Numerical Simulation of the Pohang New Harbor for Sciche Reduction

Prashant kumar, Kim kwang Ik

Department of Mathematics, Pohang University of Science and Technology,
Pohang-790-784, South Korea
Email: prashant.k@postech.ac.kr , kimki@postech.ac.kr

Abstract

Pohang new harbor (PNH) situated in the Yogil bay, the south east part of the South Korea, which is one of the largest industrial harbor in the world. There is inevitable problem during the seasonal weather, Pohang new harbor experienced with high resonance seiche oscillation. On the basis of theoretical studies, the mathematical modeling introduced based on linearized small amplitude wave theory to derive the Helmholtz equation, which is solved by improved Weber's solution. The numerical approximation conducted to analyze the power spectral density (PSD) at eight record stations, where real measurement data observed. The simulation results validated the real time measurement of wave height and tide gauge at these record stations. The modification for the improvement has introduced to reduce the seiche oscillation inside the harbor. The numerical model has applied on modified geometry of the PNH to analyze the spectral density analysis at these given record stations.

Keywords: *Pohang new harbor, Helmholtz equation, Weber's solution, Data Record stations, Power spectral density.*

1. Introduction

The Pohang New Harbor (PNH) is built to support the steel industry in South Korea, for which POSCO has been a dominating industrial power since 1970s. PNH obstructs waves coming from the East sea (also known as the Japan sea), which is on the southeastern side of the Korean peninsula. The waves, which is generated during the typhoon is coming from east side of PNH, these waves have high amplitude in PNH, which create resonance inside the harbor as well as open sea region. But a small portion of transmitted waves are reflected and diffracted repeatedly by ships and interior boundaries of the harbor. When the frequency of incident waves equals to the natural frequency of harbor, the resonance is occurred and the wave response in the harbor is larger than the incident wave. But actually, the magnitude of the wave response in the harbor, when the resonance is occurred, is restricted by various mechanisms. To protect the harbor and offshore structures, the numerical simulation has been done for specific record points.

However, many previous studies has been done on harbor oscillations, In 1952, Mc Nown analyzed the response of a circular harbor of small entrance gap by assuming that crest of standing wave occurred at the entrance. In 1961, Miles and Munk has been investigated the resonance in the rectangular harbor. In 1963, Ippen and Goda also studied the problem of a rectangular harbor connected to open sea, Fourier transformation method is used to analyze waves radiated from harbor entrance to open sea. Hwang and Tuck (1970) used a boundary integral method, which involves the boundary wave function along the harbor boundary to evaluate the oscillation in the harbors of constant depth. J.J. Lee (1971) solved the Helmholtz equation using the Weber’s solution to analyze the harbor oscillation of arbitrary shaped. In order to solve this problem, Brenkhoff (1976) used the mild slope equation with partial reflection condition to evaluate the diffraction and refraction along the boundary of the harbor. In 1986, Chou and Lin applied the boundary element method to analyze the wave induced oscillation in a harbor of arbitrary shape with rigid wall in variable depth. Chou and Han (1993, 1994) described the method based on the boundary element method to predict the wave height distribution in the harbor of variable depth with partially reflecting boundaries. In 1998, H S Chen and J R Houston calculated the water oscillation in the coastal harbors with some experimental details. H S Lee and Williams (2002) developed a boundary element modeling of multidirectional random waves in a harbor with partially reflecting boundaries.

However, the most of theoretical studies on harbor resonance problem assumed the water depth was constant both interior and exterior of the harbor. Chen et. al. (2004) shows the shelf resonance and edge wave effect at the bottom also play an important factor for harbor resonance. Hong Sik Lee and Sung Duk Kim (2009) have compared comparison of several wave spectra for the random wave diffraction by a semi-infinite breakwater.

In this paper, the mathematical formulation for Helmholtz equation and implement it on the actual PNH domain. The main analysis consists of two parts. First, we compute fluid flows under the small amplitude assumption of surface waves with a horizontal irregular geometry by using BIEM for the Helmholtz's equation, which is derived from the Euler equations as a linearized model. From this, the frequencies of dominantly excited waves at various harbor points are computed. Using the computed fluid flow information, like wave amplitude, we analyze the spectral density analysis at eight harbor record points to incident monochromatic wave trains that cause resonances inside PNH. After the Field survey and inspections of underwater, inside the PNH, six recorder points are chosen to measure the real time wave heights using WTG (Wave and Tide Gauge). Then the computer simulation results are compared with the real time data accessed by POSCO steel company Pohang at each recorder points inside PNH. Further, visualization of the spectral analysis with respect to time in different incident wave directions is demonstrated. Finally, few tactics based on the simulation results are introduced to improve the Pohang new harbor hazards.

2. Mathematical Formulation

For simplicity we make the following assumptions on the fluid motion: (i) inviscid fluid, (ii) irrotational flow, (iii) infinitesimal waves amplitude, (iv) long wavelength compared to depth, and (v) lateral boundaries are perfectly reflective and vertical throughout the sea depth. Wave terminology for small amplitude assumption described by the coordinate system shown in the Fig . 1, the x axis is taken along the entrance of the harbor; y axis is taken along the onshore direction toward the open sea. The fluid domain is separated by entrance into two different regions, called bounded region (harbor) and open sea region (outside the harbor). The incoming waves are diffracted and refracted at the entrance due to the shoreline along the entrance. The wave field has been calculated inside the harbor as well as open sea region. The angle of incidence has been taken into account while analyze the wave field inside the harbor. We have matched the solution at the entrance obtain from inside the harbor and open sea region. The boundary of the harbor considered as solid boundary, where normal derivative of wave field is zero. In the open sea region wave field has been divided as incident wave field plus reflected wave field and radiated wave field due the dispersion of waves in the open sea to infinity from the entrance.

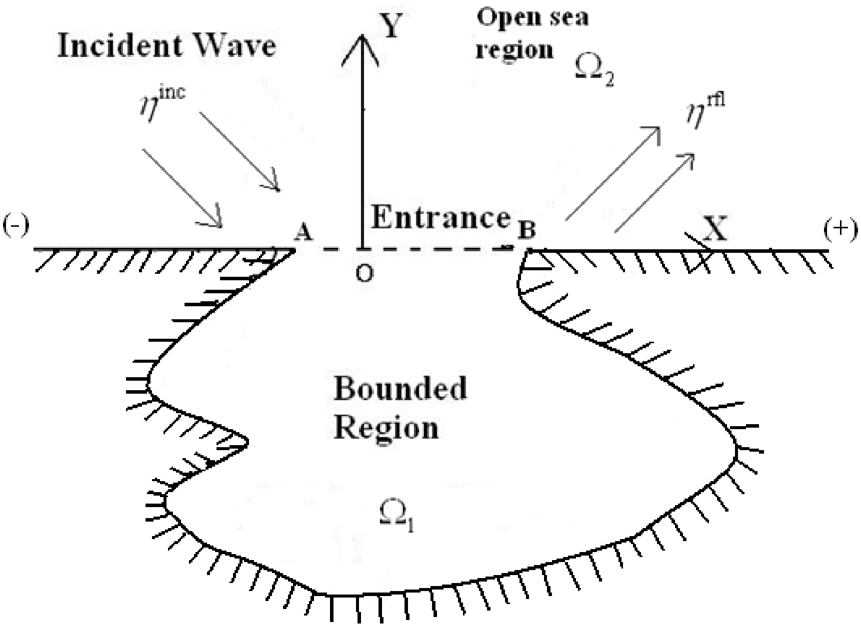

Fig. 1. Geometry of the model definition.

The governing equation for understanding the problem, we have solved the Helmholtz equation derived from Navier Stokes equation. In the numerical model, harbor coastline is considered as perfectly reflective. The bounded region (Ω_1) of the harbor includes the boundary and all complex topography nearby, and unbounded part is recalled as open sea, in which nearby harbor entrance depth is constant. The Helmholtz equation for bounder region can be described as

$$\nabla^2\eta + k^2\eta = 0 \tag{2.1}$$

where, η is wave field of the bounded region and k is the wave number described as dispersion relation explain later. For open sea region, we can write the wave fields as:

$$\eta^{\text{open}} = \eta^{\text{inc}} + \eta^{\text{rfl}} + \eta^{\text{R}} \tag{2.2}$$

where η^{open}, the wave field for open sea region, η^{inc},incident wave field, η^{rfl}, reflective wave field, due to the reflection from the coast of the harbor shown in the figure-1 and η^{R}, the radiated wave field due to the wave scattered toward entrance from the local topography of the harbor.
An incident wave field expressed as:

$$\eta^{\text{inc}} = A\exp(ik(x\cos\theta + y\sin\theta)) \tag{2.3}$$

where, A is the wave amplitude of the incident wave and θ is the angle of incident toward entrance of the harbor. The reflective wave field expressed as:

$$\eta^{\text{rfl}} = A\exp(ik(x\cos\theta - y\sin\theta)) \tag{2.4}$$

on the coast line the boundary condition:

$$\frac{\partial}{\partial y}(\eta^{\text{inc}} + \eta^{\text{rfl}}) = 0 \tag{2.5}$$

The normal flux vanish along the straight coast for radiated wave field,

$$\frac{\partial}{\partial y}\eta^{\text{R}} = 0, \tag{2.6}$$

furthermore, the radiation boundary condition for large distance satisfied the following as:

$$\lim_{kr\to\infty}(kr)^{-1/2}\left(\frac{\partial}{\partial r}-ik\right)\eta^{\mathrm{R}}\to 0 \tag{2.7}$$

The governing equation formed in open sea region in term of the radiated wave function given below as:

$$(\nabla^2+k^2)\eta^{(\mathrm{R})}=0 \tag{2.8}$$

When the depth assumed constant everywhere, walls are considered as vertical and perfectly reflective. The three dimensional potential theory for arbitrary *kh* maybe expressed as:

$$\phi(x,y,z)=\frac{-ig\eta(x,y,z)}{\omega}\frac{\cosh k(z+h)}{\cosh kh} \tag{2.9}$$

where, η satisfied the Helmholtz equation and wave number(k) and frequency ω is related by dispersion relation $\omega^2=gk\tanh kh$. The Helmholtz equation for bounded region and open sea region has been solved by using the Weber's solution given as (J. J. Lee [1970]). The boundary of harbor has discretized very precise to improve the accuracy of wave field.

3. Spectral density analysis

Irregular ocean waves are often characterized by a wave spectrum; this describes the distribution of wave energy (height) with frequency. The spectral density can be defined as an image that identifies the relative wave energy present at all frequency periods at a fixed location for a predefined time period, regardless of the energy's directional heading. The power spectral density function (PSD) shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak. The unit of PSD is energy per frequency (width) and you can obtain energy within a specific frequency range by integrating PSD within that frequency range. Computation of PSD is done directly by the method called FFT or computing autocorrelation function and then transforming it.

4. Location of port and the record points (PNH)

The field measurement data has been taken form Global mapper software package at the various specific record points. The eight specific points have chosen inside as well as outside the PNH. The spectral density analysis calculated numerically at these specific points. In the Fig. 2, the actual topography of PNH included eight record point has been shown. In which, two record points W1 and W2 have taken open sea region and other six points (W3, W4, W5, W6, W7 and W8) taken inside the PNH boundary. The incoming waves toward the entrance have shown by the red lines.

Fig. 2. The location of the measurement data at the various record points inside the boundary of PNH and the open sea region.

The location of record points outside the harbor is in term of longitude and latitude has been given below as:

W1: ($N36^{0}02^{'}16.5^{''}, E129^{0}27^{'}11.5^{''}$) W2: ($N36^{0}02^{'}16.6^{''}, E129^{0}27^{'}11.5^{''}$).

The location of interior points inside the harbor in terms of longitude and latitude has been given below as:

W3: ($N36^{0}00^{'}47.0^{''}, E129^{0}25^{'}05.4^{''}$) W4: ($N36^{0}01^{'}0.3^{''}, E129^{0}24^{'}58.7^{''}$)

W5: ($N36^{0}00^{'}58.2^{''}, E129^{0}24^{'}36.4^{''}$) W6: ($N36^{0}00^{'}50.4^{''}, E129^{0}24^{'}03.8^{''}$)

W7: ($N36^{0}00^{'}41.0^{''}, E129^{0}23^{'}35.1^{''}$) W8: ($N36^{0}01^{'}35.5^{''}, E129^{0}25^{'}01.6^{''}$).

The location of record point-1 and 2 has been taken outside the harbor to analyze the direction of waves and notifying the wave heights for real measurement data system. We have chosen six key locations inside the harbor for spectral density analysis.

5. Numerical Simulation results for spectral density analysis

The spectral density (wave spectrum) analysis has been done numerically on the basis of field data at eight specific record points interior and exterior of the PNH. The abscissa is the wave period, which has discretized from one minute range to 100 minutes. The ordinate is taken as the spectral density function, which shows the wave spectrum with respect to wave periods at specific location in the harbor. Frequency difference (60 seconds) is taken in the numerical simulation process to calculate the spectral density function for 10 minutes. Form 10 minutes to 100 minutes, the wave period difference is taken 2 minutes. The spectral density function for record point-1(W1) and record point-2(W2) have shown in the Fig. 3 in the open sea region of PNH.

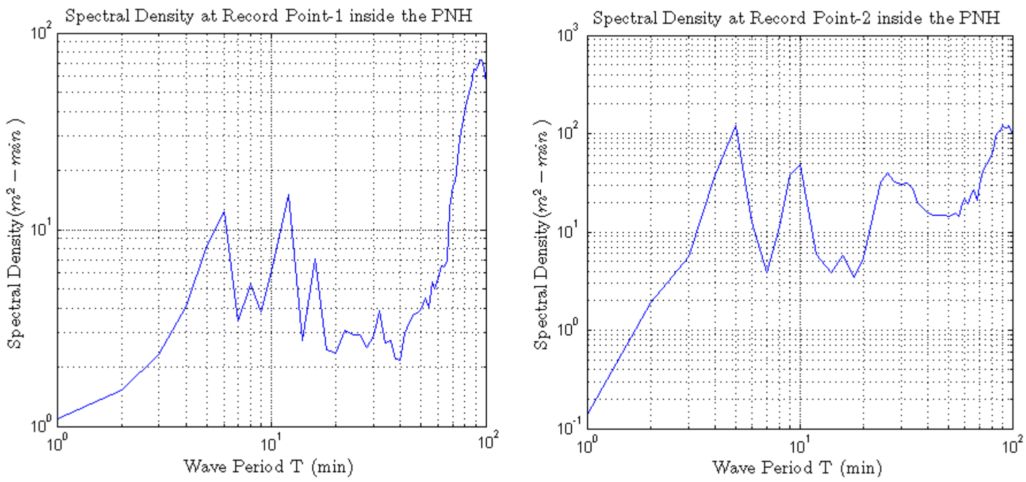

Fig. 3. Numerical simulation results for Spectral density at the record point-1 and record point-2 with wave period difference 60 seconds until 10 minutes and wave period difference 2 minutes from 10 to 100 minutes.

The resonance mode occurs at wave period approximately 5 minutes, 12 minutes, 32 minutes and 90 minutes. The waves coming with these periods can generate higher resonance at these record points. We have analyzed the spectral density for shallow water, which identify the oscillation signal with respect to the time series data. The first few resonance modes are very important to analyze the response of the waves of various wave periods. In the Fig. 4, we have numerically analyzed the spectral density inside the PNH at record points W3 and W4. We found the resonance peaks occurs at 3-5 minutes, 7-8 minutes, 30 minutes and 90 minutes. In the Fig. 5, we have analyzed the response of the resonance at record point W5 and W6. The resonance peaks occurs at 4 minutes, 10 minutes, 29 minutes and 90 minutes. In the Fig. 6, we have analyzed the spectral density at record point W7 and W8. The resonance peaks occurs at these record points approximately 3-5 minutes, 10 minutes, 28 minutes and 90 minutes. The other record points inside the harbor we have the same resonance modes except few noise. It will show that the wave of these specific wave period create higher resonance in the harbor. The range of the first record point is 3-5 minutes, the range of second resonance mode is 8-10 minutes and range of third resonance mode is 28-30 minutes are very crucial for practical applications in the harbor.

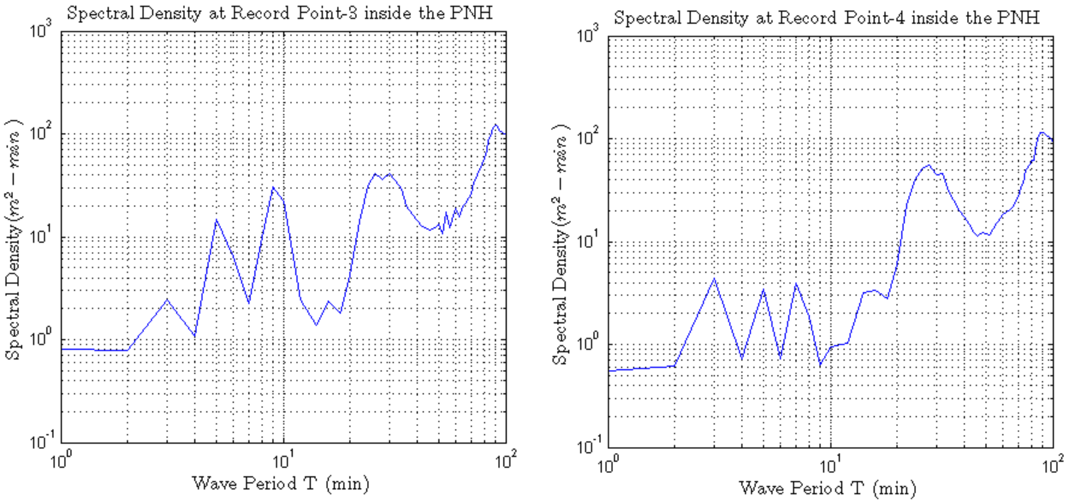

Fig. 4. Numerical simulation results for spectral density at the record point-3 and record point- 4 with wave period difference 60 seconds until 10 minutes and wave period difference 2 minutes from 10 to 100 minutes.

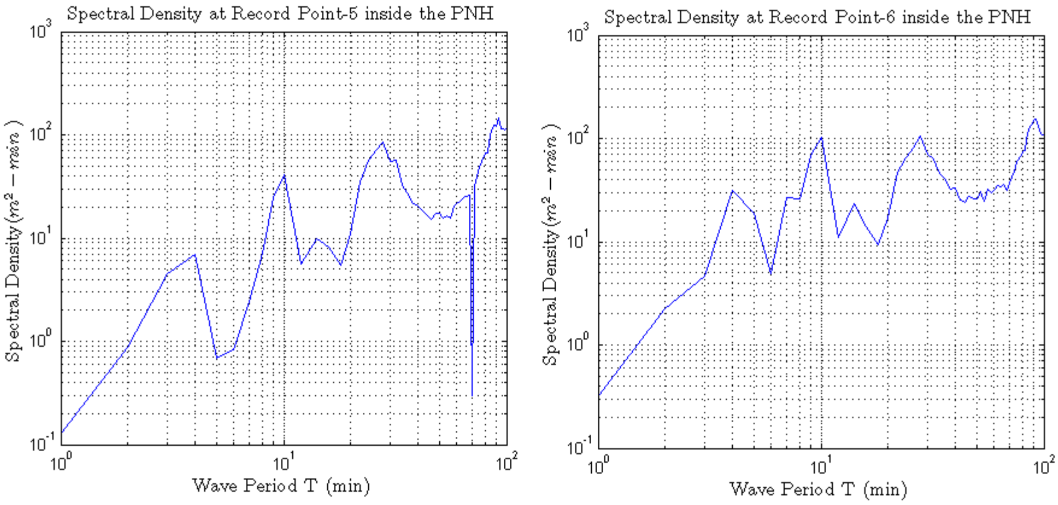

Fig. 5. Numerical simulation results for spectral density at the record point-5 and record point- 6 with wave period difference 60 seconds until 10 minutes and wave period difference 2 minutes from 10 to 100 minutes.

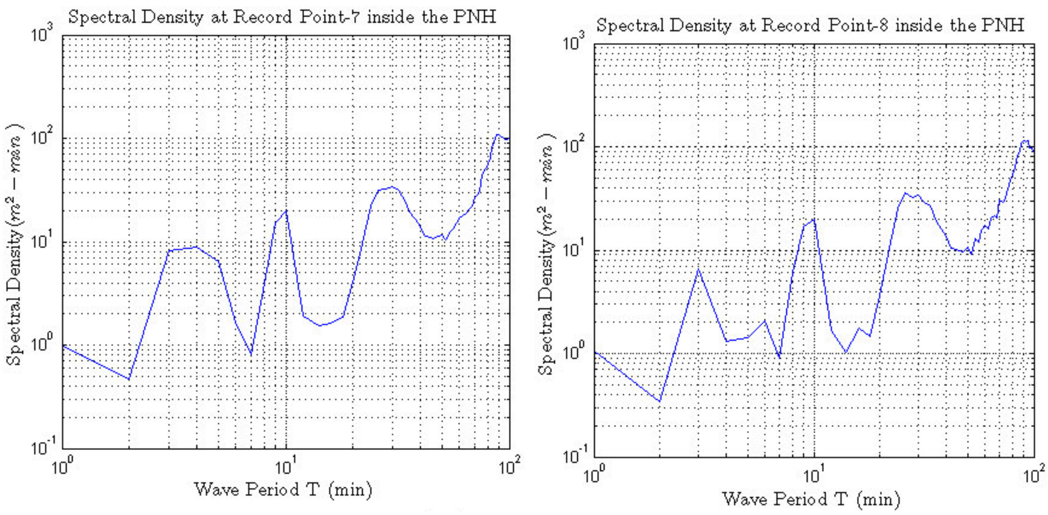

Fig. 6. Numerical simulation results for spectral density at the record point-7 and record point- 8 with wave period difference 60 seconds until 10 minutes and wave period difference 2 minutes from 10 to 100 minutes.

6. Validation of the Numerical Simulation

The wave heights were measured at eight record points, in which directional wave rider buoy at record point W1 outside the harbor and wave gauge of pressure type used at record point W3 to W8 inside the harbor. The tide gauge was measured at two record point W1 and W2 outside the harbor, in which we have used the tide gauge. The wave heights were measure at particular direction at various record points. For qualitative comparison we make use of some real time field measurement data from Pohang New harbor, provided by PSOCO steel plant, Pohang, South Korea. We compare the numerical simulation results with the real time measurement data. In the Fig. 7, we can analyze the resonance modes occur approximately same wave period range as the real measurement data predict the resonance modes. It shows the validation of our numerical calculation on the basis of our mathematical model. On the basis of numerical simulation results we can predict the resonance behavior of wave of different wave periods. We can analyze the spectral analysis of offshore waves across the boundary of harbor.

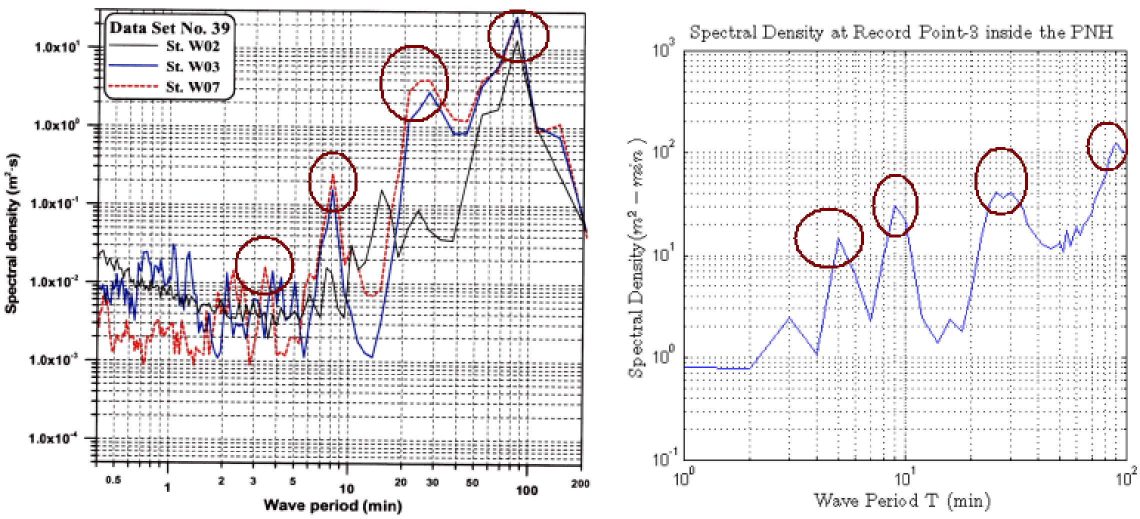

Fig.-7. Comparison of real measurement data with numerical simulation result at record point-3 (W3) inside the harbor. In the graphical comparison first resonance mode occurs at 4-5 minutes range, second resonance mode occurs at 8-9 minutes range, third resonance modes occurs at 25-30 minutes range and fourth record point occurs at approximately at 90 minutes.

7. Conclusion and Discussion

We have got strong qualitative similitude to the record point at Pohang New Harbor despite the dissimilarity of harbor geometry. Without taking consideration of friction losses at entrance, the linearized small amplitude wave theory is well known for the understanding the phenomenon of resonance modes in and outside of the harbor. Resonance modes in the spectral density verses wave period provide the key information about the oscillation generate by various wave periods. Incident wave amplitude and wave direction play an important role in diminution the resonance modes in the harbor. The waves of small wave period like 4 minutes and 8 minutes can create higher local resonance in the harbor. The Spectral density analysis provided the crucial information about the energy distribution (wave height) with respect to the frequency variation at key location in and outside the harbor. For many today's practical problems, scope of aforethought discourse is sufficient and far more accurate the methods required like the consideration of the nonlinearity to analyze the harbor resonance. We need to go towards the better precision and accountability of additional parameters to continue the greater accuracy and more genuine representation of dominant conditions.

Acknowledgement

The funding for this work was supported by department of mathematics, POSTECH and BK-21(Brain Korea-21), Pohang, South Korea.

References

Breakhoff, J.C. W., 1976. Mathematics models for simple harmonic water wave diffraction and refraction, Delft Hydrodynamics lab., report-168.

Chen H.S., Houston J.R., 1998. Calculation of water oscillation in coastal harbors, HARBS and HARBD user's Manual. Instruction rep. CERC-87-2., US army engineer waterways experiment station, coastal engineering research center, Vickburg, M.S.

Chou C.R., Lin J.G., 1986 BEM analysis of oscillation in harbor of arbitrary shaped with uneven sea bed, proc.

8th conf. on ocean engineering, R.O.C., pp.111-130.
Chou C.R., Han W. Y., 1993. Wave induced oscillation in harbours with dissipating quays, Coastal Engineering in Japan, Vol. 36, No.1.
Chou C.R., Han W. Y., 1994. Oscillation induced by irregular waves in harbours, Coastal Engineering, chapter-215, pp. 2987-3001
Cooley J.W., Lewis P.A., Welch P.D. (1970). The fast Fourier transform algorithm: Programming considerations in the calculation of sine, cosine and Laplace transforms. Journal of Sound and Vibration 12: 315–337.
Hwang L.S., Tuck E.O., 1970. On the oscillations of harbours of arbitrary shape. Journal of Fluid Mechanics,vol.-42, pp.447-464.
Ippen A.T., Goda Y., 1963. Waves induced oscillation in harbors, the solution for a rectangular harbor connected to the open sea, Report no.59, Hydrodynamics Laboratory, MIT, Washington.
Jeong W. M., Oh S.B., Chae J.W., Kim S.I., 1997. Analysis of the wave induced downtime at Pohang new harbor, Journal of Korean Society of Coastal and Ocean Engineers, ((1), pp.24-34.
Kwak M., Jeong W. M., Pyun C., Xing X., Lee J. J., 2008. Computer simulation of Pohang new harbor for seiche reduction, proceedings of the 31st International Conference on Coastal Engineering, ASCE, pp. 3996-4001.
Lee H.S., Williams A.N., 2002. Boundary element modeling of multidirectional random waves in a harbor with partially reflecting boundaries. Ocean Engineering, vol-29, pp.39-58.
Lee H.S., et. al., 2009. Boundary element modeling of multidirectional random wave in a harbor with a rectangular navigation channel, Ocean Engineering, vol-36, pp. 1287-1294.
Lee, J. J., 1971, Wave induced oscillations in harbors of arbitrary shape, Rep. KH-R-21, 1969, W. M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Pasadena, California 16, J. Fluid Mech. 1971,45,375.
Mc Nown J.S., 1952. Waves and sciche in the idealized ports, in gravity waves a symposium: National Bur. Standards circ. 521, pp-153-164.
Mei C.C., 1989. Applied Dynamics of Ocean Surface Waves, World Scientific, Singapore.
Mei C. C., Agnon Y., 1989. Long period oscillations in a harbor induced by the incident short waves, J. Fluid mech. Vol. 208, pp. 595-613.
Mei C. C., Stiannie, M,Yue, D.K-P., 2005. Theory and applications of Ocean Surface waves, part-I, World Scientific, Singapore.
Miles, J., Munk W., 196 l, Harbor Paradox, Journal of the Waterways and Harbors Division, ASCE, Vol. 87, No.-WW 3, pp. 111- 130.
Paolo De Girolano, 1996. An experiment on harbour resonance induced by incident regular waves and irregular short waves, Coastal Engineering 27, pp.47-66.
Raichlen, F., and Ippen, A. T., 1965 a. Wave Induced Oscillations in Harbors, Journal of the Hydraulics Division, ASCE, Vol. 91, No. HY 2, pp. 1-26.