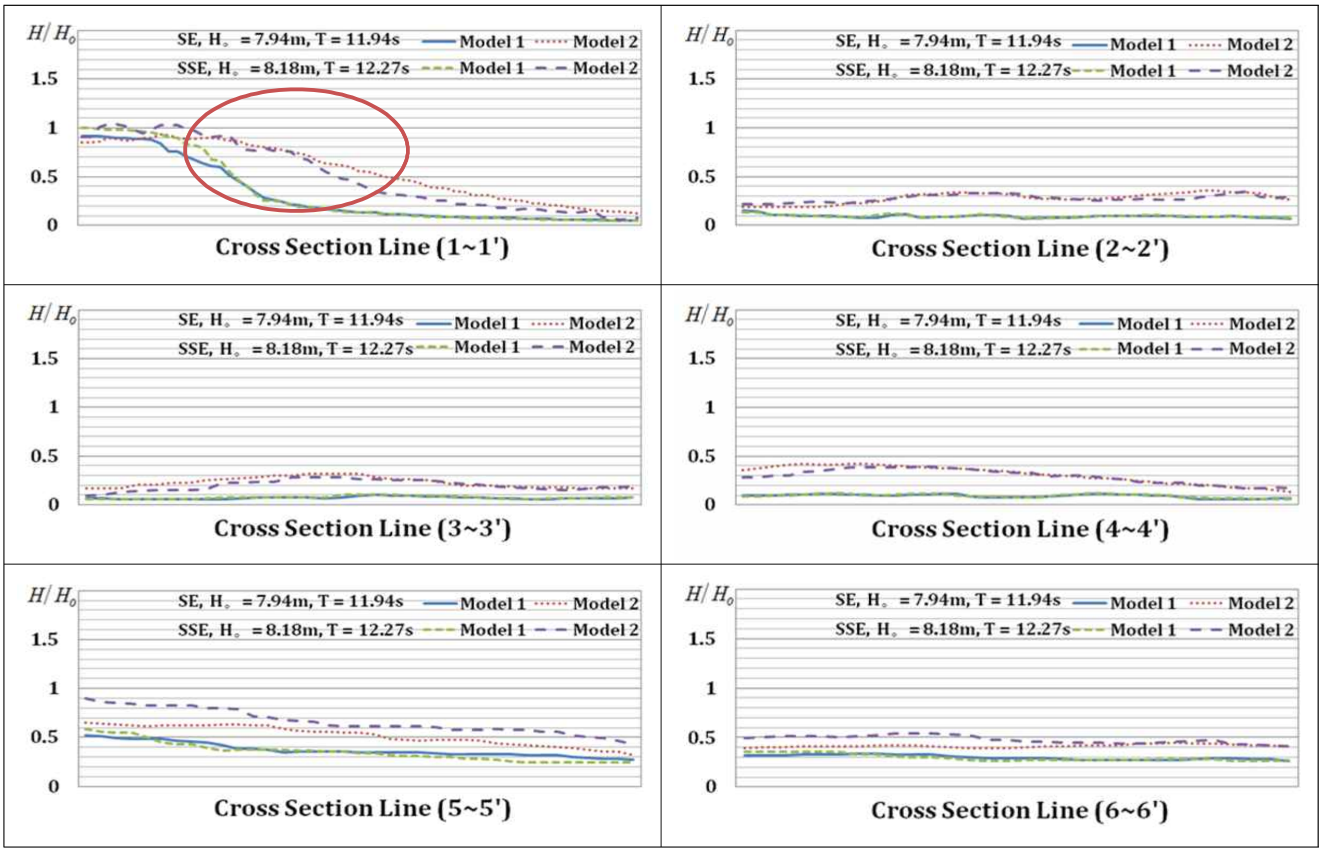
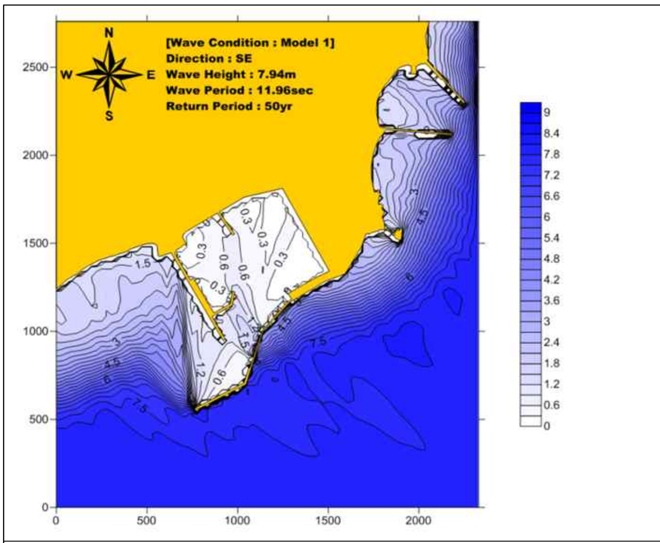


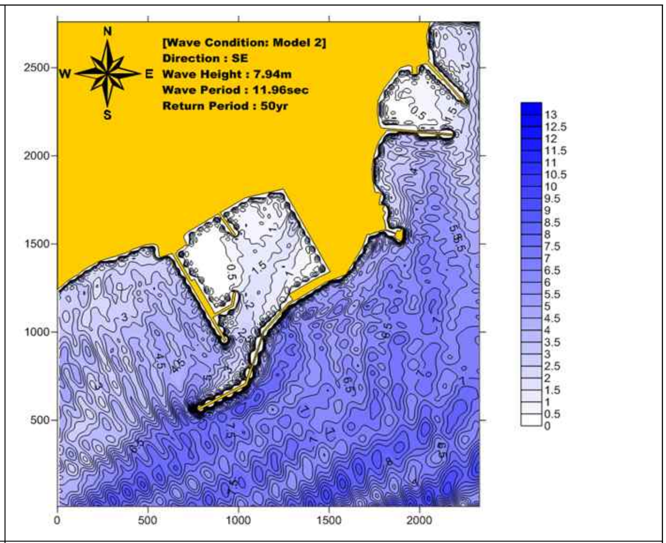
Fig. 7 Comparison of wave amplification ratio at the selected cross sections for Case 1.

To ensure the expected harbor response with respect to the incident waves, it is important to verify the numerical model formulated to apply them to the new design conditions. Unlike other numerical studies, a lot of measurements from the physical model study to this port by Korea Institute of Civil Engineering and Building Technology (KICT, 1988) are existed.

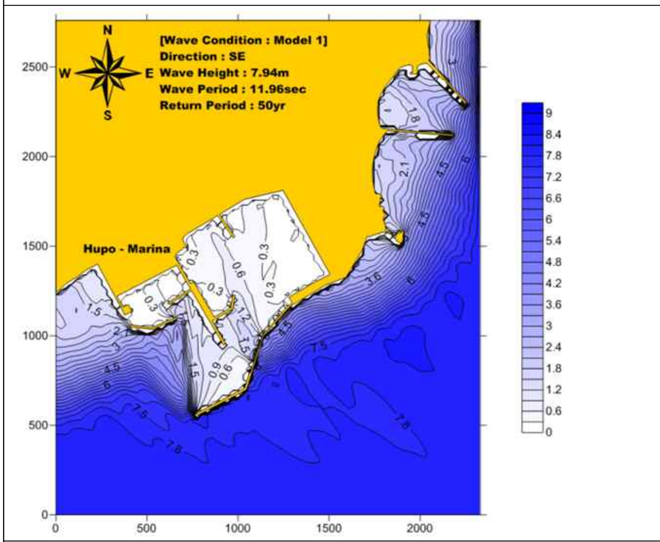
A scale physical model of Hupo harbor and its surroundings with a scaled ratio of 1:100 for the length, depth and wave height, together with 1:10 for wave period. Hence, it was able to simulate this case at laboratory scale. This test was intended to validate the representation of physical model experiment. Although the initial simulation result has produced incorrect results and therefore the shore boundary conditions were adjusted to get the best fit of responses. Simulation results of both models had the same consistencies inside harbor with hydraulic experiment by KICT, except some stations as shown in Fig.6. The three humps of the response curves indicate outside of harbor for both wave directions, which



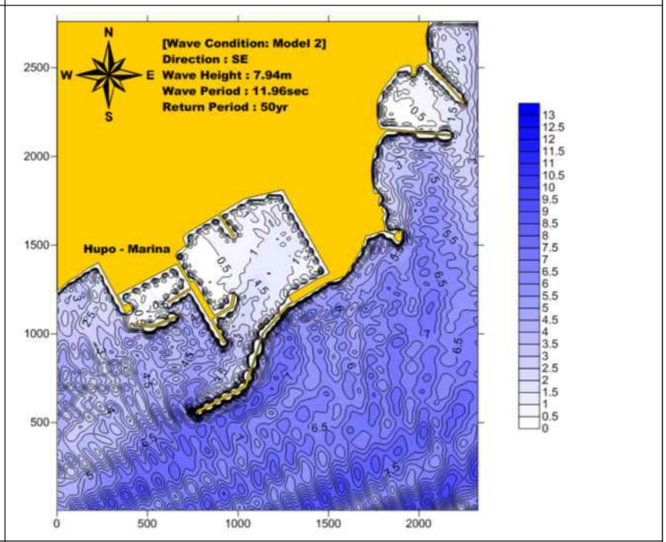
Case2: Port Extension with berth and breakwater (Model 1)



Case2: Port Extension with berth and breakwater (Model 2)



Case 4 : Marina Plan outside of the west breakwater (Model 1)



Case 4 : Marina Plan outside of the west breakwater (Model 2)

Fig. 8 Simulation results for port extension and marina plans for SE direction design wave.

agree well with the theoretical definition. The spots on the figures are the results of physical model experiment. As per matching process of the numerical models, the boundary condition along the berth and breakwaters had a large effect on the simulation results. Generally the amplification factors were less than 0.2 in the harbor. Fig.7 compares the simulated harbor responses. In each plot of Fig.7 the solid and dot lines are for SE wave and short dash and long dash lines are for SSE wave. The responses along the horizontal cross sections(line 1~1') indicates the incident waves were not reduced up to the entrance of harbor but rapidly dropped to 0.2 after passing the breakwaters. However, there were gradually decrease of responses for model 2. Model 2 seems to be higher response than model 1. As the equations and assumptions used in model1 to perform diffraction, the wave directly behind the breakwater does not impinge against but rather runs along it without being affected. In addition to this, it was found that while the front of the breakwater reflected the wave energy, the lee side of the breakwater did not reflect any energy. This creates response with an absorbing breakwater. Therefore, it is noticed that model 2 gives better result inside the harbor.

4. Numerical simulation and discussions

In order to compare the different cases an overview of the harbor responses is given for every scenario of incident wave conditions. In addition to the overall wave field, comparisons will also be made with the reference cross sections(line 1 through 6) for the port extension and dredging plans. Furthermore, some discussion of how the

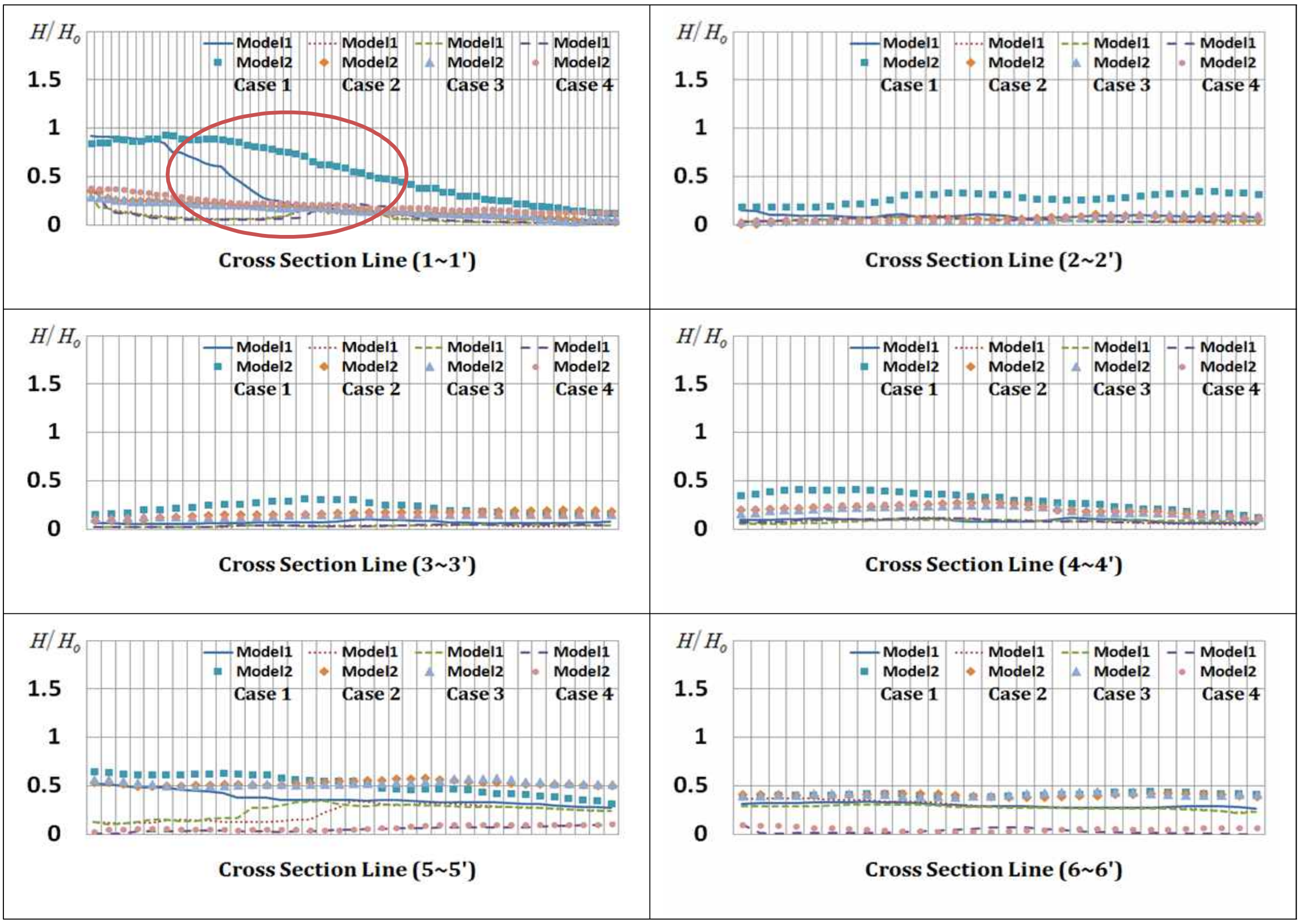


Fig. 9 Comparison of wave amplification ratio at the selected cross sections for SE wave

marina plan compares with other cases would be helpful especially given that harbor responses appear to be the cause of more tranquil water surface with the test case solutions.

4.1 Comparison of the results of the applied model

For discussion on tranquility of Hupo harbor, overall view of wave field for the design waves are presented against the present(case 1) as Fig.8. Only the responses for port extension and marina plans are presented here for SE design wave. Case 4 represents lower response than case 2 and model 2 shows higher response. As per this figure, model 2 describes wave diffraction better than model 1 leeside of the entrance breakwater as described in section 3.3. It is interesting to know over which the wave intrusion to the berthing area and wave breaker has been reduced at the marina plan case, so that the significance can be assessed with the comparisons of each cross section as shown in Fig.9 and Fig.10. As per the graphic representation at Line 1-1' in Fig.9 and Fig.10, the waves by model 1 are dampened rapidly by its absorptive function, compared to model 2, and even at line 2 through 4 in the harbor and line 5 and line 6 outside harbor, the similar trends were appeared. However, there was minor impact to the response on the line 5 and line 6 at outside of harbor for both SE and SSE waves of the case 4.That's because of trap of waves by marina breakwaters in the reduced wave zone. Among all test cases, mutual comparison between these showed that the marina plan combined with the port extension and dredging plan gave the lowest amplification and tranquil harbor conditions.

5. Conclusions and Recommendations

A set of novel methods to solve the wave action balance equation and the time dependent mild slope equation for simulating nearshore waves were discussed at the selected port. As implemented consistently those models the numerical solution would be consistent with those

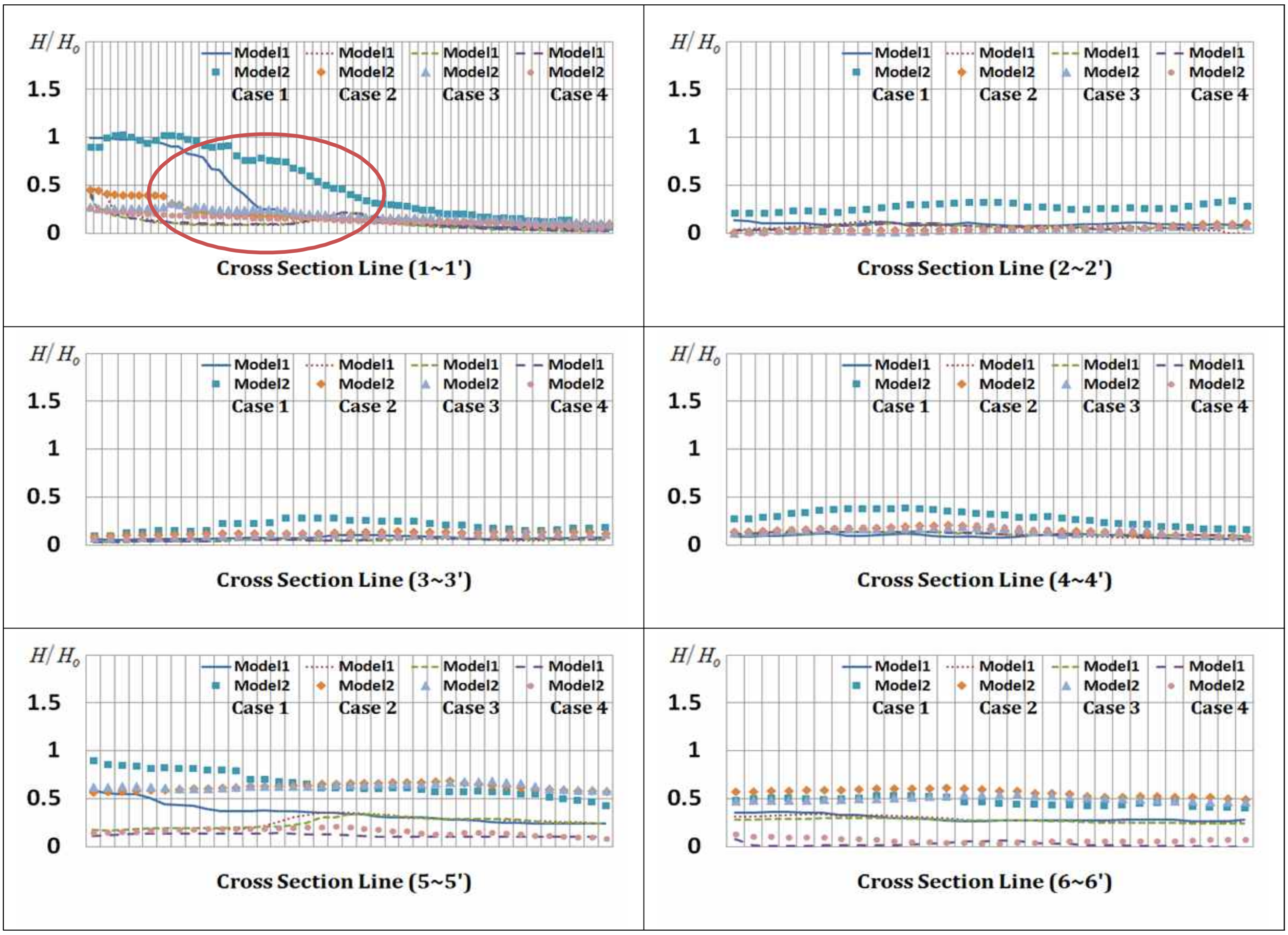


Fig. 10 Comparison of wave amplification ratio at the selected cross sections for SEE wave

produced by similar physical model. Two numerical models adequately simulated harbor tranquility after port expansion and marina development plan. We recognize that model 2 predicted higher harbor response compared to model 1. However, the nature of the problems with the numerical tests are predictable enough under the present simulation. The marina plan test of case 4 shows the most promising result in terms of harbor tranquility. Based in part on the results shown here, further application to the breakwater openings to enhance water circulation in the inner harbor for water quality conservation or other counter measure is necessary. Currently, an analysis based on the results of wave models is made but for the calculation of the siltation and sedimentation in the harbor, a sediment transport model of wave and current interaction for this area is being set up, so in due process more information on the impact of marina development will be addressable.

Acknowledgment

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