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Full Length Research Paper

An investigation of the applicability of a swelling wave simulation using maritime information for disaster prevention

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Recently disasters caused by swells are often occurring around the coastal areas of South Korea. Swells are accompanied with high waves that are approximately 10 m high and these come without particular warning. Thus, it is important to predict swells properly in order to prevent sudden coastal disasters. A systemic method to predict swells has not been established up till now. In this study, we simulated waves using maritime information such as wind, tidal current and deep sea incident wave. The simulated waves were compared with measured waves. Through this process, the applicability of swell simulation by using maritime information was examined. According to the results, when maritime information was considered, the simulation was found to reproduce the height and the changing patterns of swells relatively well.

Key words: Disaster, swell, maritime information, tidal current, deep sea incident wave.

INTRODUCTION

Recently, there have been many disasters caused by swells occurring around the coastal regions of South Korea. A swell is a wave that is generated when a wind wave escapes from the wind area and it is characterized as having a wave height that is higher than the wave height of a wind wave. Swells are typically generated under severe weather conditions, but there are also cases where even without particular warnings abnormally high waves with heights over 10 m are brought in. The following information is as regards the damage caused by swells that have occurred along the coastal regions in the recent years:

i) In May 2008 in the city of Boryeong on the west coast of Korea, a swelling wave of a couple meters occurred near a breakwater, causing the death of 9 lives and injuring 15 people. At the time of the incident the average wind velocity was at 3 to4 m/s and coupled with the clear weather, there was no sign that indicated that such a disaster would occur. In February 2008 at a harbor on the east coast of Korea a swelling wave caused the 2 deaths, 1 missing person and 15 injured people. In October 2006 because of a swelling wave, the sand beaches of the east coast were severely eroded and parts of the coastal roads were lost. Because swelling waves can be generated without the company of typhoons or other severe meteorological changes, it is difficult to come up with an appropriate plan to prevent such damages. It is also especially dangerous for houses and building near the coastal regions and tourists and people who work in the coastal areas because these waves can come at a height of up to 10 m without any meteorological warning.
ii) Research on swelling waves is still in the beginning stages and there is yet to be a specific analysis method to predict swells.
iii) If there has not been enough attention paid to the wave attenuation of the swelling wave this can bring dire errors to predicting the waves, yet there is still a lack of research in the area of wave attenuation. iv) Kantha (2006), and Talke and Stacey (2003) have analyzed the

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influence that swells have on the characteristics of the current in intertidal zones at the San Francisco bay in the U.S. According to their research the long wave at the 10 to 20 s period has a potentially large influence on the shear stress of the wave.

v) Ou et al. (2002) used the eddy simulation of the modified Rankin to calculate the wind field that is generated during a typhoon and applied the SWAN model to simulate the storm surge that occurs during a storm and compared this with the data measured through a buoy. Liang (2003) has discovered that the Doppler effect caused by a moving typhoon brings about a change in the wave height of the swell, and when a lot of typhoons influence the swell, the wave height grows to an extremely high wave.

The purpose of this research is to use available maritime information to simulate a swelling wave. Wind, tides and deep sea incident waves have been considered together to simulate the wave and this has been compared with field observation data. Tidal currents have been calculated based on tide simulations of the chosen regions.

SWAN model

The SWAN (simulating waves nearshores) model is a numerical wave model that uses the conditions of wind, water depth and current to derive the characteristic factors of the waves at near-shores, lakes and estuaries (Booji et al., 1999; Holthuijsen et al., 2000). This model allows for the consideration of wave propagation at spatial parts, refraction and shoaling by varying water depths and currents, and the wave interference and reflection caused by the inverse current. The general equation of the SWAN model is as follows:

$$\frac{\partial}{\partial t}N(\sigma,\theta)+\frac{\partial}{\partial x}c_x N(\sigma,\theta)+\frac{\partial}{\partial y}c_y N(\sigma,\theta) + \frac{\partial}{\partial \sigma}c_\sigma N(\sigma,\theta)+\frac{\partial}{\partial \theta}c_\theta N(\sigma,\theta)=\frac{S(\sigma,\theta)}{\sigma} \quad (1)$$

Where, $N(\sigma,\theta)$ is the energy spectrum over relative angular frequency, and $c_x, c_y, c_\sigma, c_\theta$ are the wave propagation velocities in x and y space and in θ and σ space, respectively. The wave propagation velocities can be defined as:

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

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

$$c_\sigma=\frac{d\sigma}{dt}=\frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t}+\vec{U}\cdot\nabla d\right]-c_\sigma\vec{k}\cdot\frac{\partial\vec{U}}{\partial s} \quad (4)$$

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

Where, $\vec{k}=(k_x,k_y)$ is the wave number vector, d is the water depth, $\vec{U}=(U_x,U_y)$ is the velocity vector, s is the coordinate in the direction of θ, m is the coordinate pependicular to s and $c_g=\vec{k}/k\cdot\partial\sigma/\partial k$ is the wave group velocity.

On the left side of Equation 1, the first term shows the rate of change of the action by time, the second and third term shows the propagation of action in the geometric space and the fourth term shows the change in relative angular frequency by varying water depths and currents. The fifth term shows the refraction caused by varying water depths and currents. Equation 1 shows that the periodic and spatial variance of action is same as the source function of the right side of the equation and is called the action conservation equation or the action balance equation. Equation 1 is first order of partially differential equation with 5 independent variables. Because the region in interest has a periodic magnitude of wave that is smaller than that of wind or tides, the term related to time can be ignored (Ris, 1997). The source function of the right side of Equation 1 is expressed as several terms which are implied by the physical process:

$$S(\sigma,\theta)=S_{in}(\sigma,\theta)+S_{ds}(\sigma,\theta)+S_{nl}(\sigma,\theta) \quad (6)$$

Where, S_{in} is the linear and exponential growth of wind input, S_{ds} is the energy dissipation by white capping, bottom friction and depth-induced breaking and S_{nl} is the quadruplet wave-wave interactions and triad wave-wave interactions, respectively.

The slot technique

The slot technique, which allows for an easy consideration of the moving boundary, is used to calculate the tidal current (Lee, 2004). This technique calculates the moving boundary by using it as the fixed boundary and has the merit of reducing calculation time. This means that there does not need to be checks of performance of calculation on all grid points in every time step. The slot equation is defined as:

$$f(z)=\begin{cases}\varepsilon+(1-\varepsilon)e^{\alpha(z-z_b)} & z\le z_b\\ 1.0 & z>z_b\end{cases} \quad (7)$$

Where, z is the vertical z-axis, z_b is the height from the sea floor, ε is the slot coefficient and α is the slot parameter.

Applying the slot technique, the continuity equation can be as follows:

$$\frac{\partial Z}{\partial t}+\frac{1}{F(z)}\frac{\partial U}{\partial x}+\frac{1}{F(z)}\frac{\partial V}{\partial y}=0 \quad (8)$$

Where Z is the tidal water level, U is the fluid velocity in *x*-direction, V is the fluid velocity in *y*-direction and $F(z)=2f(z)-f(z)^2$.

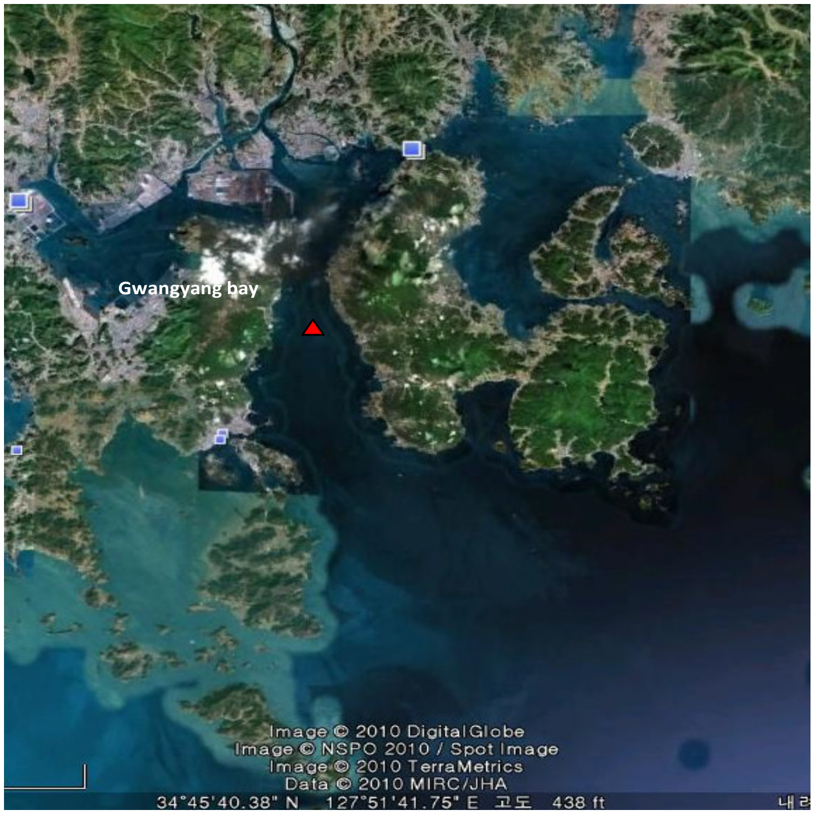


Figure 1. Research area.

The momentum equation in *x*- and *y*-direction is as follows:

$$\frac{\partial U}{\partial t}+\frac{U}{h_x}\frac{\partial U}{\partial x}+\frac{V}{h_x}\frac{\partial U}{\partial y}+h_x g\frac{\partial Z}{\partial x}-fV+g\frac{U\sqrt{U^2+V^2}}{C^2h_x^2}=0 \qquad (9)$$

$$\frac{\partial V}{\partial t}+\frac{V}{h_y}\frac{\partial V}{\partial x}+\frac{V}{h_y}\frac{\partial V}{\partial y}+h_y g\frac{\partial Z}{\partial y}-fU+g\frac{V\sqrt{U^2+V^2}}{C^2h_y^2}=0 \qquad (10)$$

Where, h_x is the cross section of current in-*x* direction over grid size in *y*-direction, h_y is the cross section of the current in-*y* direction over the grid size in *x*-direction, C is the Chezy coefficient, f is coriolis coefficient and g is the acceleration of gravity. The present study has calculated the velocity of tidal current using space-staggered grid suggested by Leendertse and Gritton (1971) and has simulated the wave by considering the effect of tidal current through this velocity, which has been substituted as velocity terms in Equations 2 to 5.

RESULTS AND DISCUSSION

The wave field area of research

Gwangyang bay was selected to gather wave observation data for this research. Figure 1 shows the wave field area of research and the observation point, as well as the wave field of the surroundings. The selected research area is a semi-enclosed configuration and the bay has small and large islands within it. Gwangyang bay, which is situated in the center of the southern coast of the Korean peninsula, is 27 km long and the width is 15 km from the south to north point. The "▲" symbol in Figure 1 represents the observation point of the wave (east longitude 127°47′09.966″, north latitude 34°50′17.808″) using the wave rider. The wave rider calculates the wave height and period of the surface waves and the wave direction using the time series of horizontal displacement. This data is analyzed and data regarding the wave height, period and direction is derived.

Simulated region

In order to simulate a wave that has considered the maritime information the broad calculation region of Gwangyang bay (length 70.2 km and width 36.6 km) has been established as the simulation region. To consider the deep sea incident wave the wave observation data of east longitude 127°51′00″, north latitude 34°16′30″ is used as input data. In order to simulate a swelling wave

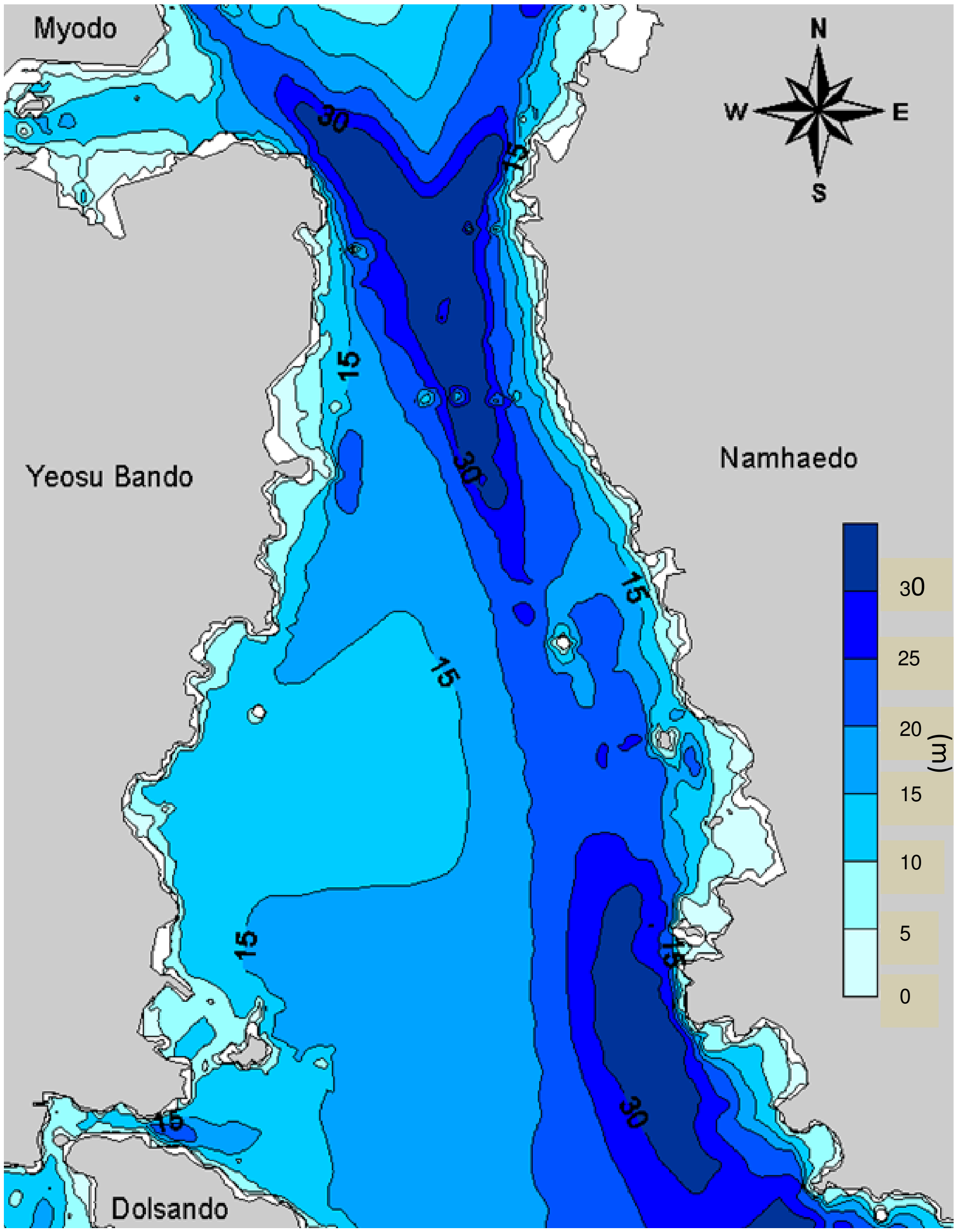


Figure 2. Water depth of research area.

after considering the maritime information of wind wave, wind and tidal current, the narrow calculation region of Gwangyang bay (length 18.0 km and width 14.2 km) has been established as the simulation region. Figure 2 represents the water depth contour of simulation performed in narrow computational area. The calculation of the simulation is subdivided by 100 m interval ($\Delta x, \Delta y$ = 100 m) and made up of 25,560 grids. The inland part of these grids is excluded from the calculation. Figure 3 illustrates the representative configuration of tidal current through tidal simulation.

Wave simulated results

In order to investigate the possibility of swelling wave simulation through consideration of maritime information a wave was simulated with consideration of winds, tides and deep sea incident waves. The data from the wave simulation was compared to the observation data in order to investigate the possibility of swelling wave simulation with consideration to maritime information. The observed data was obtained from 72 h from 1 a.m of April 5th 2002 to 0 a.m of April 7th. When looking at the meteorological

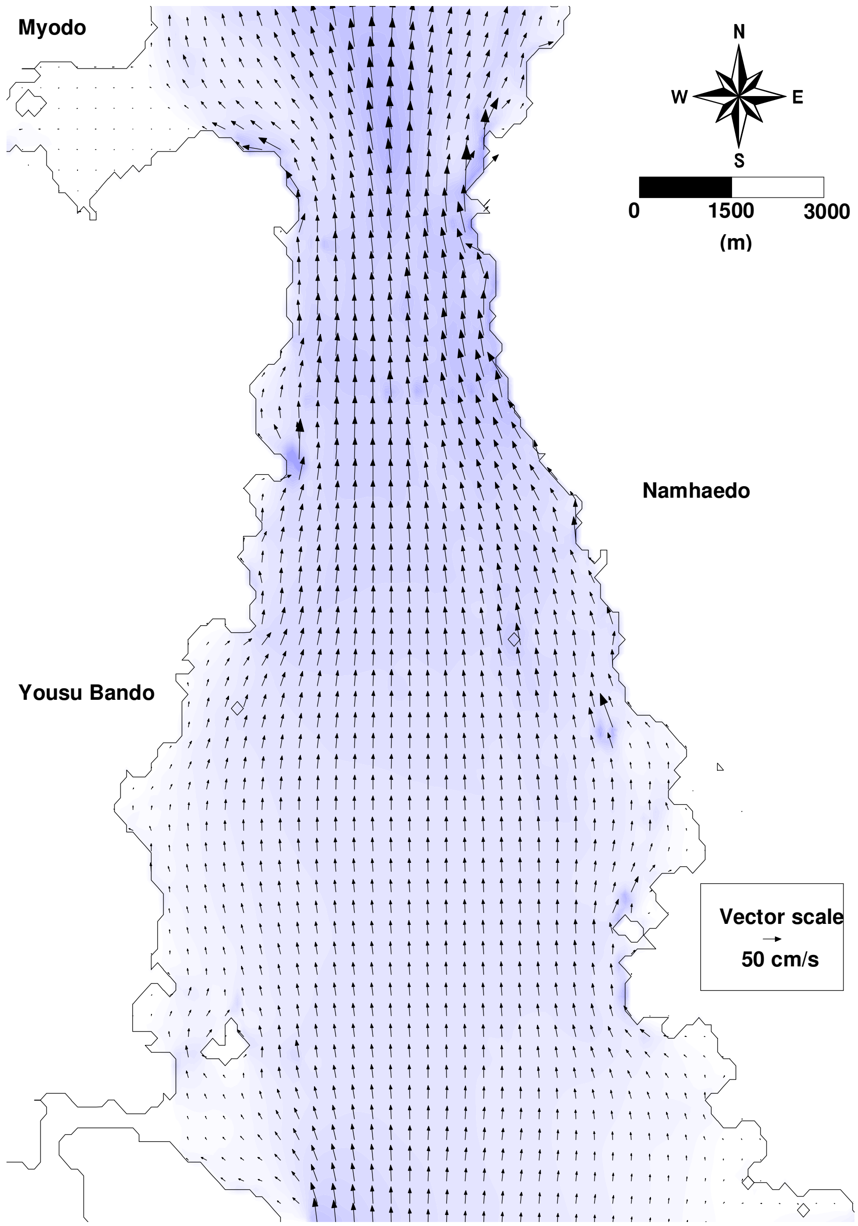
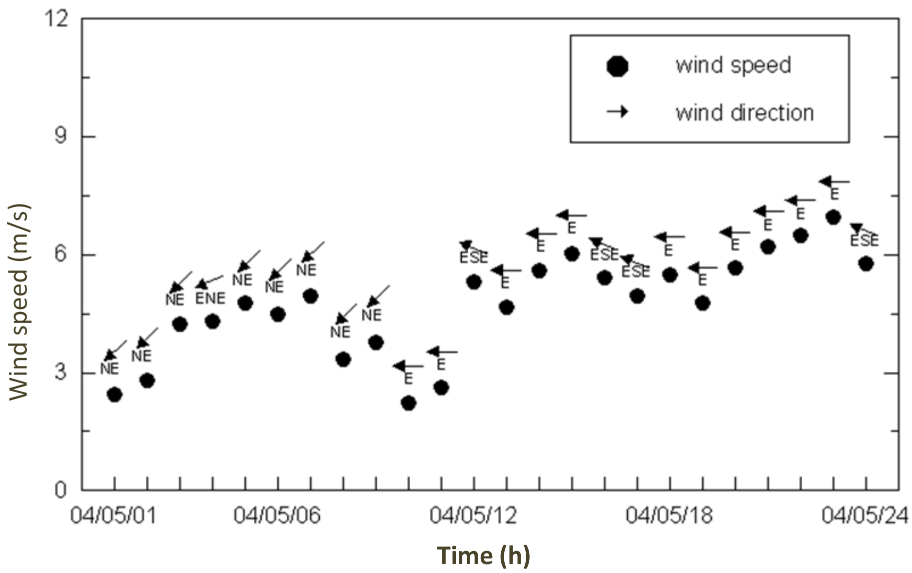


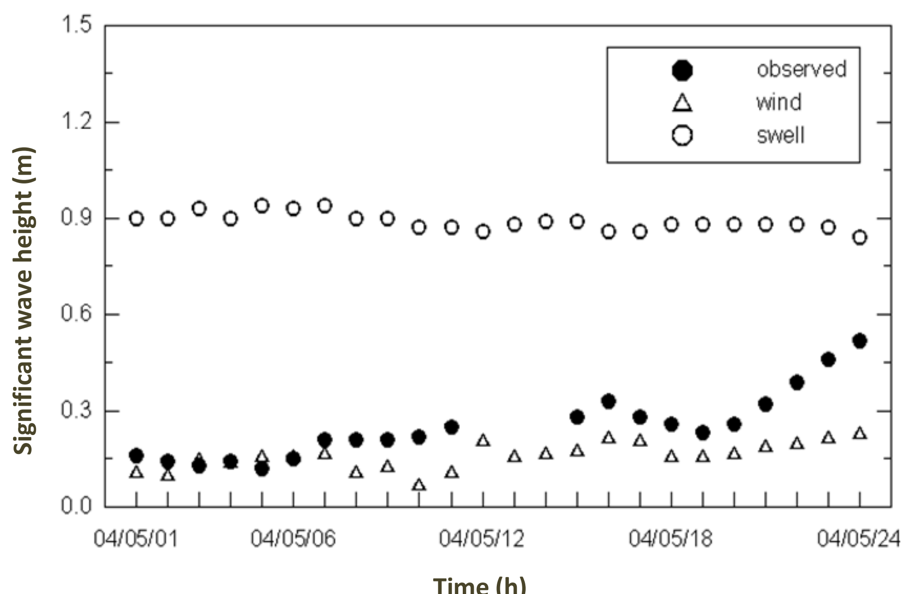
Figure 3. The tidal current of research area.

conditions of the research area during this time period, there was a typhoon warning in effect on April 5th and this was lifted on April 7th.

In order to increase the effectiveness of calculation, the Nesting technique was used to consider the influence of deep sea incident waves, by taking the results of a simulation of the broad computational area and using it as the boundary values of the narrow computational area. Also, in order to compare the swelling wave to a wind wave by using a simulation, wind information that was observed from the weather station was used. The weather station was located at north east 34°44′, 127°45′. Figures 4a to 6a illustrate the wind speed and wind direction observed from the weather station during the simulation time period. Here the wind direction was set as the direction from which the wind was blowing from. Figures 4b and 6b illustrate the observed wave height and the wave height from the simulation. The "●" in Figures 4 to 6 is the wave height observed from the observation point in Figure 1. The "△" represents the simulated wind wave height using only the wind, and "○" represents the swelling wave that has considered maritime information such as wind, tide and deep sea incident wave.



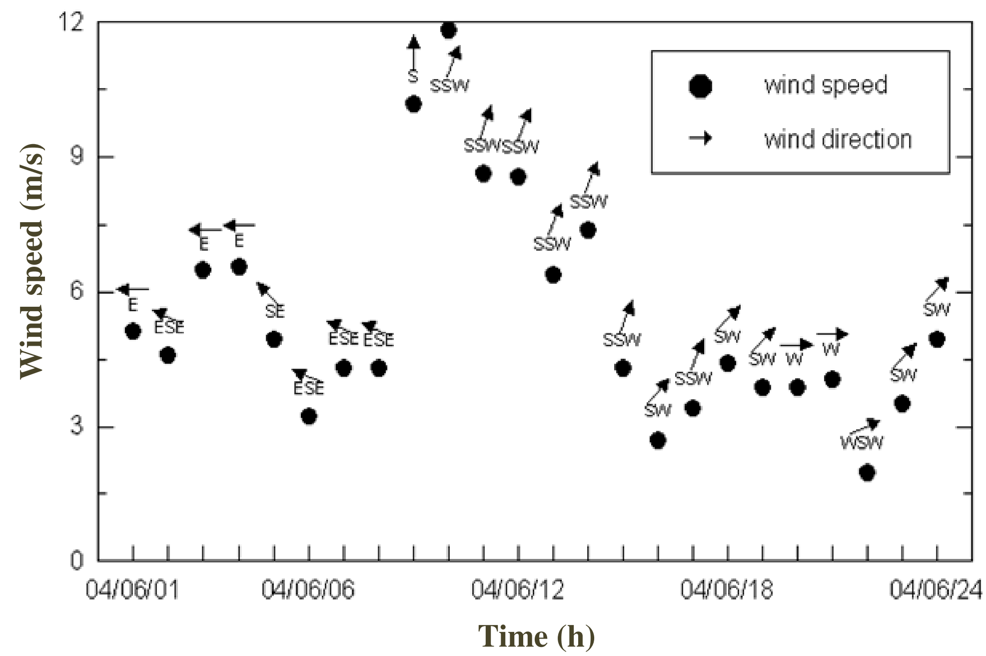
(a)



(b)

Figure 4. The simulation results from April 5th. (a) Wind direction and wind speed and (b) wave height.

As shown in Figure 4 the wind wave height that is simulated by only using the wind represents the observed wave height relatively well, but the wave height that had considered maritime information was much overestimated in comparison to the observed wave height. This is determined to be due to the fact that under normal weather conditions the wave height generated from offshore zones fails to influence the nearshore zone. Figure 5 illustrates the simulation results of April 6th when the typhoon warning was in effect. The swelling wave height that had considered maritime information was overestimated in comparison to the observed wave height, the maximum wave height and the changing aspects were very similar to the observed wave height. The wind wave height that only considered wind was underestimated when compared to the observed wind height. This result is determined to be due to the fact that when there are bad weather conditions such as storm surges the deep sea incident wave is unable to influence the nearshore zone. From a coastal disaster viewpoint, it is effective to prepare for the maximum wave height and even more effective to consider the wave simulation that



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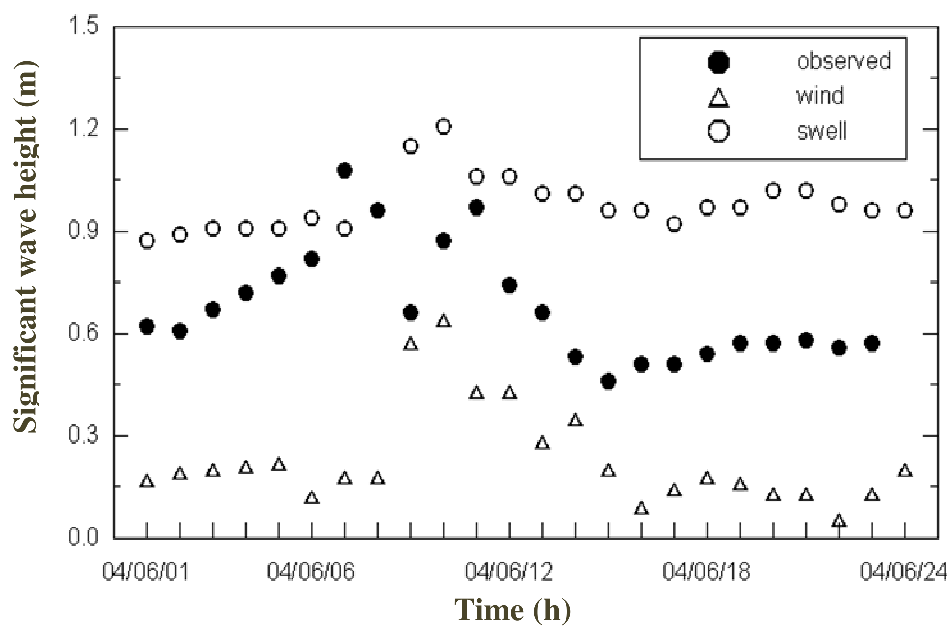
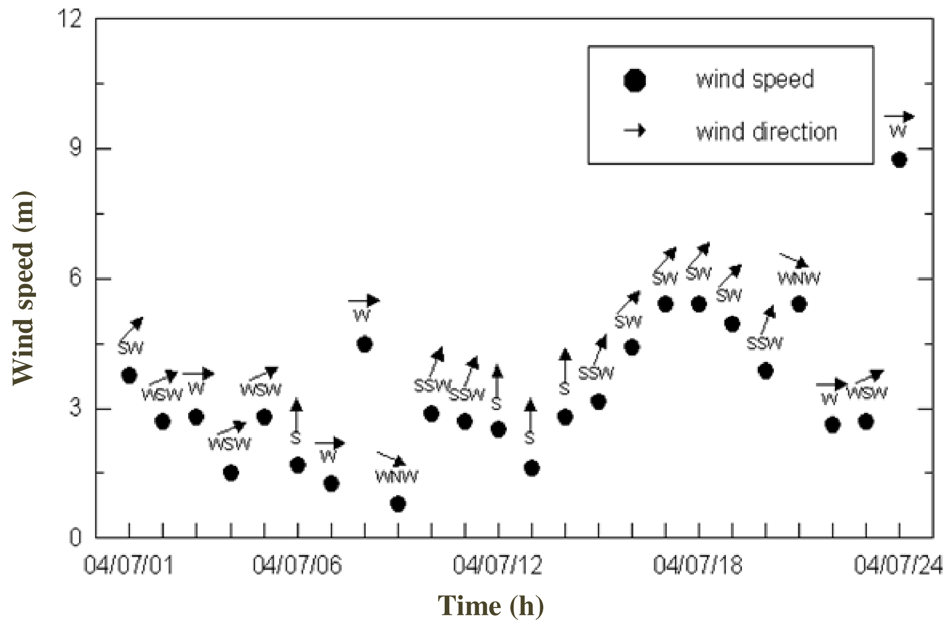


(b)

Figure 5. The simulation results from April 6th. (a) Wind direction and wind speed and (b) wave height.

considers maritime information. Figure 6 illustrates the observed wave height and simulated wave height from April 7th. As shown in the figure, the wind wave height that was simulated using only wind was much smaller than the observed wave height, but the height gap started closing at April 7th from 12 p.m. The reason why this occurs is because as the influence of the storm surge decreases the influence of deep sea incident wave also decreases, which explains why the height gap between the observed wave height and the wind wave height



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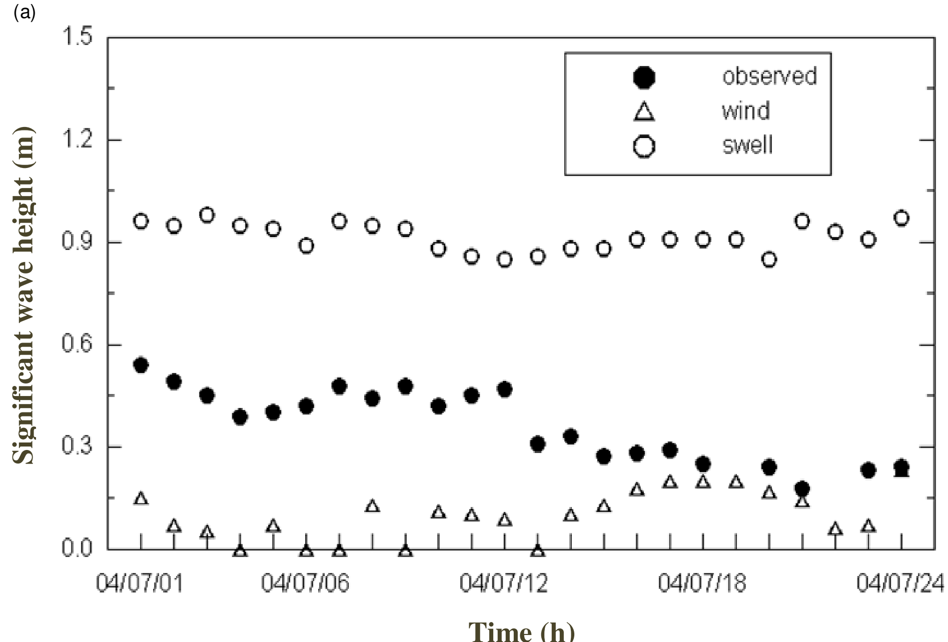

(b)

Figure 6. The simulation results from April 7th. (a) Wind direction and wind speed and (b) wave height.

decreases.

The swelling wave height that had considered the influence of tides and deep sea incident waves was much overestimated compared to the observed wave height. This difference occurs because although as time passes in reality, the influence of storm surges decreases as the deep sea incident waves do not propagate into the nearshore zone, the simulation considered the constant influence of the deep sea incident waves. When comparing the simulation results to the observed results in order to investigate the relation with wind, at the point when the direction of the wave propagation coincides with the southern wind directions (S, SW and SSW), the wave appears higher than from other directions. When the wind direction is the same as the direction of wave propagation and the wind speed is great, the wave height appeared higher.

Conclusion

Although there has been the occurrence of damage around the coastal areas because of swells, because of the complexity of the swell phenomenon there has not been complete understanding of the characteristics of swells. This study has simulated a swelling wave that has considered maritime information such as tides and deep sea incident waves and compared the results with observed data. Although a wind wave height that has only considered the wind factor can simulate an observed wave height quite well in normal weather conditions, when there are severe weather conditions such as storm surges the wind wave height that has only considered wind is underestimated compared to the observed wave height. This is due to the fact that deep sea incident waves do not dissipate but rather propagate to nearshore zones when there are severe weather conditions such as storm surges. The swelling wave height that had considered the influence of deep sea incident waves and tides during severe weather conditions was overestimated in comparison to the observed wave height, but the maximum wave height and the changing patterns were relatively similar to the observed data. From the coastal disaster viewpoint, there needs to be preparation for maximum wave height and in order to reduce the damage by swells there needs to be simulations of waves with consideration of deep sea incident waves.

When analyzing the relation to wind when the wind speed becomes faster in the longer fetch, the wave height becomes very high.

From these results, we can infer that in order to accurately simulate a swelling wave there needs to be a lot of research conducted. The lack of available observation data interfered with trying various approaches. But when taking into account that there is yet a clear solution to predicting swelling waves, the use of a swelling wave simulation that considers maritime information such as deep sea incident waves and tides, which can predict the occurrence pattern of maximum wave to a certain point, this method can contribute in establishing a system for coastal disaster management.

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