Variation of Harbor Oscillations in Yeongil Bay

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Abstract

Today, harbor oscillation problems are the most significant factor to consider when designing harbors serving very large ships. In coastal harbors, large vessels moored in the elastic hawsers are often displaced due to the resonance between long period waves and mooring systems. As a result, cargo handling may be interrupted and the hawsers may be broken, especially when the amplification becomes extreme. The most significant harbor confronted with harbor oscillation problem in Korea is Pohang New port. Many cases of problems are being reported by the pilot association and the local office of MOMAF (Ministry of Maritime Affairs and Fisheries). However, it is difficult to prevent the arrival of long waves causing oscillation within this harbor. Moreover, the Korean government has already started a new port plan at the mouth of Yeongil Bay without addressing the problems that have occurred in Pohang New port. This study deals with the variation of harbor oscillation due to the construction of a 4.1 km breakwater at the bay mouth including the arrangement of the new berths. Numerical methods used are in fairly standard form from the extended mile slope equation. The obtained numerical results were compared with field measurement from the previous and this will bring a certain level of discussion and consideration of variation to the future port development.

Keywords: Coastal harbor, Harbor oscillation, Mooring system, Numerical method, Extended mild-slope equation, Field measurement

1. Introduction

As ships are becoming bigger and faster, the control of harbor oscillation has become an inevitable process when ships do cargo work, or try to approach or leave the berth. The harbor planners, who invest large mounts of money in the construction of harbor infrastructure, and the stake-holders, who have their own piers, are concerned about reduction of the ships' mooring time in the harbor. In some ports the long period oscillation has been serious enough to prevent the loading and unloading of berthed ships for a number of days, and in extreme cases extensive damage has resulted after mooring lines have parted. Before 1980s in Korea, it was not possible to predict the effects of harbor oscillation. Since then the resonance inside harbors was recognized, and the level of construction had been proceeded too far to adopt any countermeasures. It is impossible to prevent the penetration of long period waves into a harbor unless the mouth is closed. Yeongil Bay in Korea, where the Pohang New port is located, has a very significant harbor oscillation condition. Pohang Steel Company (POSCO) had realized this soon after the construction of this port and has attempted many countermeasures, but no definite solution to reduce the phenomenon of oscillation has been found, yet.

According to the internal data from POSCO, Figure 1 shows the shutdown days of cargo handling work caused by the long period wave and bad climate in Pohang New Port from 1987 to 2001. The average number of workable days for last 3 years was just 208 days (56%) in Pohang New Port, except pier no. 1 through 4 piers. Shutdown due to Bad weather was 99 days (27%) per year, pitch and rolling disturbed 58 days (17%) per year. Pitch and rolling were observed 12.1 days (21%) in spring, 3.7 days (6%) in summer, 17.4 days (30%) in autumn and 24.8 days (43%) in winter over the last 3 years.

Harbor resonance problem had been discussed well analytically and experimentally by Ippen & Goda (1963) and Lee (1969). Hybrid element analysis of harbor oscillation problem and its application also was described well by Lee (1989). Harbor oscillation in the Pohang Old port was acknowledged by field measurements at an early stage (Chu 1974, 1976). Since the oscillations in Yeongil bay including the Pohang Old and New ports had been analyzed using the 2-dimensional FDM model by Park (1986), more comprehensive study by the Koran ministry of Construction and Transportation (1987), Kang (1989), and KORDI (1995) proved the existence of the oscillations from the field measurements and numerical analyses.

The reduction of harbor oscillation should be approached in 2 ways; changing the oscillation periods or reducing the amplification rate. In other words, it might be effective to avoid the port's natural oscillation period and the basin geometry which will encourage the resonance of waves, but it is not easy to do so. There could be means either actively directing the waves of oscillation periods to some useless space or temporary anchorage areas, or passively changing the shape of in-use berths (Lee and Hur, 2001).

Especially in Yeongil Bay's case, the building a huge breakwater has almost been finished for the construction of Yeongilman New port at the north end of Yeongil Bay entrance, to induce and service the huge logistic industries and following that the necessary container port facilities are planned without consideration of the oscillation inside the existing harbors. The change of the coastal line and arrangement of the berths due to the new port development plan will effect the oscillation inside the other area and the matter is attracting great attention.

In this study, therefore, we tried to analyze the phenomena of the oscillation periods and amplification in Pohang Old port, Pohang New port, and Yeongilman New port, using finer finite element grids in a wider basin, which covers the whole area of Yeongil Bay for the existing harbor layout and after the construction of Yeongilman New port.

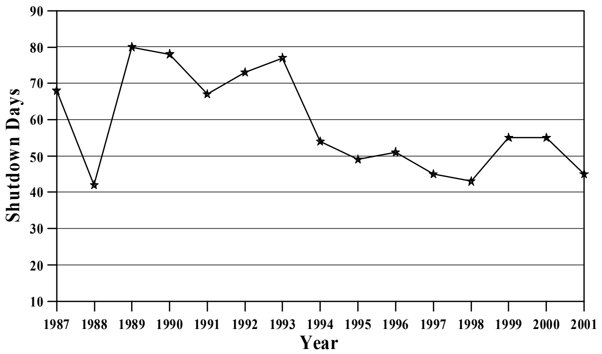


Figure 1. Shutdown period of cargo handling work due to dynamic motion of the moored vessel at Pohang New port

2. Description of Numerical model construction

2.1 Governing equation

The extended mile slope equation was used as the governing equation to consider the steep slope and curvature of the sea beds at the ports (Booij, 1983). The equation is as follows;

Equation (1) simulates wave refraction, diffraction, and reflection in coastal domains of arbitrary shape. However, various other mechanisms also influence the behavior of waves in a coastal area. The mild-slope equation can be extended as follows to include the effects of bottom friction and dissipation due to wave breaking.

$$\nabla \bullet (CC_g \nabla \hat{\eta}) + \left(\frac{C_g}{C} \sigma^2 + i\sigma w + iC_g \sigma\gamma \right) \hat{\eta} = 0 \qquad (1)$$

where $\hat{\eta}(x, y)$ = complex surface elevation function, from which the wave height can be estimated, σ = wave frequency under consideration (in radians/sec), $C(x, y)$ = phase velocity $= \sigma / k$, $C_g(x, y)$ = group velocity $= \frac{\partial \sigma}{\partial k} = nC$ with $n = \frac{1}{2}\left(1 + \frac{2kd}{\sinh 2kd}\right)$, k(x,y) = wave number (= 2 π /L), related to the local depth d(x,y) through the linear dispersion relation: $\sigma^2 = gk \tan g(kd)$, $\gamma = \frac{0.15}{d}\left(1 - \frac{0.4^2 d^2}{4a^2}\right)$ is a wave breaking parameter, following Dally et al. (1985) and Demirbilek (1994). We have used the following form of the damping factor,

$$w = \left(\frac{2n\sigma}{k}\right)\left[\frac{2f_r}{3\pi} \frac{ak^2}{(2kd + \sinh 2kd)\sinh kd}\right] \qquad (2)$$

where, w is a friction factor, $a(= H/2)$ is the wave amplitude and f_r is a friction coefficient. The friction coefficient depends on the Reynolds number and the bottom roughness. We referred Madsen (1976) and Dalrymple et al. (1984). Typically, values for f_r are in the same range as for Manning's dissipation coefficient 'n', specified as a function of (x,y) assigning larger values for elements near harbor entrances to consider entrance loss

In addition to the above relationships, simulation of nonlinear waves may be conducted by using the mild slope equation. This is accomplished by incorporating amplitude-dependent wave dispersion, which has been shown to be important in certain situations. Equation (3) is rearranged to include the nonlinear dispersion relation used in place of Equation (1).

$$\sigma^2 = gk\left[1 + (ka)^2 \frac{\cosh(4kd) - 2\tanh^2(kd)}{8\sinh^4(kd)} \tanh^5 kd\right] \bullet \tanh\left\{kd + ka\left(\frac{kd}{\sinh(kd)}\right)^4\right\} \qquad (3)$$

Coastline or permeable structures, the following partial reflection boundary condition applies along

$$\frac{\partial \eta}{\partial n} = ik \frac{1 - K_r}{1 + K_r} \hat{\eta} \qquad (4)$$

where K_r is the reflection coefficient. Along the open boundary where outgoing waves must propagate to infinity, the Sommerfeld radiation condition applies

$$\lim_{kr \to \infty} \sqrt{kr} \left(\frac{\partial}{\partial r} - ik \right) \hat{\eta}_s \to 0 \qquad (5)$$

where $\hat{\eta}_s$ is the scattering wave potential. It is shown in Mei (1983) that the desired scattered wave potential $\hat{\eta}_s$, which is a solution of the mild-slope equation and satisfies the radiation condition Equation (5), can be written as Equation (6).

$$\hat{\eta}_s = \sum_{n=0}^{\infty} H_n(kr)(a_n \cos n\theta + \beta_n \sin n\theta) \qquad (6)$$

where $H_n(kr)$ are the Hankel functions of the first kind.

2.2 Composition of the numerical model

The oscillation analysis of Yeongil Bay includes the areas of Pohang Old port, Pohang New harbor and Yeongilman New port. The construction of Yeongilman New port has already seen the completion of the 4.1 km breakwater, but the berths are still under the construction. The size of bay is 13.5km x 9.5km opened in north-east direction. For the numerical analysis of Yeongil Bay, the subject area before and after the construction of Yeongilman New port, are incorporated into the finite element models and compared the results with each other.

The model application area has a semi-circle open boundary limit which starts from the northern edge of Yeongilman New port to Jangigot, the southern edge of bay mouth. A triangular variable element was adopted as an infinite grid net and each grid has 10-100 m intervals between them. The water depths are varying with 1.0m ~ 51.3m and the surface area was discretized with 59,692 nodes before construction and 52,792 nodes after constructions shown in Figure 2 ~ Figure 4. In these figures the origin of the xyz-coordinate system is located near the eastern tip of Yeongil Bay breakwater. The radius of the semi-circle is 6.5km and the maximum water depth on the semi-circle is 51.3m. The coordinates of x-axis was set to 120° from the true north. Model analysis will focus on possible oscillation phenomenon for given incoming wave conditions. The characteristics of models are shown in Table 1. Figure 5 shows the selected stations for comparison of the model simulation results.

Table 1. Characteristics of finite element model

Plan	Node	Open boundary	Element	Calculation Time
Before	59,692	239	115,718	2h 36min
After	52,792	238	102,294	2h 29min

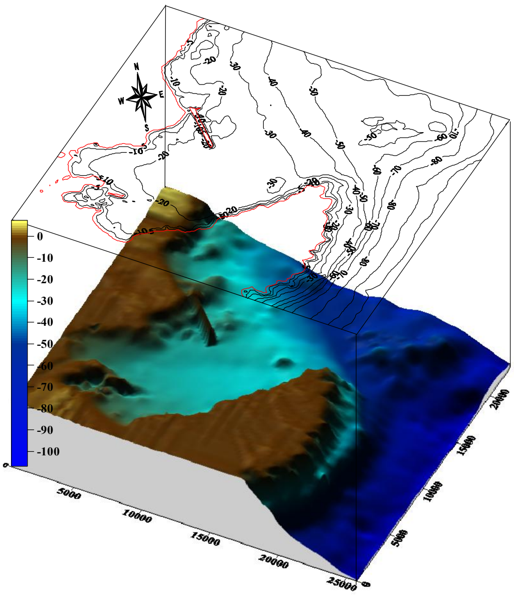


Figure 2. Study area and depth for numerical simulation

Figure 3. Finite element mesh for the present Yeongil Bay

3. Analysis by the numerical model

3.1 The characteristics of oscillation in Yeongil Bay

Yeongil Bay has a rectangular shape. The 1st oscillation period can be calculated by the simple Merian equation (SPM, 1984) as follows;

$$T_n = \frac{4l_B}{(2n-1)\sqrt{gh}} \quad , \text{ n=1,2,3,}\cdots. \qquad (7)$$

Figure 4. Finite element mesh after Yeongilman New port

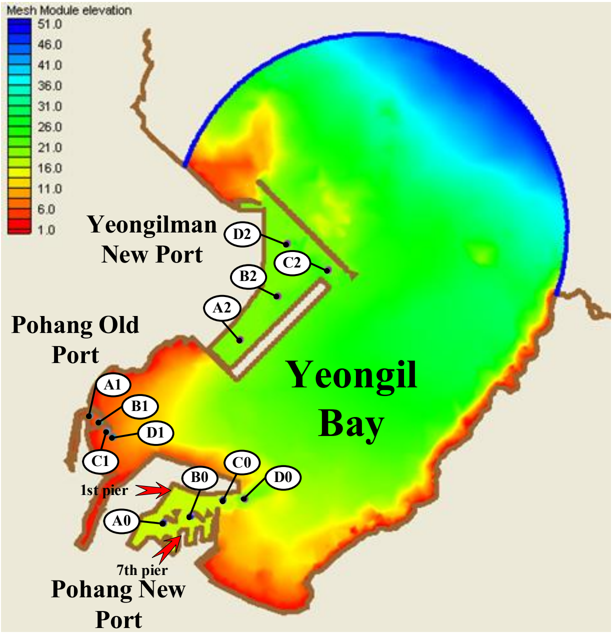


Figure 5. Selected stations for model simulation

The approximate oscillation modes are calculated as 62.7, 20.9, and 12.5 minutes. T_n is the period of natural oscillation mode, l_B is the bay length (13.5 km), g is the acceleration of gravity (9.8 $m/\sec$), h is the average water depth (21m), and b is the width of the bay (9.5 km). The correction coefficient at the entrance of the harbor is shown as;

$$\alpha = \left[1+\frac{2b}{\pi l_B}\left(0.9928-\ln\frac{\pi b}{4l_B}\right)\right]^{1/2} \qquad (8)$$

Multiplying this to Equation (7), the oscillation modes are calculated as 81.3, 27.1, and 16.3 minutes. As Pohang New port is a closed shape of bay, T_n becomes;

$$T_n = \frac{2l_B}{n\sqrt{gh}}, \quad n = 1,2,3,\cdots. \tag{9}$$

Therefore, the oscillation modes at Pohang New Port are calculated as 9.9, 5.0, and 3.3 minutes. These values are calculated roughly and should be changed according to the depth, boundary shape, energy loss inside harbor, and conditions at the mouth of the bay.

Generally, the natural period is affected by the dimensions (length, width, and depth) of the bay. Therefore, in order to control the periods, the dimensions together with the plan form should be dealt with appropriately.

Korea Ocean Research & Development Institute (KORDI, 1995) presented 75.5 min. as the Helmholtz natural period, 31.8 min. as 2nd natural period, 22.5 min. as 1st oscillation period, and 7 min. as 2nd oscillation period, in Pohang New port.

KORDI (1995) also observed the oscillation at 8m water depth between the 150,000 ton pier and No.1 pier from October, 1994, to March, 1995, and presented 80 min. as the 1st oscillation period in Yeongil Bay from 80 sets of data. After that 32 min., 29.1 min., 26.7 min., and 22.9 min. periods were observed, which are near the 1st harmonic at Pohang New port and/or 2nd harmonic at Yeongil bay. Below the 2nd periods of Pohang New port, 8 min., 5min., and 2.8 min. of periods were observed.

3.2 Simulation Results and Analysis

Figure 6 ~ Figure 15 show the results of the simulation. The start incident wave period was at 6 sec. and the incident wave directions were NE and N80E at each frequency (6sec. ~ 80min.), and each simulation was repeated 90 times. Figure 7 ~ Figure 9 show the occurrence of oscillation frequencies from the simulation.

In the case of Pohang New port before the construction of Yeongilman New port, 80 min. and 30 min. were calculated, which correspond to 1st and 2nd harmonic of Yeongil Bay, and there were 3 min., 5 min., and 10 min. of resonance period at the mouth and outside of harbor. After the construction, the strong responses were represented at 0.6 min., 16 min., 35 min., and 42 min. The construction caused to disappear 30 min. response and enhanced the responses at the periods between 35 ~ 42 min. The results are summarized in Figure 10 and Figure 11.

In the case of Pohang Old Port, 1 min., 3 min., 8 min., 17 min., 30 min., and 80 min. were calculated before the construction, and 0.5 min., 1 min., 17 min., and 80 min. were appeared after the construction. Although the responses of 3 min., 8min. and 30min. were reduced, those are too small to recognize, even in Figure 12 and Figure 13.

For the case of Yeongilman New port, 2 min., 4 min., 5 min., 12 min., 14 min., and 80 min. were appeared after the construction. The calculated oscillation periods by equation (6), 80 min., 27.1 min., and 16.3 min., were appeared at the results by numerical simulations after the construction and similar responses were shown in Pohang Old and New ports as well. The results are summarized in Figure 14 and Figure 15.

The field measurements of oscillation periods by KORDI (1995) were compared with the results of the numerical analysis. Figure 16 and Figure 17 are the comparison of harbor response with respect to wave direction at the Pier #1 and Pier #7 of Pohang New port.

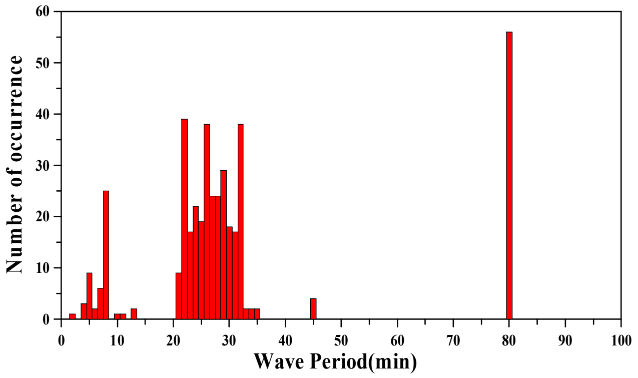


Figure 6. Mean occurrence of oscillation period at Pohang New port (1994.10.5-1995.3.10, KORDI)

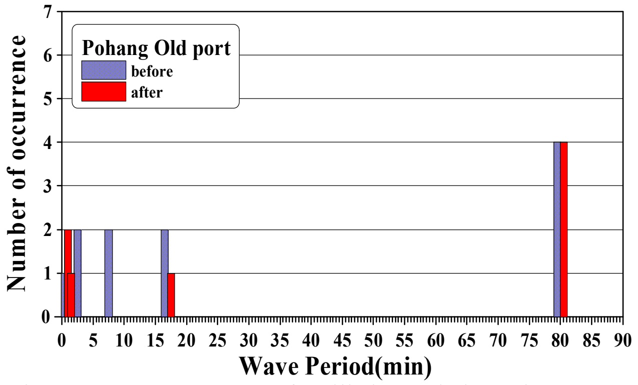


Figure 7. Mean occurrence of oscillation period at Pohang New port before and after construction of Yeongilman New port

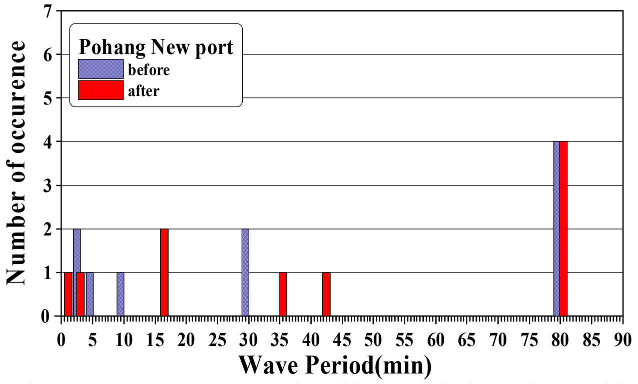


Figure 8. Mean occurrence of oscillation period at Pohang Old port after construction of Yeongilman New port

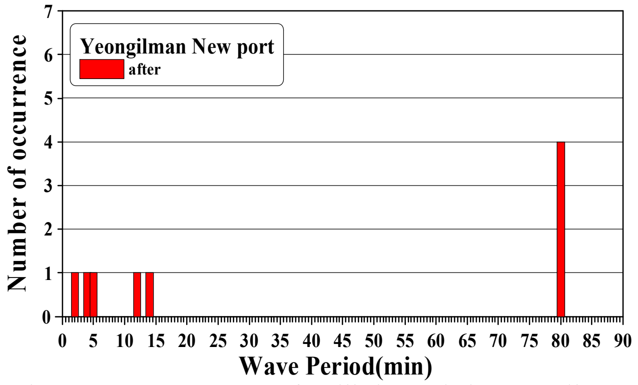


Figure 9. Mean occurrence of oscillation period at Yeongilman New port

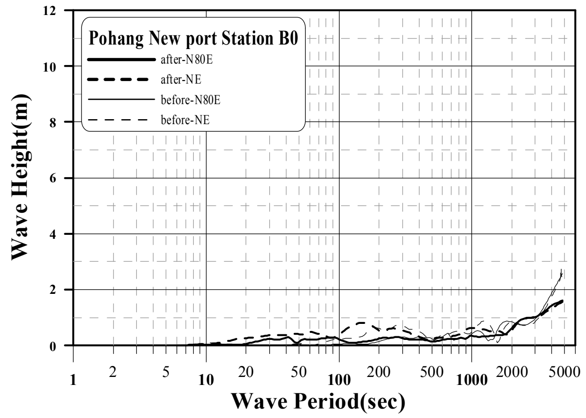


Figure 10. Comparison of port response with respect to wave direction (St.B0)

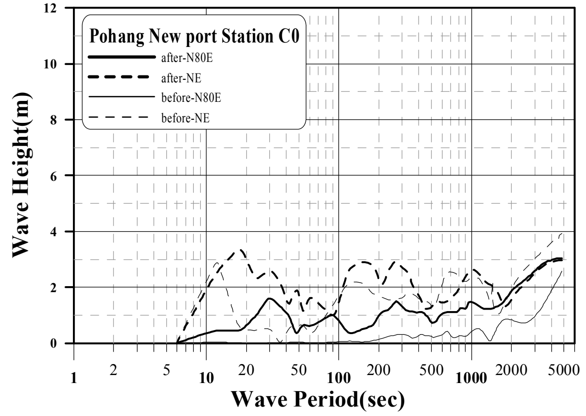


Figure 11. Comparison of port response with respect to wave direction (St.C0)

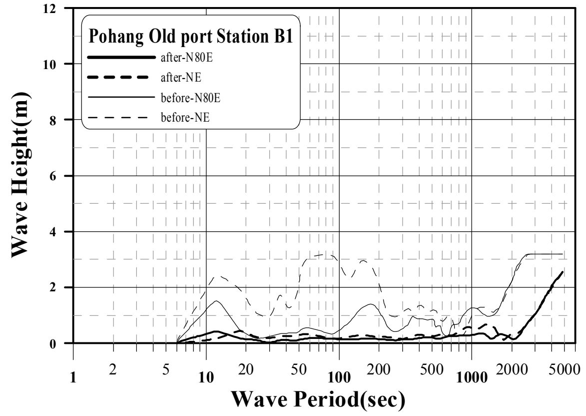


Figure 12. Comparison of port response with respect to wave direction (St.B1)

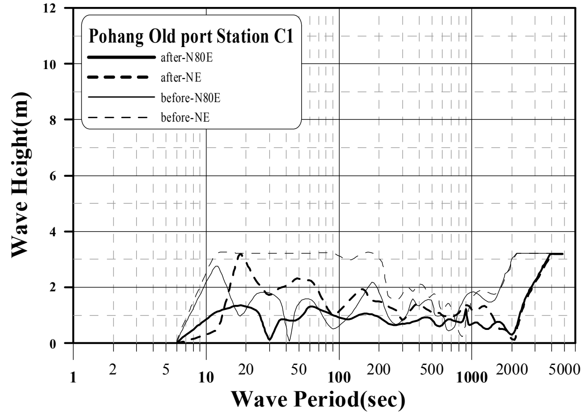


Figure 13. Comparison of port response with respect to wave direction (St.C1)

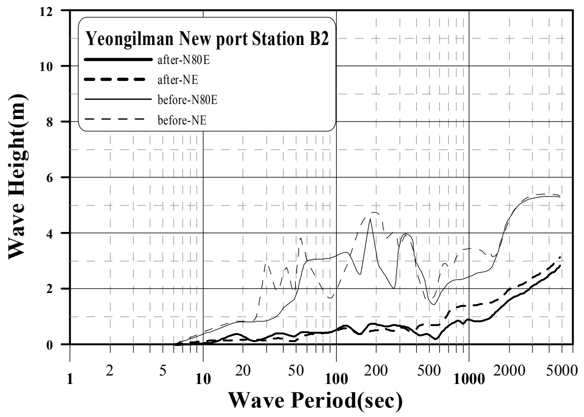


Figure 14. Comparison of port response with respect to wave direction (St.B2)

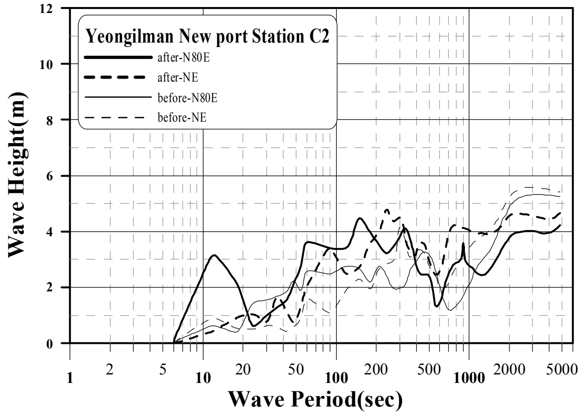
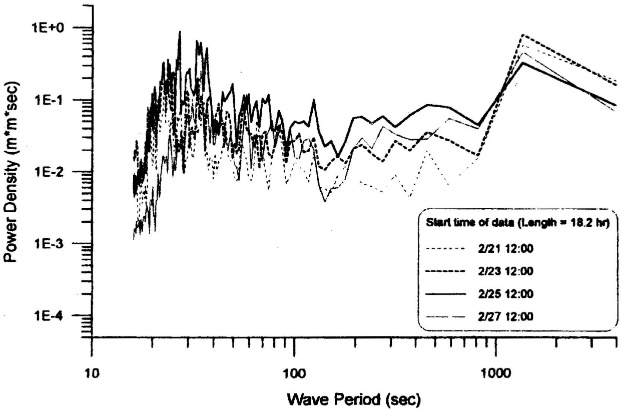


Figure 15. Comparison of port response with respect to wave direction (St.C2)



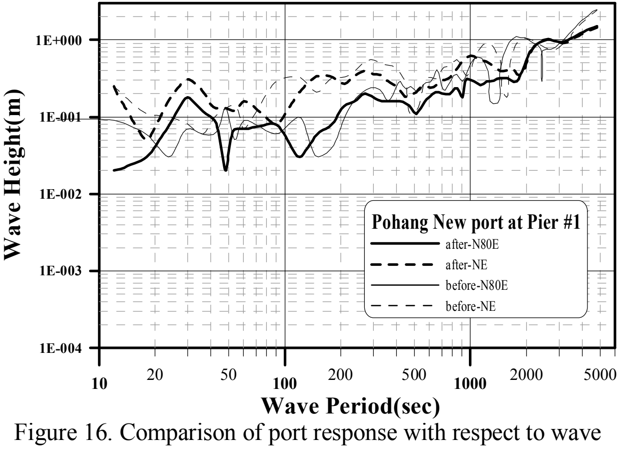
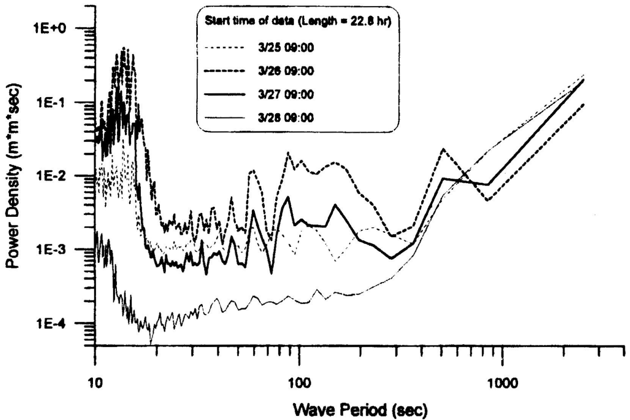


Figure 16. Comparison of port response with respect to wave direction at Pier #1 of Pohang New port



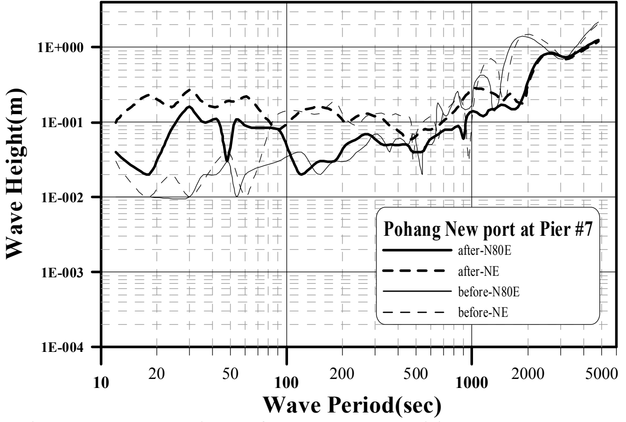


Figure 17. Comparison of port response with respect to wave direction at Pier #7 of Pohang New port

The field measurement at Pier #1 showed the highest response at the period of 25~35sec. From the numerical simulation, it showed 0.15m for 20sec, 0.6m for 3.33 min., 1.2m for 33min., etc. The field measurement at Pier #7 showed the highest response at the period of 10~18sec. From the numerical simulation, it showed 0.15m for 20sec the period of 0.3 min. showed the highest wave height as 0.3 m, 0.3m for 10~20sec, 0.45m for 1.67min~3.33min, and 0.9m for 33 min., etc. The wave heights were generally risen at the area of Pier # 7.

The general amplification factors have decreased after the construction of Yeongilman New port, but the periods of 30 min. and 80 min. showed the strong increase. Although the layout of Yeongilman New port with an attached breakwater was acceptable for its own ship, it is seen that the construction of the new port might bring some troubles to the operation of Pohang New port and other areas. Consequently, the problem of resonance only exists in inner basins and it is, therefore, still important to limit the input of wave energy caused by the structure added by the new port development plan.

4. Conclusion

Harbor oscillation problems are very important factors to maneuver the ships at the entrance of the harbor and mooring berth, and cargo handling work at the moored vessel. Especially, Pohang New port endures these difficulties caused by the harbor resonance problem. The affect of port development to other area and the counter measure must be found. The feasibility study was done in this area with only small scale focused with the project site. The aim of this study is to analyze the change of oscillation periods in Pohang Old and New ports before and after construction of the Yeongilman New port and to give important data which are necessary for the port planners and users. Most significant periods were found from the simulation within the 1st and 2nd oscillation periods of Yeongil Bay, and some periods and amplification factors had been changed and increased after construction of the new port. We only brought up the possibility here that the construction at a given area in a large bay could induce the worse cases to other places. In order to reduce the harbor oscillation, therefore, the oscillation periods should be changed and the amplification factors should be reduced by modifying to the port design plan; by adopting wave absorbing facilities and/or by rearrangement of berth plan form, etc. It is not easy to reduce the responses but we should find a way to complete the development plan. This is the next target of our research.

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