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Marine Environmental Change Due to Waterfront Development

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A two-dimensional numerical experiment and field observations were conducted to evaluate changes in sea water movement and the water quality environment related to comprehensive projects of waterfront development around Kwangyang Bay on the south coast of Korea. Tidal flow velocities, especially in the western part of the bay, were considerably slower as a result of the development projects. Accordingly, the seawater exchange ratio reduced from 38.7% to 26.3%. The impact of dredging work on the water quality environment was much stronger than expected. Furthermore, after the completion of the industrial parks and container-exclusive wharfs, COD from the waste water treatment plant will be dispersed extensively into the adjacent water at a level of less than 0.1 mg/l for up to 142.5 km^2. Therefore, consistent monitoring and management of the water quality environment is strongly recommended.

Key words : a two-dimensional numerical experiment, seawater movement, water quality environment, waterfront development, seawater exchange ratio

1. Introduction

As a result of recent economic development, a variety of coastal reclamation projects have been undertaken to create new industrial parks located in inner bays that are protected against wave action. Most inner bays, however, have an important function as a habitat of marine organisms, accordingly, it is important to take measures to minimize the impact of coastal zone development on this biological environment. Furthermore, the variations in topography and coastline induced by dredging and reclamation work inevitably affect the seawater behavior and water quality that originally existed in these coastal areas.

Kwangyang Bay is a shallow water region with an average depth of less than 10 m and a surface area of 200 km^2. The bay is also connected to the open sea through two channels towards the east and south. In addition, 7.0×10^8 m^3 of fresh water flows into the bay every year through two rivers at the north. POSCO(the leading steel manufacturer in the world) is located in the vicinity of this bay along with many other chemical companies. Dredging and reclamation work is still going on, plus large scale container-exclusive wharfs, automobile industrial parks, and electric power plants are also scheduled for construction.

Throughout 1995, which was prior to the beginning of the construction work, field observations on the bay's currents, water quality, and sediment were made to establish an existing or original standard. Based on this data, a two-dimensional numerical model could be set up to determine changes in the sea water behavior and water quality in the bay.

2. Outline of Numerical Models

2.1. Hydrodynamic Model

The numerical model used to reproduce the water level and tidal currents was DIVAST(Depth Integrated Velocity And Solute Transport), originally developed by Falconer[1] and the fundamental equations are expressed as follows:

$$\frac{\partial \eta}{\partial t}+\frac{\partial UH}{\partial x}+\frac{\partial VH}{\partial y}=0 \quad (1)$$

$$\frac{\partial UH}{\partial t}+\frac{\partial}{\partial x}\left(\beta U^2 H\right)+\frac{\partial}{\partial y}\left(\beta UVH\right)-fVH+gH\frac{\partial \eta}{\partial x}-\frac{\gamma \rho_a W_x W_s}{\rho}+\frac{gU\sqrt{U^2+V^2}}{C^2}-\varepsilon H\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right)=0 \quad (2)$$

$$\frac{\partial VH}{\partial t}+\frac{\partial}{\partial x}\left(\beta UVH\right)+\frac{\partial}{\partial y}\left(\beta V^2 H\right)+fUH+gH\frac{\partial \eta}{\partial y}-\frac{\gamma \rho_a W_y W_s}{\rho}+\frac{gV\sqrt{U^2+V^2}}{C^2}-\varepsilon H\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}\right)=0 \quad (3)$$

Where, η is the displacement of the water level, t is time, x and y are horizontal coordinates, U and V are depth mean velocities in x and y directions, H is the total depth, β is the momentum correction coefficient, g is gravity, f is the Coriolis parameter, ρ is the density of the seawater, ρ_a is the density of the air, γ is the drag coefficient due to wind on the sea surface, W_x and W_y are wind speeds in x and y directions, W_s is the wind speed, C is the *Chezy* coefficient, and ε is the depth mean eddy viscosity.

The ADI method was introduced as a numerical technique and a spatially staggered grid scheme was also adopted.

2.2. Random Walk Model

$\vec{X}(t+\Delta t)$, a new particle position at time $(t+\Delta t)$ placed in a flow field, is determined by the velocity vector $\vec{U}$ and dispersion velocity component $\vec{u}$ as follows:

$$\vec{X}(t+\Delta t)=\vec{X}(t)+\vec{U}\Delta t+\vec{u}\Delta t \quad (4)$$

In a probability process in terms of equation (4), $C(x,y,t)$, the probability distribution with time and space for each particle group, satisfies the following Fokker-Plank equation.[2]

$$\frac{\partial C}{\partial t}+\frac{\partial}{\partial x}(UC)+\frac{\partial}{\partial y}(VC)=\frac{\partial^2}{\partial x^2}(D_{xx}C)+\frac{\partial^2}{\partial x \partial y}(D_{xy}C)+\frac{\partial^2}{\partial y^2}(D_{yy}C) \quad (5)$$

$$U=u+\frac{\partial D_{xx}}{\partial x}+\frac{\partial D_{xy}}{\partial y}+\frac{D_{xx}}{h}\frac{\partial h}{\partial x}+\frac{D_{xy}}{h}\frac{\partial h}{\partial y} \quad (6)$$

$$=v+\frac{\partial D_{yy}}{\partial y}+\frac{\partial D_{xy}}{\partial x}+\frac{D_{yy}}{h}\frac{\partial h}{\partial y}+\frac{D_{xy}}{h}\frac{\partial h}{\partial x} \quad (7)$$

Where $D_{xx}=D_L\cos^2\theta+D_r\sin^2\theta$, $D_{xy}=(D_L-D_T)\sin\theta\cos\theta$, $D_{yy}=D_L\sin^2\theta+D_T\cos^2\theta$, $\theta=\tan^{-1}(v/u)$, h is a depth, D_L and D_T are the longitudinal dispersion coefficient and lateral diffusivity, respectively.

In contrast, the concentration decay of material due to various causes is expressed by particle removal with the occurrence of random numbers. The details on this procedure have been reported by Lee and Kim.[3]

3. Results and Discussion

3.1. Changes of sea water behavior

Fig. 1 roughly outlines Kwangyang Bay with two main channels towards the open sea at the south and east with approximately 120 m^3/s of fresh water flowing into the bay from the north. The dotted line denotes the scheduled reclamation areas for industrial parks, dredging soil dumping area, and container-exclusive wharfs. Fig. 2 illustrates a reproduction of the computed observation results, although the computed values tended to indicate a slightly more restricted dispersion of the flow direction than the observed results.

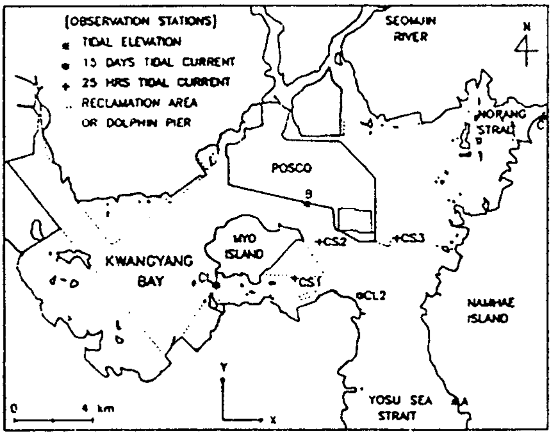

Fig. 1. Sketch of Kwangyang Bay along with the development projects.

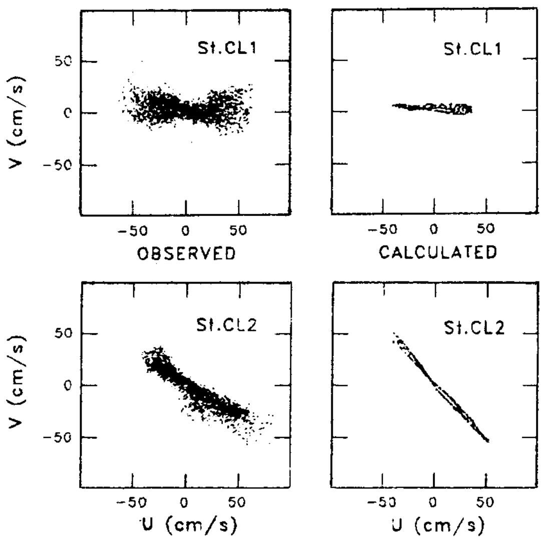

Fig. 2. Comparison of currents between the observed and computed ones.

In contrast, Figs. 3(a) and 3(b) show the computed tidal current ellipses in the spring tide. When compared to the original situation, the construction tidal flow velocities were all significantly weakened especially in the western part of Myo Island except for a slight increase in flow velocity of 2~3 cm/s around Noryang Strait. In addition, the water level was higher at the low water and yet lower at the high tide as a result of the dredging and reclamation works.

3.2. Changes of sea water exchange ratio

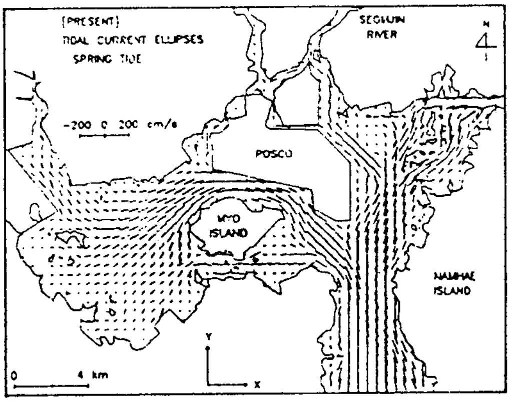

Fig. 3(a). Tidal current ellipses at the present situation.

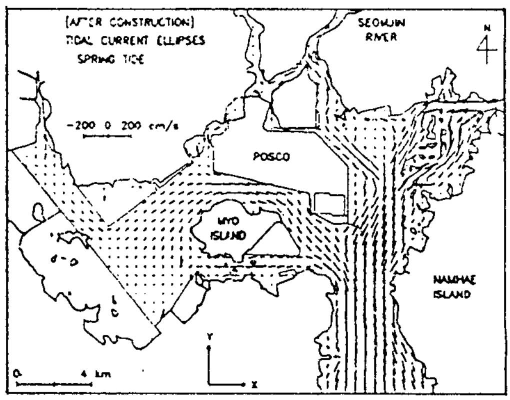

Fig. 3(b). Tidal current ellipses after the development.

If a particle of seawater is assumed to return to its original position after a tidal period, no sea water exchange will occur. However, in reality, nonlinearity and topographic factors produce a net mass transport. Therefore, a seawater exchange ratio can be evaluated by putting a number of particle tracers into a flow field already obtained by numerical computation and pursuing their tracks. The previously described random walk model can be used to pursue these particles, and in this case the sea water exchange ratio E_v is defined by the following equation:

$$E_v = \frac{V_{RES}}{V_{MAX}} \quad (8)$$

Where, V_{MAX} is the maximum volume of the inner sea water transferred to the outer sea, and V_{RES} is the volume of the inner sea water remaining in the outer sea after a tidal period. By setting the neighboring areas of St. CL2 as the boundary of the bay, as shown in Fig.1, the computed seawater exchange ratios for the two cases, i.e., before and after development can be obtained, as shown in Fig. 4. Comparing the results, the seawater exchange ratios were 38.7% and 26.3% before and after development, respectively.

This means that the sea water exchange ratio

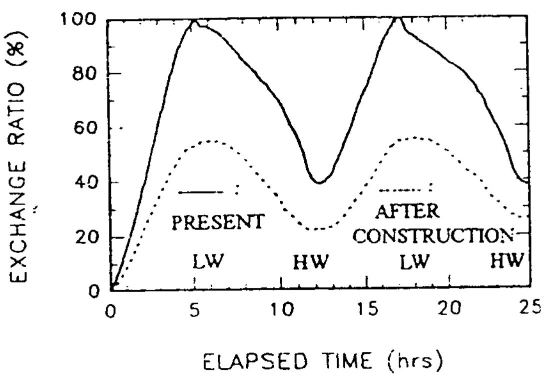

Fig. 4. The seawater exchange ratio at the present situation and after the development.

decreased by a difference of 12.4% after development. This is probably the result of the decrease in the tidal exchange currents of up to 40% due to the large reduction in the sea surface area.

3.3. Changes of water quality environment

As previously mentioned, Kwangyang Bay is open to the south so that waves can come into the bay. However, most of the waves are refracted around the coastlines of Yosu harbor and Namhae Island before approaching the entrance, as shown

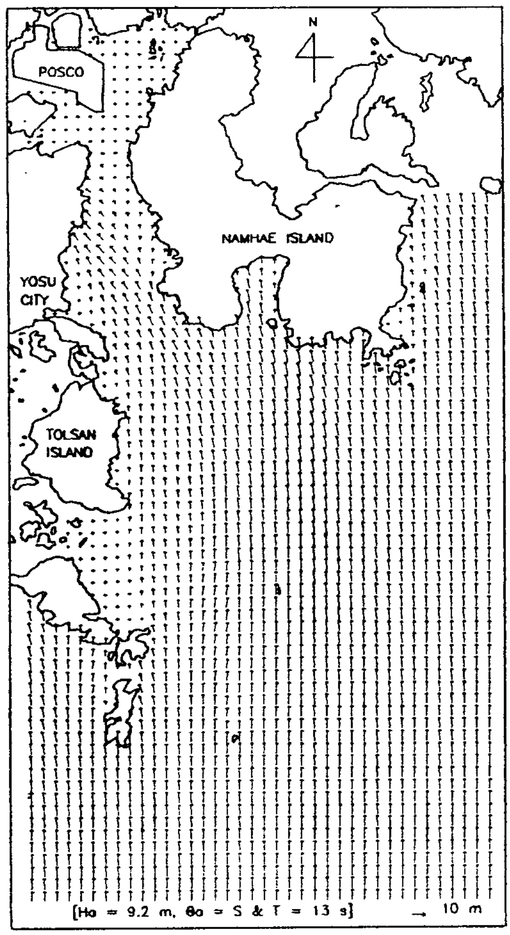

Fig. 5. Incident deep water waves toward Kwangyang Bay.

in Fig. 5, where H_θ, θ_0 and T denote wave height, direction, and the period of a fifty year -frequency design wave, respectively. Therefore, the wave energies were negligible in the bay.

For the coastal zone development, dredging and reclamation works has been scheduled in the region as shown in Fig. 1. Figs. 6(a) and 6(b) illustrate the typical features of particles released from a source of shore protection works at the flood flow and the maximum increase in SS concentration described in terms of a random walk model, respectively. This study only considered the decay of SS concentrations, although deposition, floating, and cohesion processes are also influential in solving SS dispersion problems.[3)]

Most of the increased SS concentrations resulted from the dredging work, therefore, the dispersion boundary of SS was pretty large compared with other developments.[5,6)]

In contrast, when the waterfront facilities are completed, a waste water treatment plant is supposed to be in operation. In this case, the amount of waste water and level of COD to be discharged will be 70,000 m^3 and 40 mg/l, respectively.[5,6)] For convenience, the decay of COD concentrations was not considered because the plankton and organic matter budgets are still unclear. The longitudinal and lateral dispersion coefficients D_L and D_T were given as $5.93hu_*$ and $1.5hu_*$, similarly to Elder[7)], respectively, where h is the depth at any point and u_* is the shear velocity. Using the same random walk model as for SS dispersion, the estimated results for the distribution of COD concentrations in the flood flow and the maximum range increase after discharge from the plant are shown in Fig. 7(a) and 7(b). Although there is no area where the COD level increases by more than 10 mg/l, an increase of less than 0.1 mg/l extends up to 142.85 km^2. Even the increase in the COD level is low, it still continuously affects the adjacent water as a pollutant load.

4. Conclusion

A numerical experiment was performed to assess the impact of waterfront development projects on

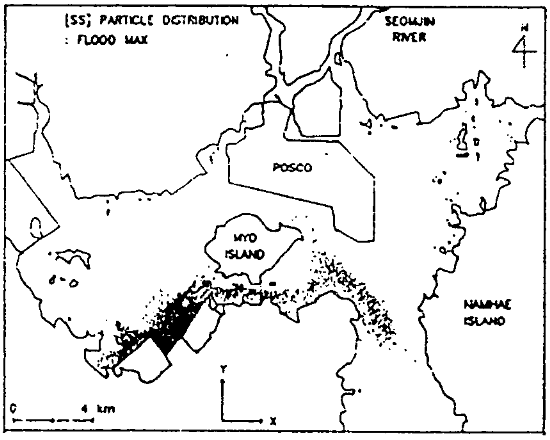

Fig. 6(a). Particle tracks of suspended solids at the flood flow.

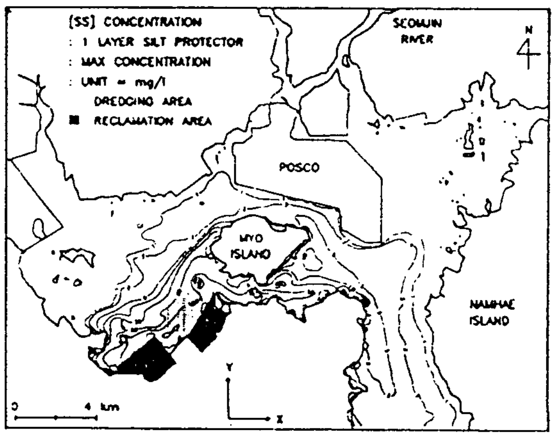

Fig. 6(b). The maximum increase range in suspended solids concentration.

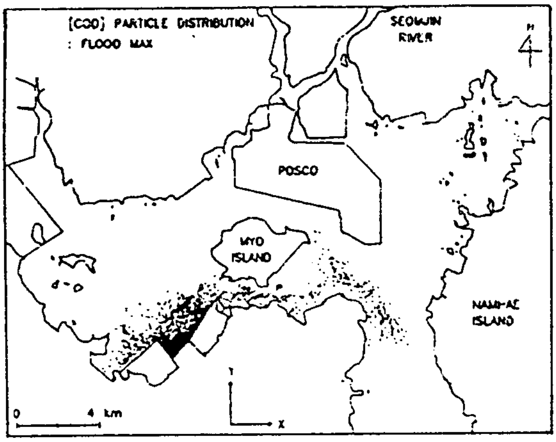

Fig. 7(a). Distributions of COD particle at the flood flow.

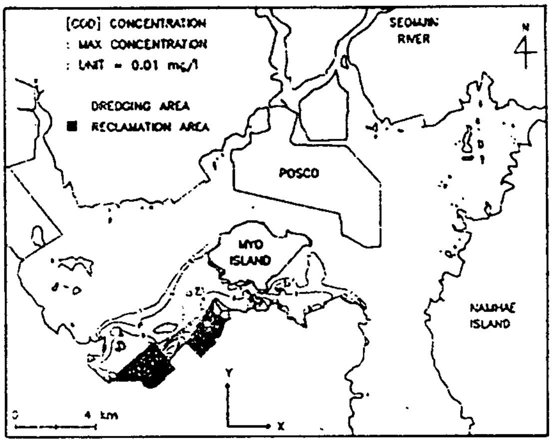

Fig. 7(b). The maximum increase range in COD concentration.

the flow and water quality environment in a semi-enclosed inner bay. A change of a sedimentary environment was determined, especially in the western part of the bay, due to a rise in thewater level and a remarkable decrease in the currents. Moreover, the seawater exchange ratio decreased approximately 30%, compared to the situation prior to development. Conversely, the suspended solids and waste water discharged from the reclamation work areas and industrial parks will possibly take up room to weigh the water quality pollution in the adjacent water. Accordingly, certain mitigating measures should be introduced in advance of the development projects to minimize or moderate the impact on the marine environment. One further way to reduce water quality pollution would be the application of Special Rules for Coastal Zone Management currently being proposed by the Central Government.

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