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# Control of Seiches by Adjustment of Entrance Channel Width
# 유입수로폭의 조정을 통한 항만부진동 제어

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**Abstract** □ Based on the facts that significant parts of the harbor response spectrum usually reside in the vicinity of the Helmholtz mode in the eastern part of Korea, economically feasible redemption measures of seiches for malfunctioned harbors already in service is proposed by extending the wisdom of perforated breakwaters and adjusting the width of entrance channel as a control tool. It turns out that as the entrance channel is getting narrower, the harbor system is getting slender due to the increase of added hydrodynamic length so that harbor response can be effectively diminished and separated from the incident wave spectrum where considerable amount of wave energy is located at the lower frequency range.

**Keywords :** seiches, Helmholtz mode, narrow-banded random waves, response spectra, natural frequency

**要　旨 :** 우리나라 항만의 응답스펙트럼중 상당부분을 설명하는 Helmholtz mode를 중심으로 기운영되고 있는 항만중 정온도 확보에 어려움을 겪고 있는 항만을 대상으로 입사된 파랑에너지의 항내체류시간의 최소화를 통해 경제적 항내정온도 개선책을 모색하고자 고유진동수 등 항만 시스템의 동적특성을 해석하였다. 이를 기초로 항내정온도 개선책으로 유공방파제 등에 부분적으로 도입되고 있는 에너지 소산 구조를 확대적용하는 방안과 항만유입수로 폭을 제어수단으로 활용하는 방안을 제안한다. 수치모의 결과 항만유입수로폭이 축소됨에 따라 부가 hydrodynamic length에 의해 항만의 고유진동수는 감소하고 따라서 lower bound tunning을 통해 내습하는 파랑의 spectrum의 energy containing part와 유리할 수 있음을 입증하였다.

**핵심용어 :** 부진동, 헬름홀츠 모드, 협대역 불규칙 파열, 응답 스펙트럼, 고유진동수

## 1. INTRODUCTION

State of art review about the harbor tranquillity problem casts an impression that oscillations free harbor system is just few steps away. The underlying structure of harbor resonance phenomenon is well known (Mei, 1989), but it was frequently reported that working condition within the harbor system in the eastern part of Korea is severely deteriorated during the considerable extension of the operating hour. It has been pointed out that this malfunction is partially due to ill alignment of wave breaker and the deployment of harbor system vulnerable to relatively long waves. Even at the harbor system where significant parts of the expected response spectrum was well separated from the incident wave spectrum at the design stage, there still exist some possibilities of response of resonance mode being excited due to the randomness which is the intrinsic property of gravity waves, and the effects of which is not clear yet on the harbor response. Hence, it is inevitable to introduce additional damping structure into the harbor system to retain sufficient tranquillity unless the possibilities of the occurrence of seiches be totally removed, which is physically implausible. Among many measures to enhance the energy dissipation process, the front runners are radically narrowing the entrance chan-

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nel with floating wave breaker, installation of submerged perforated wave breaker from the viewpoint of economical feasibility and workability. In 1975, Unluata and Mei pointed out that the entrance loss should be considered to remedy the harbor paradox problem and sequentially derived the boundary condition which should be imposed at the constriction site in the matched asymptotic expansions technique. With this condition, they investigated the effects of entrance loss on the response of rectangular harbor with a centered entrance and showed that reduction of resonant peaks by entrance loss is more pronounced for larger amplitudes, longer waves or lower resonant modes and narrower entrance. Harbor response to transient incident waves was also tackled by Mei (1989) by Fourier representation of the simple harmonic response satisfying the radiation boundary condition at infinity and the boundary condition at a constriction in the matched asymptotic expansions technique and it was shown that the response of the Helmholtz mode could be excited when the harbor system with comparable dimensions in both horizontal directions are exposed to the incident waves of broad-banded. Mei (1989) also pointed out that the apparent inertia term can be neglected for a case of longer waves, larger amplitudes and the harbor system with severely narrowed entrance channel based on the facts that with very likely separation around a restriction, added hydrodynamic length is subject to reduction so that the inertia term is relatively small. Under the situation that the tsunami of sufficiently long duration causes costly delays due to persistent oscillations within the harbor, dynamic characteristics of basin oscillations should be unveiled more thoroughly for the optimal operation of the harbor system. Furthermore, there are practical limits in narrowing harbor entrance in order to sustain the role of navigational channel. In this case, the apparent inertia term should be considered albeit small. Unlike Unluata and Mei (1975) and Mei (1989), it is the intent of this study to explore the redemption measures of oscillations within the harbor system by minimizing the resident time of intruded wave energy by enhancing the dissipation process. In this study, our attention is centered on oscillations in Helmholz mode only based on the facts that harbor response spectrum usually reaches its maxim at Helmholz mode in the eastern part of Korea (Jeong *et al.*, 1995).

## 2. REVIEW OF HARBOR OSCILLATION

The peak amplitude at resonance can be limited by radiation damping associated with energy escaped seaward from the harbor entrance and frictional loss near the harbor entrance. With matched asymptotic expansion technique based on the facts that various parts of the physical domain are governed by vastly different scales and a friction loss formula which is quadratic in the local velocity, Mei (1989) showed that first representing the net momentum flux through the harbor entrance in terms of loss coefficient $f$ and then utilizing the equivalent linearization technique, the reduction in the amplitude of the response $R$ due to the frictional loss at a constriction is given by

$$R = \left[ \frac{2}{1 + (1 + 16\gamma/(ka)^2)^{1/2}} \right] \tag{1}$$

where $r = 2fA/3\pi a$, $f = (r_c - 1)^2$, and $A$, $h$, $r_c$ and $2a$ are the amplitude of incident waves, water depth at a construction, the ratio of gross area of the channel to the one at Vena contracta and entrance width, respectively. In (1), the natural wave numbers of the closed basin $k$ are given by $k = [(m\pi/L)^2 + (n\pi/W)^2]^{1/2}$ where $L$ and $W$ are basin length and width, respectively. Considering that for usual breakwater dimension and wave periods, the Keulegan-Carpenter number (or equivalently the Strouhal number) $U_0T/D$, where $U_0$, $D$ and $T$ are the velocity amplitude, the body dimension and wave period, respectively, can be rather large and quadratic friction loss formula is valid only for high values of Keulegan-Carpenter number, relatively accurate information can be deduced from (1). It can be clearly seen from (1) that the reduction of resonant peaks by entrance loss is more pronounced for larger $f$, larger amplitude, longer waves or lower resonant modes and narrower entrance. With regard to the parameter $16\gamma/(ka)^2$, it should be pointed out that the loss coefficient f may depend on the Stouhal, Reynolds numbers and the geometry of the breakwater tips at the entrance and (1) is valid only for $16\gamma/(ka)^2 \leq O(1)$. Ito (1970) recommended $f$=1.5 for the Ofunato tsunami breakwater. For a harbor with comparable dimensions in both horizontal dimensions, the lowest resonance mode (Helmholtz mode) constitutes most part of response spectrum and in this case $16\gamma/(ka)^2 > O(1)$, violating the underlying assumption of (1).

## 3. EQUATION OF MOTION

The harbor response of the Helmholtz mode to the incident waves can be described by

$$\ddot{x} + 2\beta\omega_n \dot{x} + \omega_n^2 x = \omega_n^2 \zeta \qquad (2)$$

where for brevity, the argument $t$ in $x(t)$ and $\zeta$(t) is dropped and over dot denotes time derivative (Mei 1989; Lin 1967). In (2), $x$ and $\zeta$ are the water surface displacement at landward and offshore side of a constriction, respectively, and the natural frequency of a basin $\omega_n$ and damping coefficient $2\beta\omega_n$ are given by

$$\omega_n^2 = 2gha/SL_0 \qquad (3)$$

and

$$2\beta\omega_n = cf\,|U_0|/2L_0 \qquad (4)$$

respectively. In (3) and (4), $c$=8/3$\pi$, $L_0$ is the added hydrodynamic length and $S$ is surface area of the basin. For added hydrodynamic length, by the analogy of long waves of small amplitude to sound waves, analytical results known for several acoustic orifices may be applied. In 1968, Morse and Ingard showed $L_0/W \cong (1/\pi)$ ln 0.5(tan$2a\pi/4W$+cot$2a\pi/4W$). In the derivation of (2), the principles of mass and momentum conservation, quadratic friction loss formula and equivalent linearization technique are used. Following the Mei's proposal that $U_0$ can be approximated by Torricelli's law $|U_0| \cong (gA/fah)^{1/2}$ for a case of $16\gamma/(ka)^2 > O(1)$, the damping coefficient in (2) is reduced to $2\beta\omega_n$=0.5c$(fgA/ah)^{1/2}/L_0$. Following the standard technique in the stochastic analysis to explain the intrinsic randomness in incident waves (Ochi, 1992), the impulse response function $h(t)$ is given by

$$h(t) = \frac{1}{\omega_n\sqrt{1-\beta^2}}\sin(\omega_n\sqrt{1-\beta^2}t)\,e^{-\beta\omega_n t} \qquad (5)$$

whereas the frequency response function $H(\omega)$, response spectral density function $Sxx(\omega)$ and $x$ are given by, respectively,

$$H(\omega) = \int_{-\infty}^{\infty} h(\tau)e^{-i\omega\tau}d\tau$$
$$S_{xx}(\omega) = |H(\omega)|^2 S_{\zeta\zeta}(\omega) \qquad (6)$$
$$x(t) = \int_0^t \zeta(\tau)h(t-\tau)d\tau$$

where $S_{\zeta\zeta}(\omega)$ is the incident wave spectral density function. From (6), $H(\omega)$ is given by (Lin, 1967)

$$H(\omega) = 1/(\omega_n^2 - \omega^2 + i2\beta\omega_n\omega) \qquad (7)$$

## 4. VERIFICATION

To verify (2) be a suitable model for the analysis of seich dynamic characteristics within the harbor system, numerical computations of wave patterns using the finite elements method through Galerkin weak formulation with 3503 nodal points and 5824 triangle elements was implemented over the domain depicted in the definition sketch, Fig. 1. The depth throughout the computation domain was assumed to be constant (10 m) by periodic dredging, and hence the pertinent wave

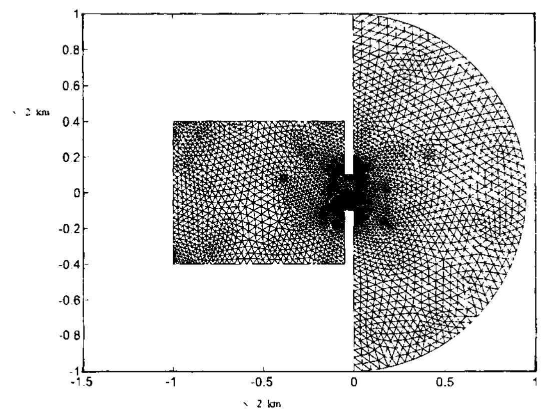


**Fig. 1.** Definition stetch.

model for this problem, time harmonic mild slope equation, should be reduced to Helmholz equation given in (8).

$$\nabla^2 x + k^2 x = 0 \tag{8}$$

First order absorbing boundary condition given in Eq. (9) was imposed along the perforated breakwaters based on the assumption that the adopted perforated breakwaters effectively dissipate the incident wave energy (Beak *et al.*, 1991)

$$\partial x/\partial n - ik\,(1-r)x = 0 \tag{9}$$

where $i$ is the imaginary unit, n denotes the outward normal direction and $r$ is the complex reflection coefficient. The boundary within an inner harbor was assumed to consist of perfectly reflective vertical walls for brevity and along the open boundary, a radiation boundary conditions for scattered waves was imposed. In Figs. 8, 9 and 10, wave patterns within the computational domain was plotted when the waves of $k$=0.00037, 0.00039 and 0.00041 were normally attacking from the deep water (a value of L=1900 m, W=1600 m and 2a=200m being used). It can be clearly seen that for this case, the harbor response is of the Helmholtz mode and the fundamental mode of this system is around $k$=0.00039 the corresponding frequency of which are somewhat deviated from (3). However, this discrepancy is partially caused by the unexplained entrance loss in (8) and apparent inertia term reflected in (2) so that the predictive capability of (2) can be acceptable.

## 5. NUMERICAL RESULTS

To quantify the above results, we must specify added hydrodynamic length, the spectrum from which the quantity $\beta$ may be calculated. In this study, we shall use a transient wave packet with a carrier frequency $\omega_0$ and a slowly varying Gaussian envelope so that $\zeta$ in (2) is $\zeta = A\exp[-\Omega^2 t^2]\cos\omega_0 t$ and amplitude spectrum takes the form

$$S_{\zeta\zeta(\omega)} = \frac{A}{8\Omega\sqrt{\pi}}\left[\exp[-(\frac{\omega-\omega_0}{2\Omega})^2] + \exp[-(\frac{\omega+\omega_0}{2\Omega})^2]\right]$$

where $\omega_0/\Omega \gg 1$ which implies that the important part of the spectrum is narrow. The impulse response function in (5) and frequency response function in (7) is plotted in Fig. 4 and Fig. 5, respectively, for varying entrance width (2a=600 m, 400 m). Here, it is obvious that as the harbor entrance is getting narrower, the amplitude of impulse response function is getting diminished and

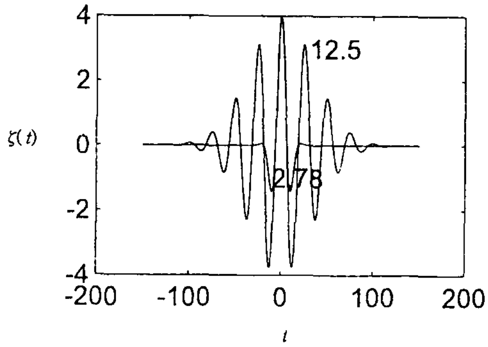


**Fig. 2.** An incident wave packet.

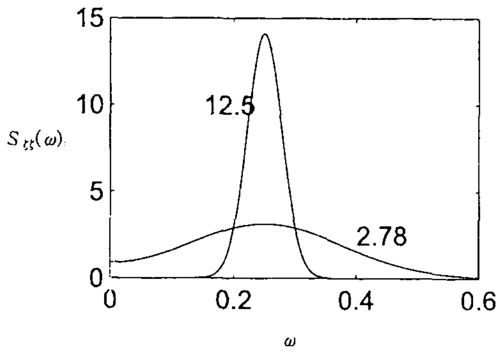


**Fig. 3.** Incident wave spectra.

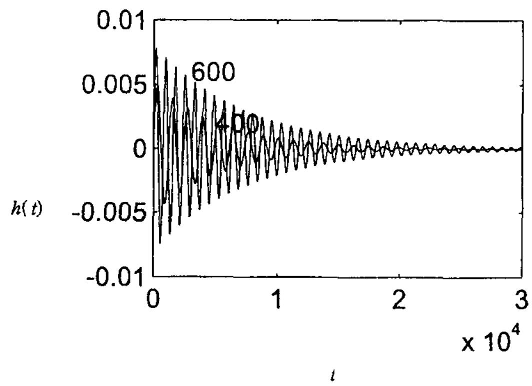


**Fig. 4.** Impulse response function for varying entrance width.

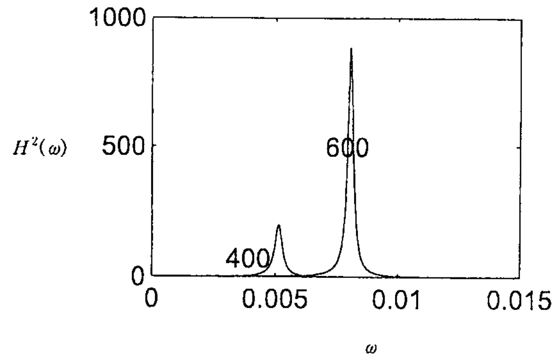


**Fig. 5.** Frequency response function for varying entrance width.

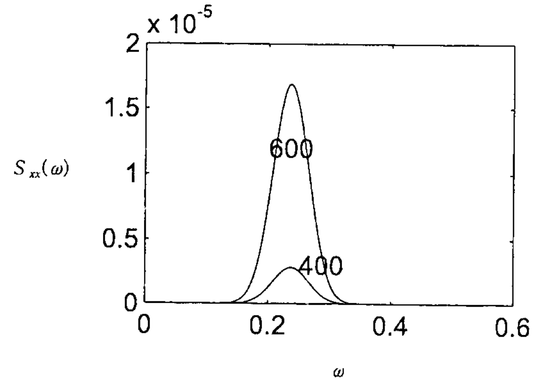


**Fig. 6.** Response spectra for varying entrance width ($\omega_0/\Omega$ =12.5).

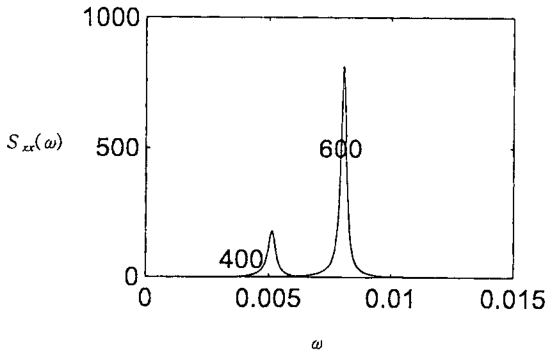


**Fig. 7.** Response spectra for varying entrance width ($\omega_0/\Omega$ =2.78).

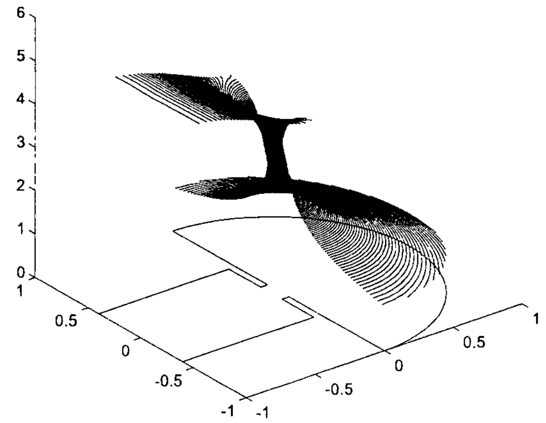


**Fig. 8.** Wave height within the inner harbor for the incident wave of $k$=0.00037.

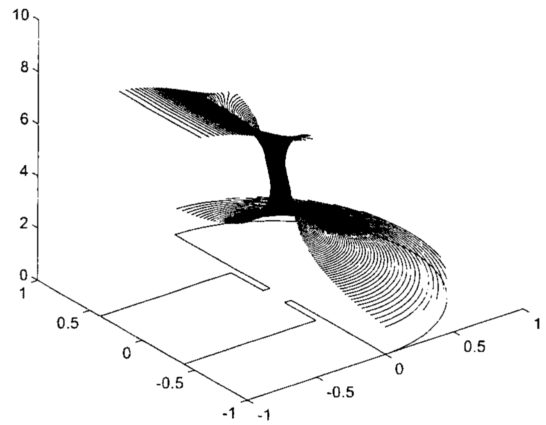


**Fig. 9.** Wave height within the inner harbor for the incident wave of $k$=0.00039.

the area under frequency response function also shrinks with the peak frequency where the maxima in frequency response function is occurring being shifted toward the lower frequency range. It is due to the facts that with narrower entrance, harbor system is getting slender in spite of the increase in added hydrodynamic length for both small and large gaps and the energy loss at the entrance is severely enhanced. Hence, the possibilities of oscillations in resonance mode is negligible so that the harbor with a narrower entrance can be a effective shelter against the wind waves whose typical energy containing frequency range is much higher than the peak frequency. In Fig. 2 and Fig. 3, an incident wave packet and the spectrum of a transient wave packet with $\omega_0/\Omega$=12.5 and 2.78 is plotted, respectively, and corresponding response spectra for 2a=600 and 400 m are plotted in Fig. 6 and Fig. 7. It is shown that with relatively narrower entrance, the frequency spectrum rather rapidly shrinks in a case of $\omega_0/\Omega$=12.5 which can be regarded as narrow banded whereas for finite banded case ($\omega_0/\Omega$=2.78), the response spectra cannot be negligible even in the narrowest case. These

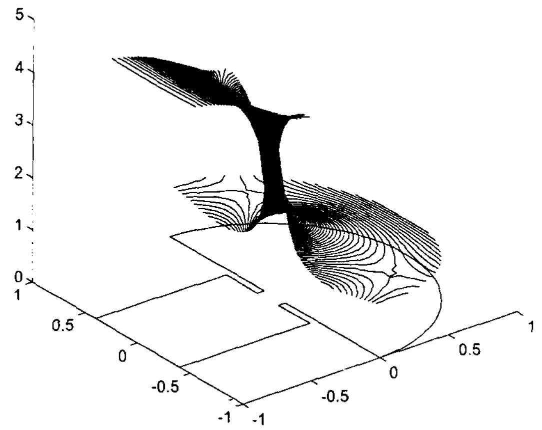


**Fig. 10.** Wave height within the inner harbor for the incident wave of $k$=0.00041.

facts are consistent with our intuition because harbor with narrower entrance is very vulnerable to a relatively long pulse due to its high transmissivity.

## 6. CONCLUSIONS

Although much progress has been made quite recently in the numerical analysis of harbor tranquillity problem, our understanding of this complicated phenomenon seems like to often fall short of the complete. Hence, some harbors have frequently failed in providing a safe shelter for vessels during storm conditions and tsunami attack. Furthermore, the complete suppression of harbor oscillations for the safe anchorage of vessels is very difficult and expensive goal to achieve since harbor is usually exposed to the waves the spectra of which is quite broad banded and ship motions are quite sensitive to wave frequency. In this study, dynamic characteristics of harbor response were investigated to develop some economic auxiliary measures for improving harbor tranquillity within the port already in service which was frequently malfunctioned due to the unexplained randomness at the design stage by extending the wisdom of perforated breakwater and sequentially natural wave frequency and damping coefficient models were derived and verified for the hypothetical harbor system. It was shown that harbor with rather narrower entrance could be a effective shelter against a wave packet where the important part of the spectrum is narrow banded due to enhanced energy dissipation around the entrance and shortened natural frequency of harbor system. Furthermore, it turns out that harbor oscillations excited by the long pulse close to the natural frequency can also be controlled by narrowing the harbor entrance.

## REFERENCES

Beak, U.I., Abbott, M.B. and Dingemans, M.W., 1991. Higher order absorbing boundary conditions for time harmonic mild-slope models, M.Sc. Thesis, International Institute for Hydraulic and Environmental Engineering, Delft, Netherlands.

Ito, Y., 1970. Head loss at tsunami breakwater opening. *Proc. 12th Int. Conf. Coastal Eng.*, ASCE, pp. 2123-2131.

Jeong, W.M., Jung, K.T. and Chae, J.W., 1995. Resonant oscillations in Mukho harbor. *J. Korean Soc. of Coastal and Ocean Engrs.*, **7**(1), pp. 46-56 (in Korean).

Lin, Y.K., 1967. *Probabilistic theory of structural dynamics*. McGraw-Hill, New York, NY.

Mei, C.C., 1989. *The applied dynamics of ocean surface waves*. World Scientific, Singapore.

Morse, P.M. and Ingard, K.U., 1968. *Theoretical acoustics*. McGraw-Hill, New York, NY.

Ochi, M.K., 1992. *Applied probability and stochastic processes in engineering and physical sciences*. John Wiley & Sons, New York, NY.

Papoulis, A., 1965. *Probability, random variables and stochastic processes*. McGraw-Hill, New York, NY.

Unluata, U. and Mei, C.C., 1975. Effects of entrance loss in harbor oscillations. *J. Waterways, Harbors and Coastal Eng. Div.*, ASCE, **101**, pp. 161-180.