INVESTIGATION ON 2007 ABNORMAL WAVE OCCURRED AT THE WEST COAST OF KOREA

S-B. Woo [1], H-M. Eom [2] and M-S. Kim [1]

ABSTRACT: Swell-type unexpected waves occurred along western coast of Korean at March, 2007 and it caused several deaths and heavy economic loss. Available field measurement data are collected to investigate this event, numerical model is setup to reproduce this unknown waves. We found several 1-min interval tidal elevation and sea level pressure (SLP) data along the western coast of Korea and analyzed it using wavelet technique. The wavelet power spectrum for sea water level anomalies is computed using the Morlet mother function. The high wave energy is occurred between 8 and 16 minutes during 0～2 KST 31 March 2007, and the sudden pressure jump of 3～5 hPa occurred simultaneously with high wave energy event. The numerical experiments of the abnormal wave were performed using 2-dimensional shallow water wave model (COMCOT), and air pressure forcing is made from the variation of SLP field and pressure jump from weather charts. We assume the air pressure jump of around 5 hPa is moving from Shandong of China to west coast of Korea. The sea water level by the travel of SLP field was changed all over west coast of Korea with low frequency and SLP field was not considered an original forcing of the abnormal wave. The sea level under the forcing of air pressure jump was obviously amplified by the Proudman resonant effect and it can reproduce the 2007 abnormal wave qualitatively.

Keywords: Abnormal waves, wavelet power spectrum, pressure jump, proudman resonant, COMCOT

INTRODUCTION

Abnormal wave occurred along the west coast of Korea from 00:40, March 31st 2007 and caused property damage and bodily injuries. Fig. 1 shows the areas in which damage occurred. At 01:10, houses, cars, and ships were flooded at Jilli and Bulgeum in Wido-myeon, Buan-gun, Jeollabuk-do and at 01:30, ships docked at Daehang, Hapgu, and Songpo in Byeonsan-myeon were inundated. At 01:50, one casualty occurred and shops and ships were flooded near the Yeonggwang nuclear power plant at Yeonggwang-gun, Jeollanam-do and around Beopseongpo harbor, Hongnong, Baeksu, and Yeomsan in Beopseong-myeon. Around 02:00, houses and ships were flooded at Seonyudo, Okdo-myeon, Gunsan-si, Jeollabuk-do and six casualties occurred at Yongdu-maeul, Jangho-ri, Sangha-myeon, Gochang-gun. Such abnormal waves also occurred on February 2005 and May 2008 near Ongpo-ri, Jeju-do and Boryeong, Chungcheongnam-do respectively.

Domestic studies on abnormal waves were conducted after damage caused by the wave which occurred along the west coast of Korea on March 31st 2007. In March 2007, Choi et al.(2008) conducted research on the abnormal wave that occurred along the west coast including Yeonggwang, Jeollanam-do. They analyzed atmospheric pressure data observed at Automatic Weather Station (AWS), which is run by Korea Meteorological Administration, and tidal information observed at Korea Hydrographic and Oceanographic Administration's tidal stations through a high-pass filter. Using weather charts, they proposed the possibility of regional atmospheric pressure disturbance formation. Although they conducted an experiment on the formation process of long ocean waves with a one-dimensional numerical model and showed that amplitude increases as a result of a resonance effect between pressure jump and long ocean waves, the spacial transformation of waves due to topography was not considered. Choi et al.(2009) analyzed abnormal wave that occurred at Boryeong in May 2008 using tidal data from tidal stations and wave data observed from buoys, but were not able to find a clear cause. The movement of atmospheric pressure was inferred through data from AWS located in coastal and inland areas and radar. Various factors on the formation of abnormal waves were mentioned.

In previous domestic research, the propagation direction and velocity of pressure jump were not investigated because time series data observed at tidal stations and AWS were analyzed, and wave transformation based on topography was not considered because numerical experiments were conducted using an

[1] Department of Oceanography, Inha University, Inha-ro 100, Incheon, 402-751, SOUTH KOREA
[2] Marine Meteorology Division, Observation Infrastructure Bureau, Korea Meteorological Administration, Seoul, 156-720, SOUTH KOREA

one-dimensional model. In this research, we plan to study abnormal waves by conducting quantitative analysis on time series data using wavelets and a two-dimensional numerical model to consider wave transformation. Through wavelet analysis, we deducted the arrival time and propagation direction of the abnormal wave from tidal data and sea-level pressure data from tidal stations and AWS respectively. Using the pressure data from weather charts, we conducted an analysis of the pressure belt, as well as propagation direction and velocity of the pressure jump. Also, we verified the validity of these analysis results with numerical model experiments.

DATA ANALYSIS

We collected data from tidal stations and AWS located in the west coast to analyze the cause of abnormal waves. Fig. 1 shows the location of the stations. We collected one minute tidal data observed for a month during March 2007 from seven tidal stations in the west coast (Anheung, Boryeong, Janghang, Gunsan, Wido, Yeonggwang, *Daeh*eucksan-do). Fig. 2 displays sea level values observed at six tidal stations after excluding tidal components from the original data. Reviewing the non-tidal component, abnormal oscillation of sea level was observed at all 7 tidal stations during the period that abnormal wave occurred. Among the stations, Yeonggwang and Wido observed a sea level change of over 1m, while Boryeong and Janghang had longer periods of sea level oscillation than other stations.

To determine the propagation direction of the abnormal wave, one must compute the time at which abnormal sea level change occurred from each observation point and compared them with each other. But when conducting analysis by simply using the change in sea level, researchers may choose different values of sea level change and time of occurrence. Therefore, this can cause the arrival time to be inaccurate and lack credibility in interpreting the propagation direction of the abnormal

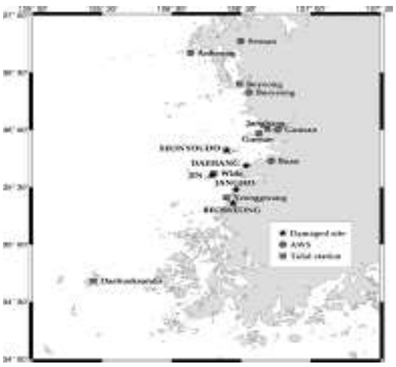

Fig. 1 Location map of damaged areas by abnormal wavee on 31 March 2007, tidal stations and automatic weather stations around west coast.

wave. To quantitatively analyze the time of occurrence for the abnormal wave, we state the arrival time as the time at which the magnitude of the energy passes a certain value. To conduct this analysis, a wavelet method was used to display the time series data in the form of energy change based on time and period.

We conducted wavelet analysis on the remaining component of the observed sea level data after excluding the tidal component. Fig. 3 displays the wavelet power spectrum based on time and period. At all points, the high power spectrum that occurred at approximately 01:00, March 31st has a period between 10 and 60 minutes and continues until around 09:00. At Boryeong and Janghang tidal stations, a high power spectrum with 32~60 minute period occurred between 01:00 and 02:00 and was analyzed to have had an abnormal wave with a longer period component compared to other places. At Wido and Yeonggwang tidal stations, a power spectrum of over 2,000 cm2 was shown in an area that had a 16-minute period between 01:00 and 02:00.

We determined the arrival time as the time when the power spectrum first reaches its maximum value within the 95% confidence interval on the wavelet analysis result. Fig. 3 provides the change in added energy based on time. The abnormal wave arrived at points in the order of Anheung(00:42), Heucksan-do(00:57), Wido(01:07), Gunsan(01:25), Yeonggwang(01:38), Janghang(01:48) and Boryeong(01:56).

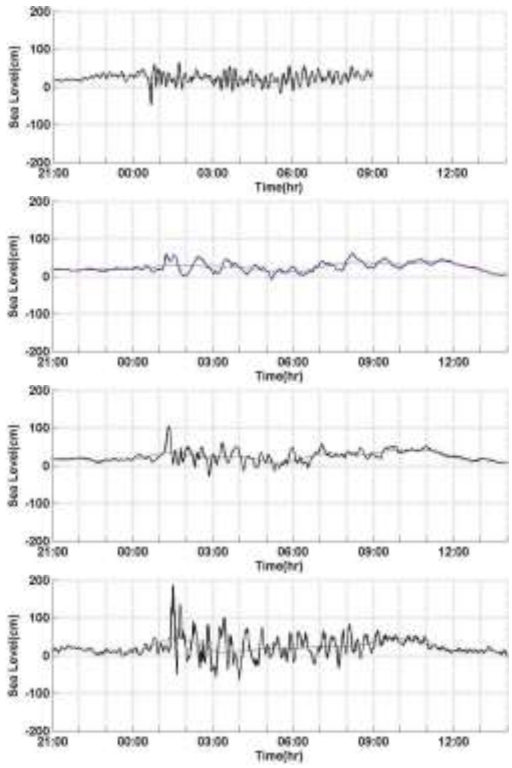

Fig. 2 Sea level oscillations for the period 2100 KST 30~1800 KST 31 March at 4 tidal staions ((a) Anheung, (b) Boryeong, (c) Gunsan, (d) Yeonggwang).

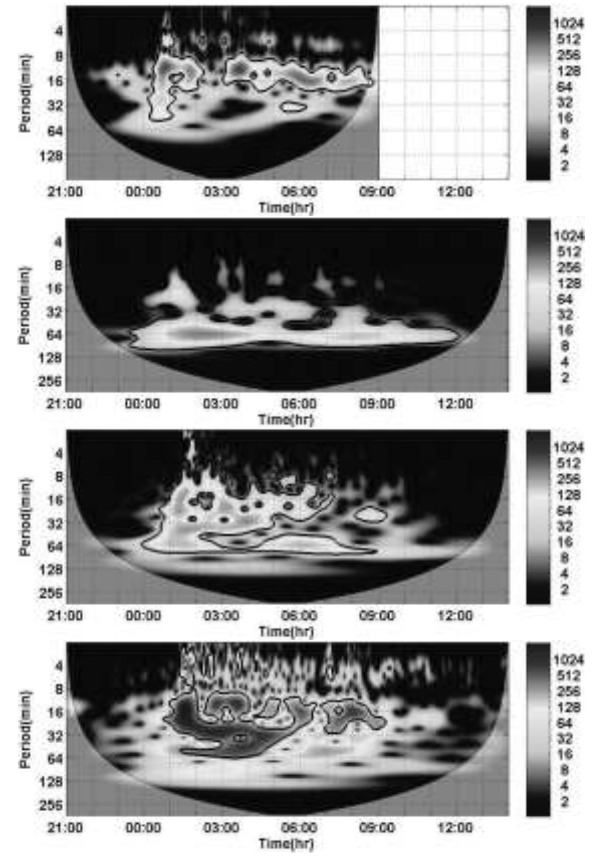

Fig. 3 The wavelet spectrum of sea level oscillations at 4 tidal staions ((a) Anheung, (b) Boryeong, (c) Gunsan, (d) Yeonggwang).

Based on this analysis result, we studied the propagation direction of the abnormal wave and provided the result in Fig. 4. The velocity of the shallow water wave can be computed with the depth of the water and the propagated distance can be computed from this data by applying the propagation time between each point (Oh, 2009). After obtaining the propagated distance with the difference in arrival time, we can draw a circle that has this distance as its radius and consider the circle's tangent line which crosses the previous occurrence point as the crest line of the abnormal wave. Based on this analysis, it was shown that the abnormal wave came from the northwest.

To find what caused the abnormal wave to occur, we conducted an analysis of the one minute sea level pressure data collected through AWS run by Korea Meteorological Administration. Using data from Seosan, Boryeong, Gunsan, Buan, Heucksan-do stations located along the west coast, long period components were eliminated (Fig. 5). Although there was no drastic atmospheric pressure change at Heucksan-do, a change of maximum 4hPa continuously occurred at Seosan from 23:00, March 30th to 06:00, March 31st. At Boryeong, Gunsan, and Buan, a large pressure change of 4hPa was observed from 00:00 to 01:00, March 31st and although it seemed to wane afterwards, a change of maximum 6hPa recurred from 05:00 to 08:00.

In Fig. 6, the distribution of sea level pressure data measured at AWS throughout the entire Korean peninsula is displayed. Looking at the pressure distribution at approximately 01:00, March 31st, 2007,

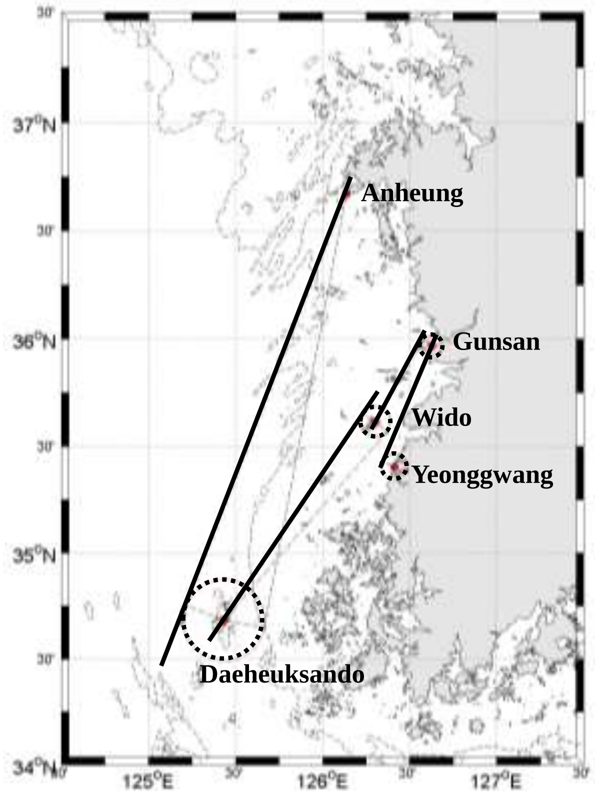

Fig. 4 Calculation method of the propagation direction of abnormal wave by using arrival time and wave celerity.

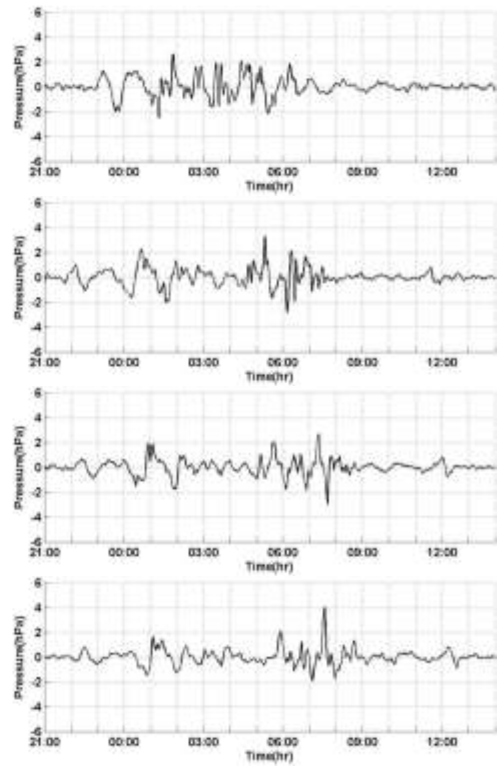

Fig. 5 Time variation of the detrended mean sea level pressure measured at 4 AWS ((a) Seosan, (b) Boryeong, (c) Gunsan, (d) Buan).

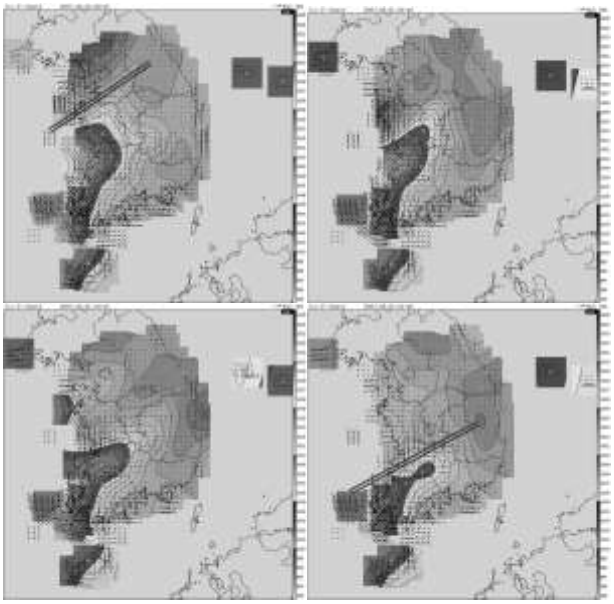

Fig. 6 Mean sea level pressure measured at AWS at (a) 0000 KST 31 March, (b) 0030 KST, (c) 0100 KST, (d) 0130 KST.

we can see the pressure jump progressing in the inland area of the peninsula as it propagates from the northwest to the southeast in the western region. But since AWS observation data at the time of the 2007 abnormal wave only exist for inland areas, the pressure jump propagation in the sea was inferred using weather chart data.

3 hourly weather charts provided by Korea Meteorological Administration are shown in Fig. 7. It took approximately 9 hours for the low pressure located at Bohai bay, north of Shandong peninsula, to move to the southeast coast of Korea , and the mean propagation velocity of the pressure belt was approximately 28m/s. Although the pressure jump was not marked on the weather charts, it is shown that the pressure belt and jump moved in a similar pattern. Assuming that the average depth in the eastern waters of the Yellow Sea is 60km, the velocity of the shallow water wave($c = \sqrt{gh}$) is 25m/s, which is similar to the propagation velocity of the pressure jump. It can be judged that the shallow water waves developed through resonance with the pressure jump and attacked the west coast.

NUMERICAL EXPERIMENT

We conducted numerical experiments to confirm the results of analyzing observation data from the previous section and to reproduce the abnormal wave that occurred in the west coast. Table 2 shows the area of computation and conditions of the numerical model. The area of computation was set to include the Yellow Sea, East China Sea, and Bohai bay and the entire area is consisted of 750m grids. For the depth of water, KorBathy30s data from Korea Ocean Research & Development Institute(Suh, 2008) was mainly used but because the water level near Bohai bay were not

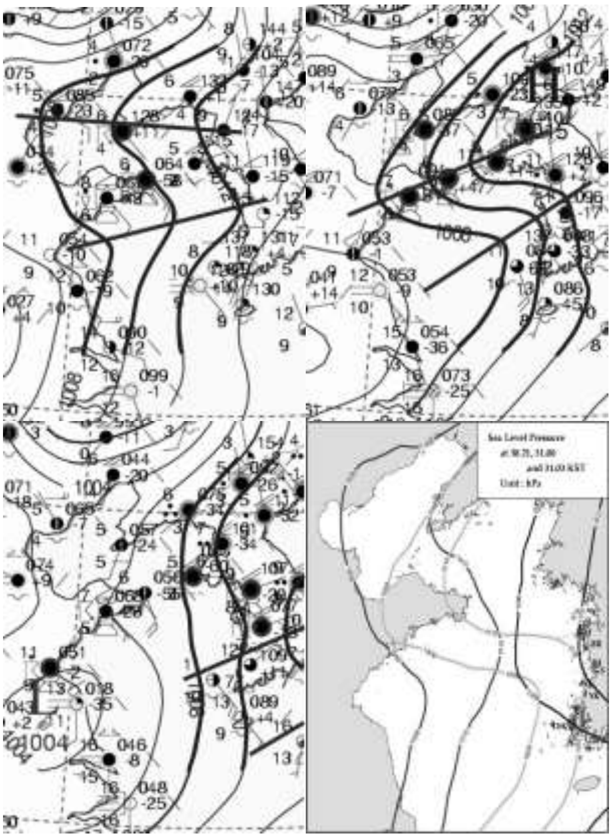

Fig. 7 3 hourly weather charts for the period 2100 KST 30~0300 KST 31 March and illustration of pressure contours on 2100 KST 30(red line). 0000KST 31(green line) and 0300 KST 31(blue line).

included, ETOPO5 data(NGDC, 1988) was added.

The form of pressure jump was referenced from AWS atmospheric pressure observation data and the pressure's movement pattern was simply expressed. The amplitude of the pressure jump was set to 5.3 hPa and its period was set to 60 minutes in reference to the wavelet analysis result of the observation data. Two types of experiments were conducted, one that inputted pressure data from the weather charts and the other that applied pressure jump and weather chart pressure at the same time. The propagation of the pressure jump was set by referring to pressure distribution change observed in AWS and the movement of the pressure belt on weather charts. Pressure distribution shown in the 3 hourly weather chart was used for the weather chart pressure data. Atmospheric pressure and sea level distribution were presented as experiment results. The results computed from numerical experiments were compared with the sea level data observed from the tidal stations.

The numerical model used in this study was COMCOT(Cornell Multi-grid Coupled Tsunami Model) (Liu et al., 1998), a model that Professor Liu's team at Cornell University developed to simulate the creation and propagation of tsunamis. This model was applied for the simulation because abnormal waves share similar spatial-temporal characteristics as tsunamis.

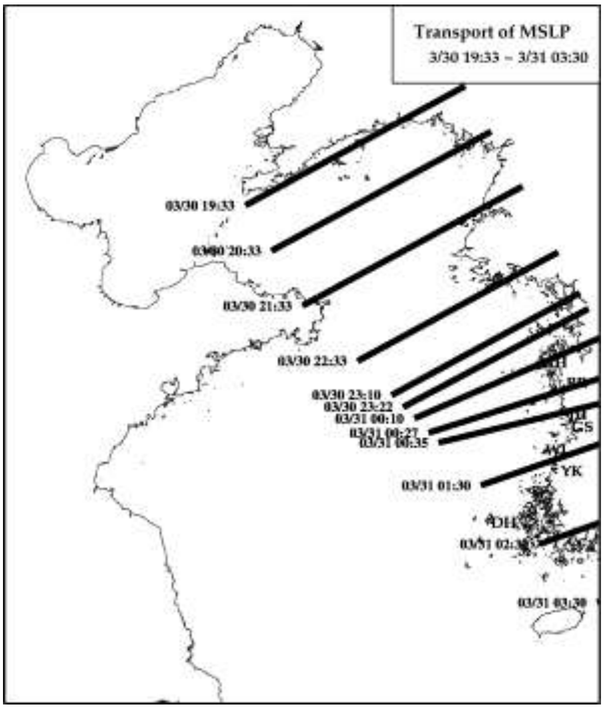

Fig. 8 Moving pattern of pressure disturbance from 1930 KST 30 to 0230 KST 31 March.

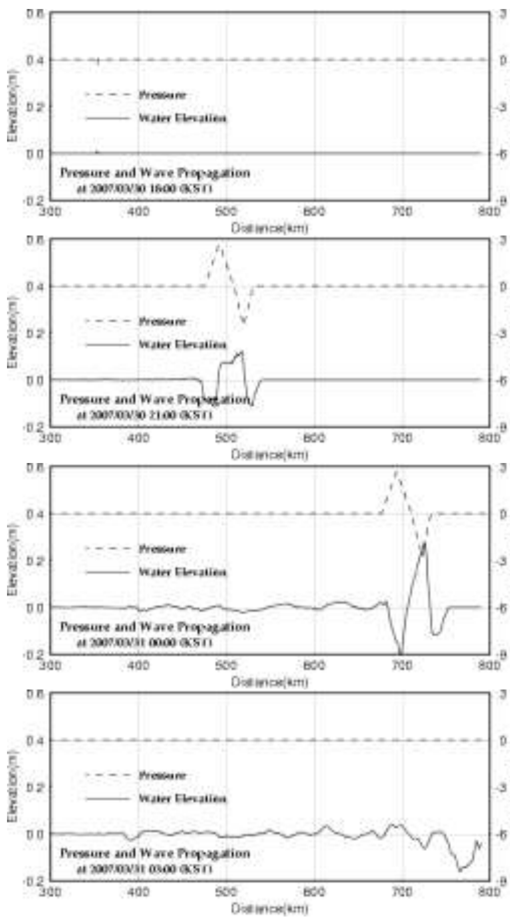

Fig. 9 The snapshot of mean sea level pressure and water elevation for the experiment at (a) 1800 KST 30 March, (b) 2100 KST 30 March, (c) 0000 KST 31 March and (d) 0300 KST 31 March.

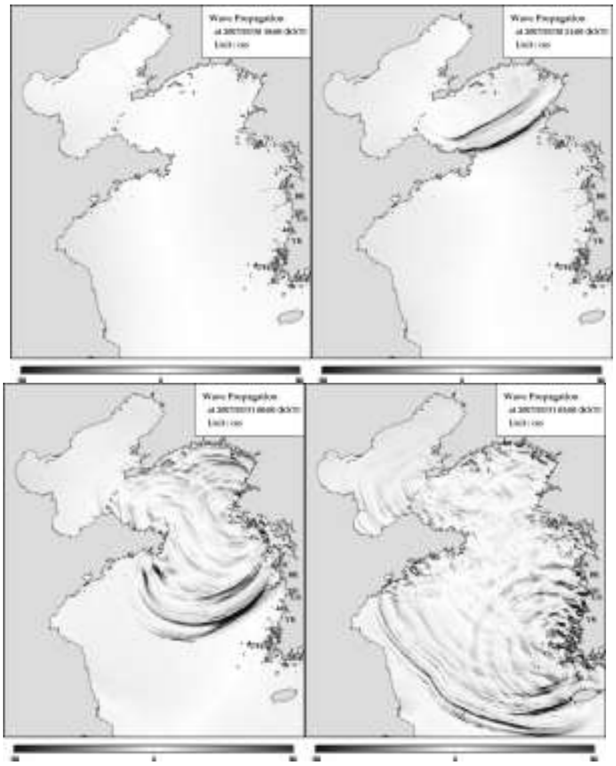

Fig. 10 Spatial distribution of wave propagations for the experiment at (a) 1800 KST 30 March, (b) 2100 KST 30 March, (c) 0000 KST 31 March and (d) 0300 KST 31 March.

Experiment applied both the pressure data from the weather charts and the pressure jump, in which the pressure jump moved from the north of Shandong peninsula to the west coast of Korea(Fig. 8). The results showed that abnormal waves occurred as pressure moved. Fig. 9 displays the change in pressure and sea level based on time along the line that connects the waters of Bohai bay, located north of Shandong, to Yeonggwang. Sea level oscillation that occurs as the pressure jump progresses increased gradually due to Proudman resonance. Pressure change was inputted in a simplified linear form, but it was confirmed that sea level change was caused by this is transformed due to propagation velocity difference depending on depth of water. Fig. 10 shows the sea level distribution, and we can see that sea level distribution due to pressure on weather charts and change due to the pressure jump are occurring simultaneously.

DISCUSSION AND CONCLUSION

This study analyzed data observed during the period in which an abnormal wave attacked the west coast of Korea on March 31st, 2007 and conducted numerical experiments. Pressure distribution provided in Korea Meteorological Administration's weather charts and pressure jump observed at AWS were used as external force conditions of the numerical model and it was confirmed that abnormal waves were created and developed by pressure jumps. Experiment results showed that the initial arrival time of the abnormal wave was similar to the observed value, which shows that the movement direction and velocity of the pressure jump assumed in this experiment are valid.

However, the magnitude of the computed sea level was smaller than that of the observed value and the following are a few reasons why it was computed as such. First, abnormal waves that are created in external waters transform due to wave transformation processes like secondary undulation, refraction, diffraction and shallow waters as they propagate to the coast, but this transformation effect was not properly reflected. This can be improved with a numerical model that can simulate the coast in detail. Second, it is because of the uncertainty and limitation of sea level pressure in weather charts, which was used as an external force condition in this experiment. Because marine observation data that can be used when creating weather charts is insufficient, the pressure information on the sea as marked in weather charts can be inaccurate. Also, because the weather charts are recorded on a 3-hour basis, the pressure jump that is shown in one minute AWS observation data is not properly shown. Therefore, there is low possibility that pressure jumps can be expressed in weather chart both in the perspective of space and time.

To clearly find the cause of the abnormal wave, weather observation data near the Yellow Sea must be collected and an understanding of the weather condition at this period must be enhanced. Also, a verification of the external force conditions applied in the numerical model experiment must be conducted by comparing weather chart data with AWS observation data. Although the pressure jump propagated in a linear form in this experiment, it is more valid to have in a curved arc form. In future research, we are planning to compute weather conditions in detail both in terms of space and time with a mesoscale atmospheric model (WRF: Weather Research and Forecasting, Wang et al., 2008) to have the pressure jump appear, and produce wave transformation on the coast by establishing a variable grid system like FVCOM(Unstructered Grid Finite Volume Coastal Ocean Model, Chen et al., 2003).

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