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Basic Analysis for Improvement of Mooring Stability Under Long Wave Impact

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Abstract : *This study suggests a general process of analyzing the mooring and cargo handling limit waves, which is an incident to the new energy port under long wave agitation. To reduce damages of ships and harbor structures due to strong wave responses, it is necessary to predict the change of wave field in the mooring berth to make the proper decision by dock master. The berthing area at a new LNG port in the east coast of Korea in this study is frequently affected by oscillations from waves of 8.5~13s periods in the wintertime. The long period waves give difficulties on port operation by lowering the annual berthing ratio. It needs to find the event waves from the real time offshore wave records, which cause over the mooring limits. For that purpose, the wave records from field measurement and offshore wave buoy were analyzed. From numerical simulation, the response characteristics of long period waves in the berthing area were deduced with or without breakwater expansion plan, analyzing the offshore field wave data collected for two years. Some event wave cases caused over the cargo handling and mooring limits as per the standard Korean port design guideline, and those were used for the decision of port operation by dock master, comparing with the real time offshore wave observations.*

Key words : *Long Wave, Wave Observation, Mooring Stability, Numerical Model Simulation*

1. Introduction

The safe mooring and cargo handling limit for a new port development due to the offshore incident waves have been studied and the post research continues because of unexpected environment change after port development. Long wave agitation problems in a harbor are getting attentions when designing harbors serving very large ships. Cargo handling may be interrupted and berthing structures may be broken, especially the agitation becomes extreme. The issue of harbor tranquility is keenly related to mooring stability and cargo handling work. The most significant harbor with oscillation problems in Korea is the Pohang New Port in Youngil Bay which is located in the southeast coast. Many cases of problems are being reported by the Pohang pilot association and the local office of MOF (Ministry of Ocean and Fisheries). As per Korean design standard and explanation for port and fishing port (MOF, 2014), the cargo handling limit wave heights at the mooring facilities are 0.3m for small vessel, 0.5m for medium and large vessels, and 0.7~1.5m for very large vessel. On the other hand, the limit wave height considering ship mooring motion at Pohang New Port indicates lower than 0.5m as shown in Table 1. Other cases just like the site of this study appear that more preparation and consideration for safe mooring are necessary. It is difficult to prevent the arrival of long waves causing oscillations within the harbor. Another factor is lack of wave data from field observation for engineering construction and planning. Since no wave gauge installed at the exact site, it is relied on weather data collected from the offshore stations or near ports. Decision of berthing or unberthing operation is not easy job before prevail of long wave agitation. The purpose of this study is to predict possible wave climate at a LNG terminal in the east coast of Korea for the new built fuel port to determine a safe mooring and cargo handling plan under the combinations of wind waves and swell. As per KOGAS (2016) LNG terminal, LNG carrier of 137,000DWT shows over 50cm motion for 1m wave height and over 8.5s wave periods and 170,000DWT shows same over 9.0s wave periods. The purpose of this study is to predict possible wave climate at a gas terminal for new built fuel port to determine a safe mooring and cargo handling plan under the combinations of wind waves and swell. It needs to find

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the event waves from the real time offshore wave records which cause over the mooring and cargo handling limit. For that purpose a short period field measurement at LNG terminal and long term offshore and nearshore wave buoy records at Donghae, Uljin, Samcheok, and Jukbeon of KMA(Korea Meteorological Administration) were analyzed.

Table 1 Allowable wave height for loading and unloading at Pohang New port

Type of Ship	5,000DWT	10,000DWT	30,000DWT
Short Wave	0.27～0.50m	0.33～0.50m	0.50m
Short & Long Wave	0.19～0.50m	0.22～0.50m	0.42～0.50m
<Deep Water Wave Condition> Ho : 0.19～0.50m, To : 8～12s, Dir : 75 deg			

2. Field Wave Measurement and Analysis

We tried to analyze and predict wave heights and directions in- and out-side the harbor from incoming waves at offshore wave observation stations to determine if there is any suggestion on port operation policy or guideline for safe ship manoeuver. Fig.1 is an example of analyzed significant waves from KMA offshore stations for the extraordinary waves and mooring analysis. Red dashed circle indicates the chosen event wave parameters for numerical model input. The wave periods between 8 and 13s recorded at offshore stations are prevalent as shown .

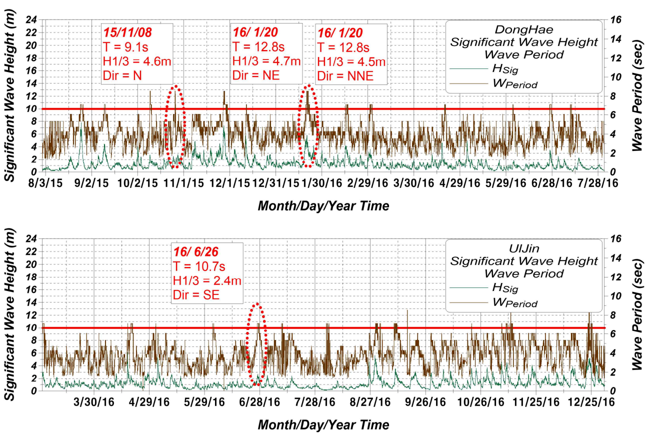

Fig. 1 Time-series of the observed wave data at Donghae and Uljin offshore buoys

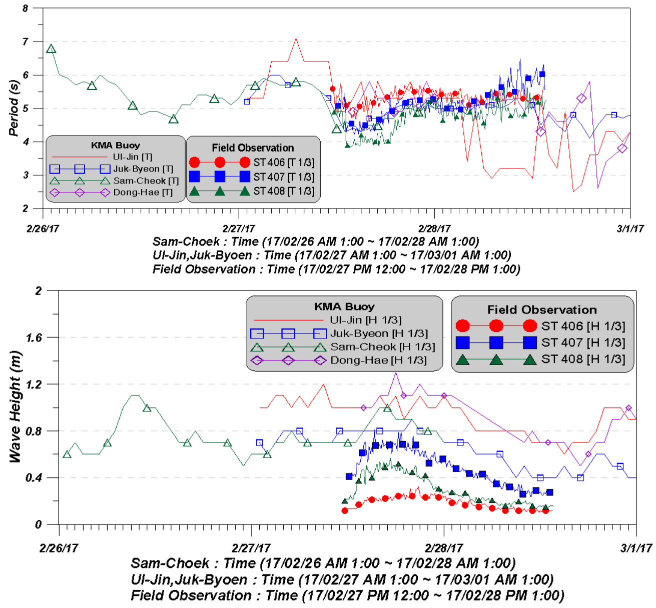

Fig. 2 Comparison of waves between KMA offshore wave observation records and field measurement

Before numerical simulation, field wave measurement was done in the harbor and compared with offshore wave observation records to make sure the real time wave records are okay as shown in Fig.2. Wave periods are close each other and wave heights at the terminal are reduced in the process of propagation from offshore stations and due to breakwaters. The distance and water depth of the KMA buoys and field measurement stations from Hosan LNG terminal are shown in Fig.3 and Table 2.

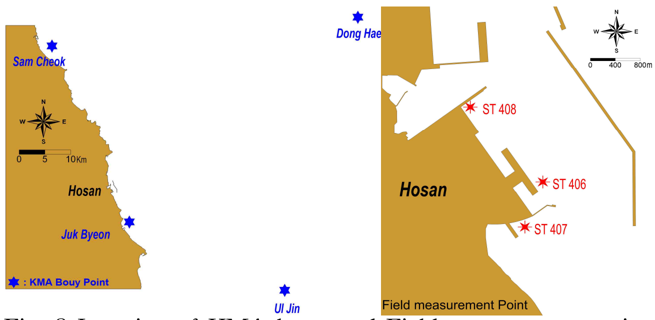

Fig. 3 Location of KMA buoy and Field measurement point

Table 2 Distance and water depth of KMA buoys and field measurement stations from Hosan LNG terminal

	Dong Hae	Uljin	Sam Cheok	Juk Byeon	Observed stations
Depth (m)	1400	700	20	10	18
Distance (km)	63.5	55.9	27.1	9.0	0

3. Application of Numerical Model

3.1 Basic Theory

For prediction of wave climate and limit waves at the given port, it is necessary to apply two numerical models. One is FDM(finite difference method) wave model based on the wave action balance equation was defined as equation (1). This method has been successfully applied to various wave propagation situations in the context of finite difference model.

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

where, N is the wave action density spectrum, t is time, c_x, c_y are representing the spatial propagation speeds, and c_σ,$c_\theta$are the propagation speeds in terms of frequency and directional domains, σ is the equivalent relative frequency, θ is the wave direction, 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). The input parameters are depicted from offshore wave observation stations and FDM model will be used for wide area. Therefore, it is necessary to adopt nesting method for numerical wave prediction at the berthing terminal.

Another is the HEM(hybrid element method) steady -state wave model identifying the regional wave transformations and is to be utilized for evaluation of the harbor responses such as wave reflection, wave dispersion, nearshore wave refraction and diffraction, etc. The physics embodied in extended mild-slope wave model, to include the effects of frictional dissipation and wave breaking, are based on solving the two-dimensional elliptic mild-slope equation originally by Berkhoff (1972). The detail information necessary refers to Houston (1981), Kirby & Dalrymple (1986), and Demirbilek(1994). The basic equation may be written as Equation (2):

$$\nabla \cdot (CC_g \nabla \hat{\eta}) + (CC_g \sigma^2 + i\sigma w + iC_g \sigma\gamma)\hat{\eta} = 0 \quad (2)$$

where $\hat{\eta}(x,y)$ = complex surface elevation function, from which the wave height can be estimated, $\sigma =$ wave frequency under consideration (in radians/second), $C(x,y) =$ phase velocity= σ/k, $C_g(x,y)$ =group velocity $= \partial\sigma/\partial k = nC$ with $\sigma^2 = gktanh(kd)$, $k(x,y) =$ wave number $=2\pi/L$, related to the local depth d(x,y) through the linear dispersion relation: $n=\{1+2kd/(\sinh 2kd)\}/2$, $w =$ friction factor, and $\gamma =$ a wave breaking parameter. HEM model will be applied to the narrow coastal zone which covers the berthing area. After numerical model formulation under given shore boundary and bottom bathymetry, selected event waves from offshore wave records were introduced to the model as shown in Table 3.

Table 3 Summary of numerical formulation (FDM & HEM)

FDM	Wide area	Narrow area	HEM	Present	Expansion
Model range	73km x 61km	3km x 4km	Nodes	26,051	26,083
Grid	292x244, S=250m	150x200, △S=20m	Elements	50,673	50,705
D.L condition	D.L (+) 0.32 m				

3.2 Model Formulation

The considered port is a newly expanded and strategically important port for domestic base industries both electricity and gas by handling coals and LNG. The berthing facilities are protected by two detached breakwaters, which are parallel to coastline, having 900m and 1,400m of length. Because of its orientation, storm waves or long wave may cause substantial problems to ship mooring and cargo handling work. Moreover, the present northern breakwater was constructed 500m shorter than the original plan. From this viewpoint, additional 500m was added to the northern breakwater in this study and we tried to analyze and predict wave heights and directions in- and out-side the harbor to determine if there is any suggestion on port operation policy or guideline for safe ship manoeuver. Since the new port area is large and wave periods as small as 8 and 13s are prevalent as shown in Fig.1, we came to Table 3 to meet the required grid size (model requires a minimum 6 to 10 elements per wavelength), which gives 10m interval inside breakwaters. The mesh for present new port contains a total of 50,673 elements and 26,051 nodes, whereas a total of 50,705 elements and 26,083 nodes for the expansion of northern breakwater plan. Bathymetric data were collected from engineering Co., Ltd. and the numerical chart. Six extraordinary waves, which were depicted from

Table 4 Summary of numerical input (FDM & HEM)

Event / No	Deepwater Dominant Waves (Buoy measurement, KMA)							Shallow water Model Input (HEM)		
	Wind speed (m/s)	Wind direction (deg)	Hs (m)	Ts (sec)	Direction (deg)	Station	Date	Hs (m)	Ts (sec)	Direction (deg)
1	11.9	5	4.9	9.1	55	Donghae	16.1.19	4.2	9.6	56.5
2	9.7	282	4.4	8	31	Donghae	16.1.19	3.5	8.5	36
3	6.4	53	3.9	10.7	29	Donghae	16.1.20	3.8	10.9	33.3
4	9.5	291	6.1	10.7	146	Uljin	16.1.20	4.0	10.9	115.6
5	9.3	295	5.7	10.7	162	Uljin	16.1.20	3.4	10.9	137.6
6	9	275	4.9	10.7	155	Uljin	16.1.20	3.2	10.9	135.6

offshore wave data set as shown in Fig. 2 and HEM model input were deduced from FDM model as shown in Table 4.

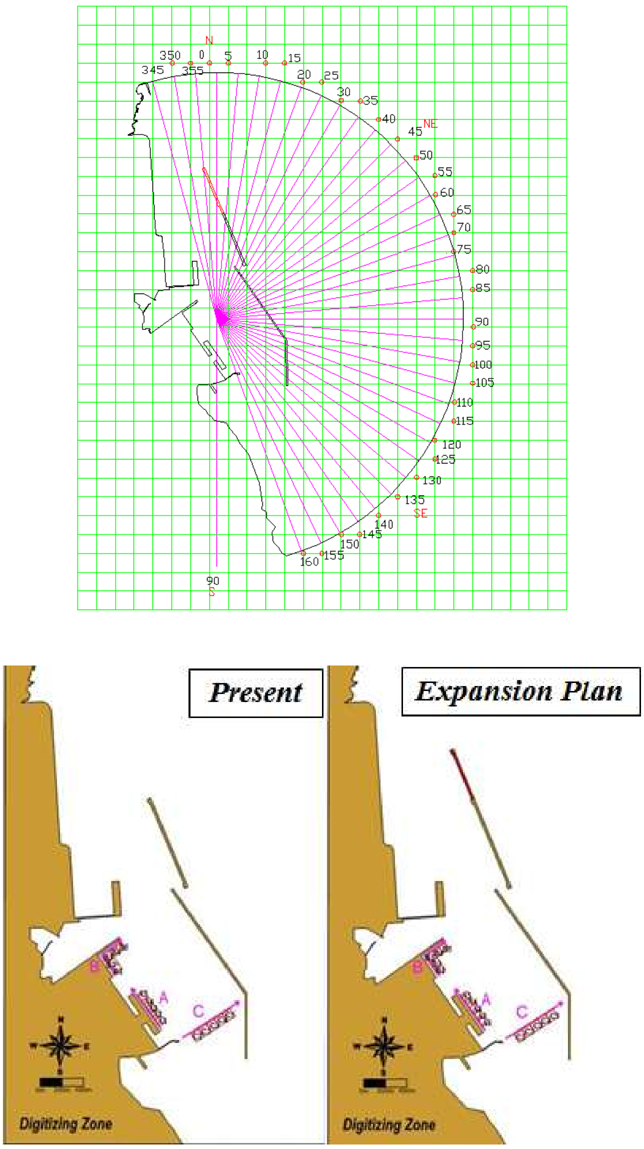

Fig. 4 Incident wave directions and selected stations for analysis of harbor responses

However, at the new port, because of the significant variability in wave height depending on location, it is difficult to figure out what make strong response to berthing area causing unable to mooring. Waves traveling to the north to south and vice versa depending on winter or summer are most likely to affect the new port, since they have a clear path through the breakwater gap. Therefore, cargo handling limit waves at the berthing area were calculated from input of 6 wave directions from north and 6 directions from south considering the openings. The open boundary input causing cargo handling limit at the terminal will be introduced to find the event waves at the offshore wave observation stations. Fig. 4 shows the incident wave directions and selected terminal stations for prediction of cargo handling limit wave input at offshore wave stations.

4. Result and Analysis

For the existing configuration of the port, northern incident waves in wintertime brought problems to mooring and cargo handling. The north breakwater was extended to 1,400m. Due to addition of 500m more to the northern end, unexpected variations on harbor responses in the new port were shown at some cases. Fig.5 and Fig.6 show the harbor responses for the event wave of H=4.2m, T=9.6s, and Dir=56.5°. For this event, the wave height after breakwater extension was reduced at station A and B but increased at station C. The general trend of responses shows in a way of wave height reduction to the harbor basin but induces some difficulties to southern ship passage. Therefore, in wintertime at this terminal, the breakwater extension will help ship maneuvering operation and cargo handling work.

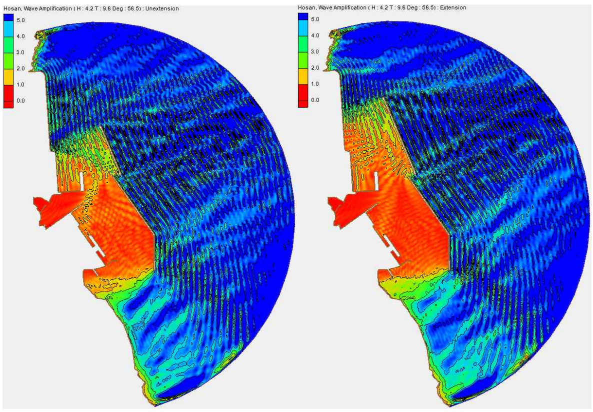

Fig. 5 Wave height distributions (Before & After extension), H=4.2m, T=9.6s, Dir=56.5°

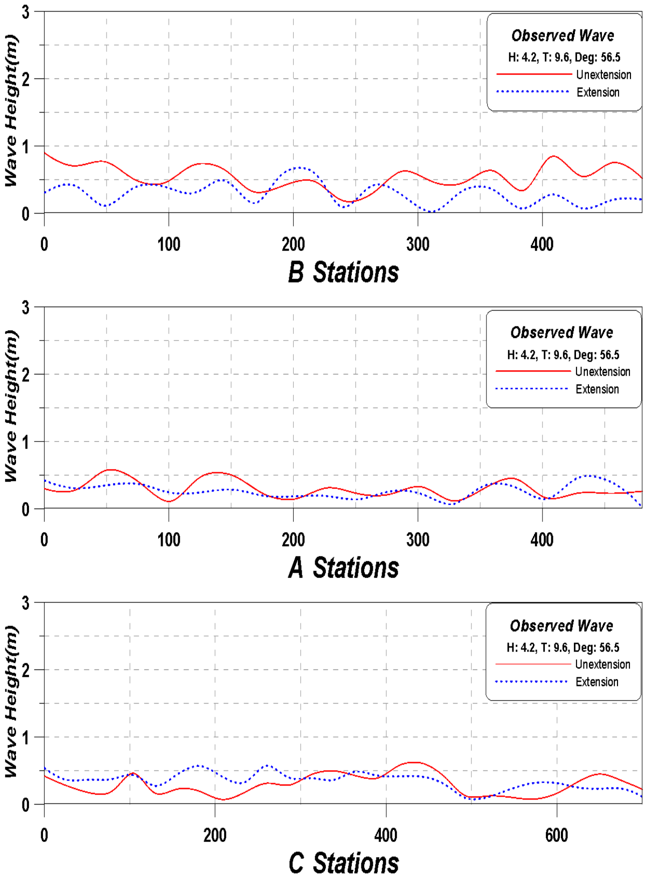

Fig. 6 Wave height distribution at selected stations (H=4.2m, T=9.6s, Dir=56.5°)

Fig. 7 through Fig. 9 shows the numerical result for berthing limit wave calculation at outside of LNG terminal. Fig.6 is showing the limit wave input at HEM open boundary for waves from north and south with wave period of 6s to 13s. Fig. 8 and Fig. 9 are showing the limit wave input at coastal wave observation buoys, Samcheok (north) and Jukbyen (south), respectively. The extended breakwater protects higher waves for short period between 6 to 10s from north. In summary, the cargo handling limit wave heights for the wave period of 8 to 13s are calculated and summarized at Donghae (5~8.5m), Samcheok(4~6.5m) from north and Uljin(3.5~5m), Jukbyen(1.5~3m) from south, respectively as shown in Table 5. In the end, this information is necessary for decision of whether berthing or not and the rest of analysis would cover evaluation from the real time buoy observations.

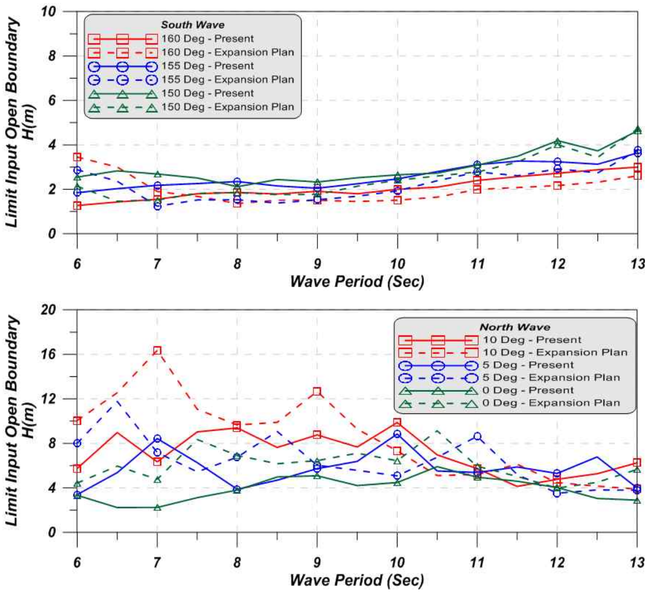

Fig. 7 Comparison of cargo handling limit input waves at open boundary of HEM

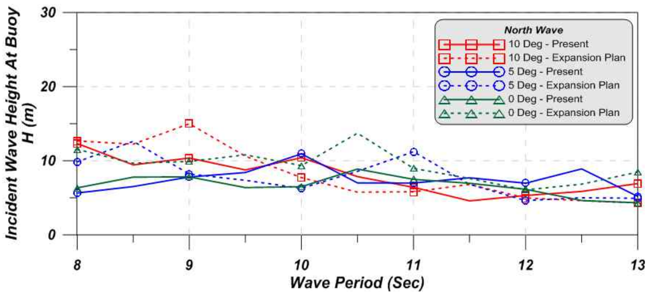

Fig. 8 Calculated cargo handling limit wave height at Samcheok buoy

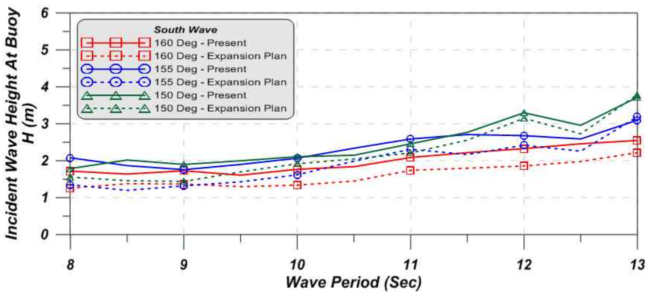

Fig. 9 Calculated cargo handling limit wave height at Jukbyen buoy

Table 5 Wave response in the harbor and transformed cargo handling limit wave at observation stations

Limit of Input Wave from North			
Observation Buoy	Wave Dir (°)	Height (m)	Period (s)
Donghae (Offshore)	345°	11.08 ~ 13.14	8.0 ~ 8.5
		12.63 ~ 13.90	10.0 ~ 11.5
	350°	7.02 ~ 8.48	8.0 ~ 8.5
		7.94 ~ 8.5	11.0 ~ 11.5
	355°	5.13 ~ 7.24	8.0 ~ 9.5
		5.93 ~ 7.10	11.5 ~ 13.0
	0°	7.71 ~ 7.89	9.5 ~ 10.0
		5.41 ~ 7.59	12.0 ~ 13.0
	5°	6.64 ~ 7.51	8.0 ~ 8.5
		6.28	13.0
	10°	5.34 ~ 7.33	11.0 ~ 13.0
Samcheok (Coastal)	345°	8.09 ~ 9.73	8.0 ~ 8.5
		9.04 ~ 9.53	10.0 ~ 11.5
	350°	5.39 ~ 6.6	8.0 ~ 8.5
		6.16 ~ 6.28	10.5 ~ 11.5
	355°	4.11 ~ 5.76	8.0 ~ 9.5
		4.61 ~ 5.48	11.5 ~ 13.0
	0°	6.35	8.0
		4.34 ~ 6.16	12.0 ~ 13.0
	5°	5.66 ~ 6.53	8.0 ~ 8.5
		5.2	13.0
	10°	4.6 ~ 6.42	11.0 ~12.5

Limit of Input Wave from South			
Observation Buoy	Wave Dir (°)	Height (m)	Period (s)
Uljin (Offshore)	135°	3.60 ~ 4.87	8.5 ~ 11.0
	140°	4.33 ~ 4.89	8.0 ~ 10.5
	145°	4.46 ~ 4.60	8.5 ~ 9.0
	150°	3.99 ~ 4.87	8.0 ~ 10.5
	155°	4.24 ~ 4.60	8.5 ~ 9.5
	160°	4.25 ~ 4.89	8.0 ~ 10.0
Jukbyen (Coastal)	135°	2.08 ~ 2.80	8.0 ~ 11.0
	140°	2.32 ~ 2.81	8.0 ~ 11.0
	145°	2.29 ~ 2.58	8.0 ~ 9.5
	150°	1.79 ~ 2.96	8.0 ~ 12.5
	155°	1.76 ~ 2.71	8.0 ~ 12.5
	160°	1.71 ~ 2.55	8.0 ~ 13.0

5. Conclusion

It was convinced that the field measurements were coincide with the nearshore wave records very well. We recognized that those waves from offshore station were reduced at the terminal in the process of wave propagation to shallow water. Numerical simulation to get cargo handling limit wave was done for 6 wave directions from north and 6 from south, together with 3 eastern directions. Therefore, 225 simulation cases were conducted 6 to 13s wave period with respect to each wave direction. The response characteristics of long period waves in the berthing area were deduced with or without breakwater expansion plan for selected event waves. The general trend of responses shows in a way of wave height reduction to the harbor basin. The numerical solutions for berthing limit wave input in terms of wave periods and directions at both offshore and coastal wave observation stations give very important information and those will be used for the decision of port operation by dock master, comparing with the real time offshore wave observations. Furthermore, these would be introduced to the future port operation and expansion plan.

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