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Calmness Analysis of Jeju Harbor by Finite Element Technique

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ABSTRACT : *본 연구에서는 입사파에 의한 항내 정온도 계산 시 사용되는 수치해석 기법에 대한 검증 및 실제 항만에 대한 적용을 하였다. 해석기법은 유한요소기법 (finite element technique)을 사용하였고 기본방정식은 경계조건과 마찰을 고려한 완경사방정식 (mild-slope equation)을 사용하였다. 해석의 검증을 위하여 임의형상 항만에 대해 본 해석법을 적용하여 수치해석을 실시한 결과와 다른 수치해석결과 및 실험결과를 비교 했을 때 좋은 일치를 나타내었다. 제주항에 대해서 2가지의 각기 다른 입사파 조건을 적용하여 계산한 결과 제주항의 방파제 설계파인 NNW방향 (Case 2)인 경우가 NE방향 (Case 1)인 경우보다 약간 양호한 정온을 확보하는 것을 알 수 있었다.*

1. Introduction

The most important functions of ports and harbors are that they are used to transport cargo and passengers safely and rapidly and offer safe anchorage for ships. In order to fulfill these functions sufficiently, harbors must be kept calm, regardless of various incident waves. A number of numerical analysis and experimental studies, aimed at promoting calm harbors, have been carried out, such as the numerical analysis by Kashiyama (1993) and Sato et al. (1988) and experimental studies by Saito et al. (1993). This calmness research can be usefully applied at the stage of planning and designing of harbors. However, if the configuration of the boundary and water depth is complicated, the calmness problem must be solved using a numerical method. Furthermore, it is difficult to prepare an appropriate mesh in accordance with the variation of water depth. Kim et al. (2000) have developed an automatic mesh generation method in which the finite element mesh data can be generated so that the element length is matched up to the wavelength, according to the depth in the whole domain. In this study, the finite element method is applied to the mild- slope equation, which is applicable to a wide range of wave frequencies. The numerical tests, for which experimental results exist are performed. Finally, the finite element method is applied to the actual harbor calmness analysis of Jeju Harbor, Korea.

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2. Basic Equations and Boundary Conditions

The fluid is assumed to be incompressible and inviscid, and the flow is irrotational. As shown in Fig. 1, considering the effect on variable depth, the basic equations for the analysis of harbor oscillation for shallow water should use the mild-slope equation (Berkhoff, 1972; Chen, 1986).

$$\frac{\partial}{\partial x}\lambda c c_g \frac{\partial \phi}{\partial x} + \frac{\partial}{\partial y}\lambda c c_g \frac{\partial \phi}{\partial y} + \frac{\omega^2 c_g}{c}\phi = 0 \quad in\ \Omega_i \tag{1}$$

$$\lambda = \frac{1}{1 + \frac{i\beta a_0}{h \sinh kh} e^{i\gamma}} \tag{2}$$

where h is the depth, ϕ is the velocity potential, ω is the angular frequency, g is the gravitational acceleration, Ω is

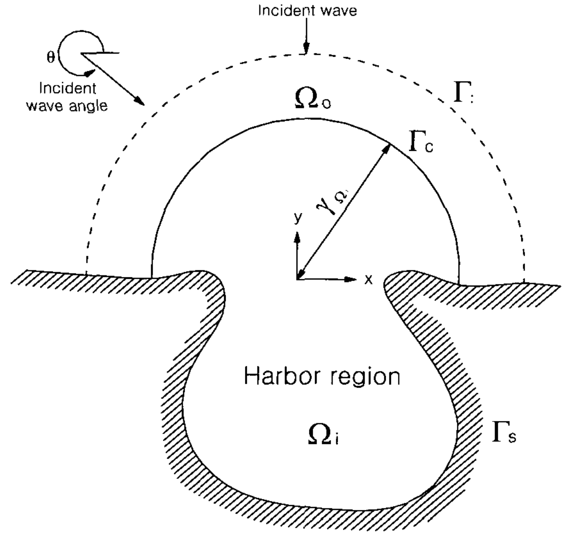

Fig. 1 Definition sketch

the field region, β is the bottom friction coefficient, a_0 is the incident wave amplitude, k is the wave number, i is $\sqrt{-1}$, and γ is the phase difference.

Along the solid wall, Γ_s, we adopt the absorbing boundary condition similar to the impedance condition used in acoustics and express in terms of the reflection coefficient of the boundary, K_r.

$$\frac{\partial\phi}{\partial n} - a\phi = 0 \qquad on \quad \Gamma_S \tag{3}$$

where, n is the unit normal vector outward from the water region, $a = ik\frac{1-K_r}{1+K_r}$. The matching boundary condition on the interface, Γ_C, can be expressed as follows:

$$\left(\lambda h\frac{\partial\phi}{\partial n}\right)_{\Omega_i} = \left(\lambda h\frac{\partial\phi}{\partial n}\right)_{\Omega_o}, \quad \phi_{\Omega_i} = \phi_{\Omega_o} \ on \ \Gamma_C \tag{4}$$

The boundary condition in outward region Γ_∞ is imposed to the radiation condition, and the equation can be expressed as follows:

$$\lim_{r \to \infty}\sqrt{r}\left(\frac{\partial}{\partial r} - ik\right)(\phi - \phi_0) = 0 \quad on \quad \Gamma_\infty \tag{5}$$

where (r, θ) are polar coordinates.

ϕ_0 is the velocity potential of the incident wave, and can be expressed as follows:

$$\begin{aligned}\phi_0 = &-\frac{iga_o}{w}\{\exp[ikr\cos(\theta - \theta_o)] \\ &+ K_r\exp[ikr\cos(\theta + \theta_o)]\}\end{aligned} \tag{6}$$

where θ_o is the incident wave angle.

From the basic equation (1), considering boundary condition (3), (4) and (5), the calmness simulation of the harbor can be performed.

3. Numerical Results and Discussions

3.1 Verification analysis for calmness of finite element models

The present method is applied to the harbor calmness analysis of the arbitrary shape harbor with a constant water depth.

In order to check the validity for the arbitrary shape harbor, we use the same dimensions of an arbitrary shape harbor as the ones used by Sato et al. (1988), Saito et al. (1993) and Kashiyama (1993).

The expected value of the reflection coefficient on the wave dissipating structure is assumed to be 0.4, and on the perpendicular structure, it is assumed to be 0.9. For the numerical condition, the incident wave height is assumed to be 1.0m; the wave period is assumed to be 10sec, and the water depth is assumed to be a constant of 7m.

Fig. 2 shows the finite element idealization mesh, based on the linear triangle. The total numbers of finite elements and nodes are 70,791, and 35,967, respectively.

The distance from the tip of the breakwater to the open boundary is about 75m, which, in this case, is nearly equal to an incident wave length (=78.92m). The element size is assumed to be a constant of 4m, which is the appropriate element size, since the ratio of wavelength and element size is about 20. Fig. 3 shows the comparison of the numerical result for harbor calmness; the incident wave angle is 270°; the wave height is 1m; and the wave period is 10sec, with the numerical results by Sato et al. (1988) and Kashiyama (1993), and experimental results by Saito et al. (1993).

In this figure, the ordinate is the amplification ratio, and the abscissa is the length of the harbor. As shown in Fig. 3, the comparison section is four, which is Line-1 and Line-2 at the vertical direction, and Line-3 and Line-4 at the horizontal direction.

For the vertical section of Line-1 and Line-2, the numerical results show good agreement with respect to the loop and node excepting the experimental results by Saito et al. (1993), and show slightly higher than wave height between the main breakwater and the sub-breakwater.

The numerical results for the horizontal section of Line-3 and Line-4 show good agreement with respect to the loop and node.

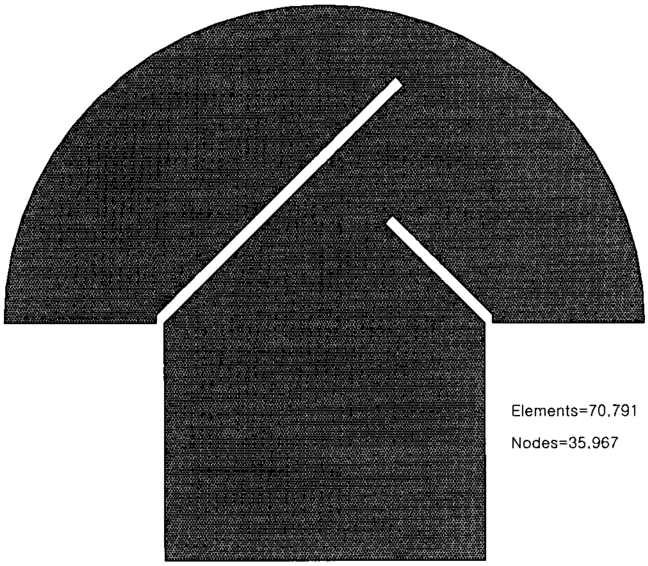

Fig. 2 Finite element mesh for arbitrary shape harbor

3.2 Calmness analysis of Jeju Harbor

Juju Harbor is the gateway to Jeju, and located on the north end of Jeju Island. It has a yearly cargo capacity of 2,135,000ton, a simultaneous berth capacity of 24vessels, and the maximum berth capacity is 20,000ton. Juju Harbor is a projection harbor, with a length of 1.5km from east to west, a width of 1.8km from south to north, and a depth of 2~11m. The breakwater is located on the boundary with the open sea. Its length is 2,960m, and the harbor area is 790,00m^2. In order to estimate the amplification condition of Jeju Harbor calmness, Fig. 4 shows the finite element idealization mesh obtained by the present automatic mesh generation. The total number of finite elements and nodal points are 48,890 and 25,072, respectively.

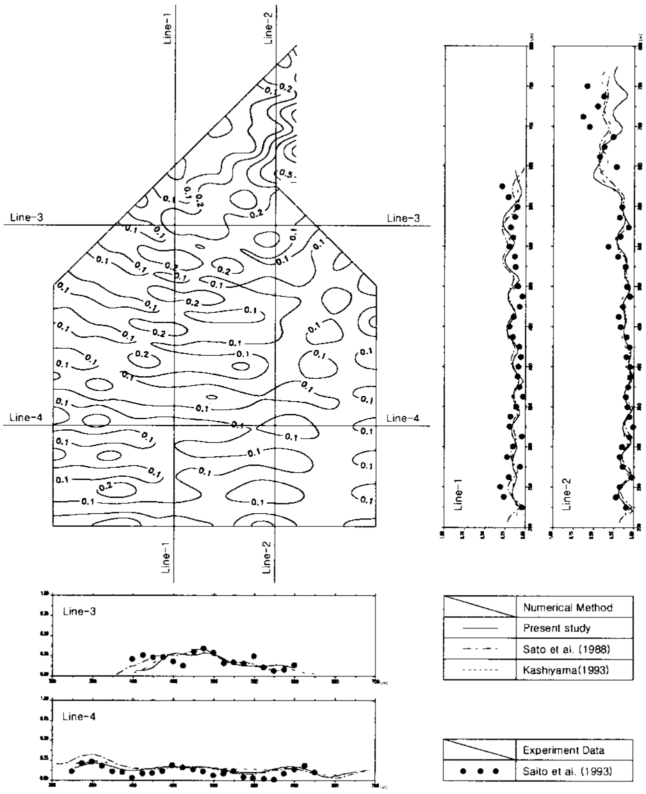

Fig. 3 Comparison of relative wave height distribution in arbitrary shape harbor

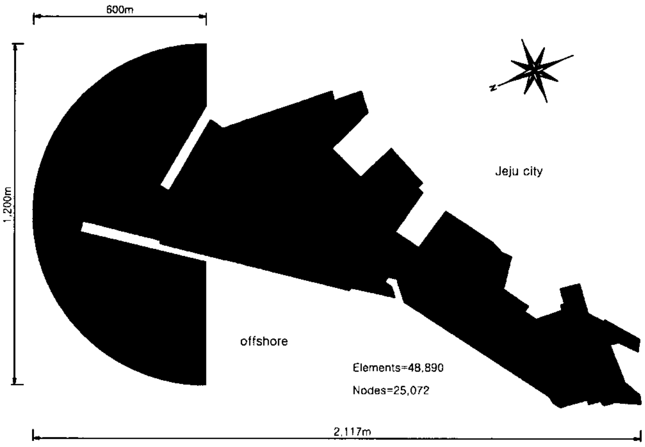

Fig. 4 Finite element mesh diagram of Jeju Harbor

Because the water depth of Jeju Harbor is about 2~13m, element sizes are generated differently. It also satisfies the proposition that the ratio of the wavelength to the element size is greater than 10.

Fig. 5 shows the topographical map of Jeju Harbor. As shown in Table 1, numerical computations are carried out two cases. The reflection coefficient on the wave dissipating structure is assumed to be 0.4~0.6 ; on the perpendicular structure, it is assumed to be 0.9.

Because the numerical result is not affected much by the friction coefficient, the friction coefficient of the bottom is 0. Fig. 6 shows the computed relative wave height distribution, using the finite element mesh shown in Fig. 4.

Table 2 shows the computed relative wave height in the vicinity of each pier of Jeju Harbor.

The computed relative wave height of Jeju Harbor is shown relatively high at pier 4, pier 5 and pier 6, and relatively low at pier 1, pier 2 and pier 3, compared with that of the Ministry of Maritime Affairs & Fisheries, Korea (1999).

Also, case 2 is ensured the calm more then case 1. Fig. 7 shows the computed wave height distribution of Jeju Harbor, using a three dimensional graphic technique.

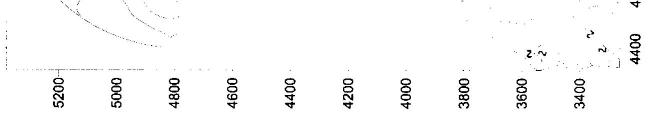

Fig. 5 Water depth diagram of Jeju Harbor

Table 1 Incident wave condition(Cheong et al.(2000))

Cases	Wave height (m)	Period (sec)	Direction
1	4.7	9.0	NE
2	7.0	11.0	NNW

Table 2 Computed relative wave height(unit: m)

Cases	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5	Pier 6
1	0.3	0.3	0.7	2.5	1.5	1.5
2	0.2	0.2	0.7	1.7	1.7	1.0

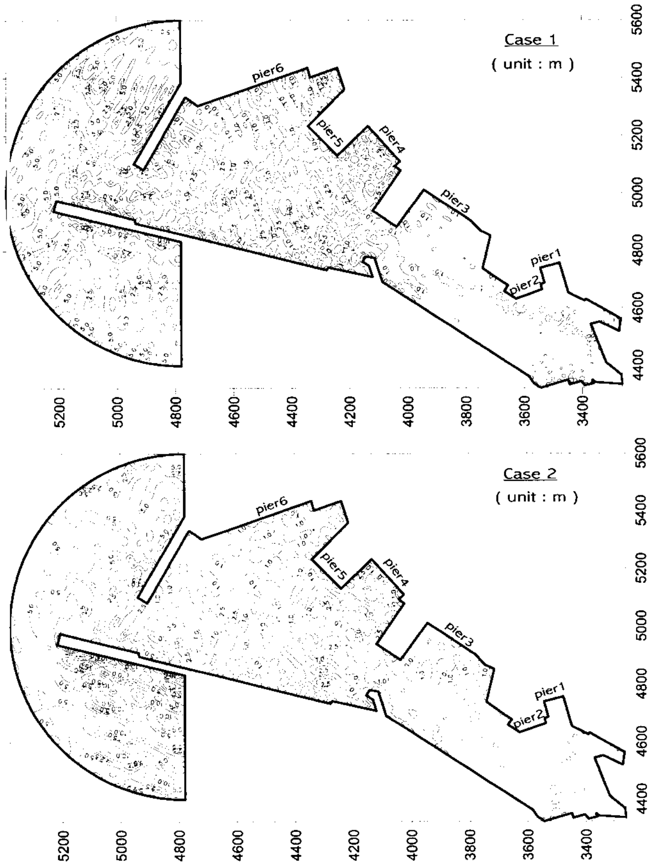

Fig. 6 Computed relative wave height of Jeju Harbor

4. Conclusions and Remarks

In this study, the mild-slope equation as a basic equation to calculate the harbor calmness is used, which is the numerical analysis model in consideration of the bottom friction reduction. The calmness analysis for the arbitrary shape harbor is in very good agreement with the numerical result by Sato et al. (1988) and Kashiyama (1993), and the experimental result by Saito et al. (1993). The calmness analysis of Jeju Harbor, in two cases, is computed, and as a result, the relative wave height distribution of Jeju Harbor is known and compared with that of the Ministry of Maritime Affairs and Fisheries, Korea (1999). This numerical computation method in the calmness analysis of the harbor and port will be used broadly.

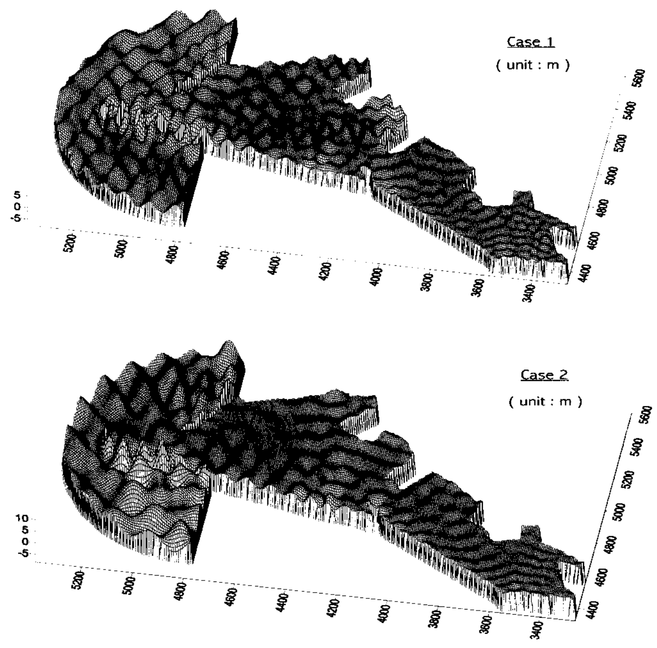

Fig. 7 The three dimensional wave profiles of Jeju Harbor

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