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Numerical Study on the Seawater Purification by Artificial Reef

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Introduction

Recently, the development of coastal areas leads to a sudden increase in the discharge of pollutant into the sea, which leads to serious environmental problems such as the increase of nutrient concentration, the development of phytoplankton and degradadtion of water quality. Thus, together with controlling the discharge of pollutant into the sea, some measurements must be taken to improve the water quality in the coastal area.

Usually, the artificial reef at the coast line is constructed using pieces of rocks. On the surface of submerged rocks, there is a thin film where a large amount of bacteria inhabits. The bacteria there can absorb organic pollutant in the sea water, decomposes it and purify the sea water. Also selfish and zooplankton inhabiting in the spaces between rocks can consume phytoplankton, which can further improve the sea water quality (Oda, 1990). This valuable property of the artificial reef should be utilized for purifying the sea water.

It is clear that the purification efficiency of the artificial reef should increase with the increase of the discharge of sea water through the rocks. On the other hand, the increase of the discharge of sea water through the rocks can be implemented by the construction of a impermeable pile at the sea end of the reef surface as shown in Fig. 1 since with the present of the pile, during flood and ebb tide, the sea water has to flow through the rocks to enter the interior region above the reef surface behind the pile.

The purpose of this study is to investigate the purification efficiency of the artificial reef with the construction of the pile by a numerical model.

Theory and Model Development

Usually a three-dimensional model should be required to get a detailed distribution of the flow and some biological quantities in the coastal area. However, due to time limitation, at this stage, only a two-dimensional model is employed. Using static pressure assumption, the main equations of the model are as:

Continuity equations:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum equations

$$\frac{\partial u}{\partial t} + \frac{1}{\lambda}\left[u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right] + g\lambda\frac{\partial \zeta}{\partial x} = A_l\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] - \frac{K}{D\lambda}u\sqrt{u^2+v^2}, \tag{2}$$

$$0 = -g - \frac{1}{\rho}\frac{\partial p}{\partial y}, \tag{3}$$

Equation for the transport and diffusion of a organic matter, represented by COD

$$\lambda\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}D\lambda\frac{\partial C}{\partial x}+\frac{\partial}{\partial y}D\lambda\frac{\partial C}{\partial y}-k_rC\lambda+\lambda Q, \tag{4}$$

where u and v are the horizontal and vertical components of the flow velocity vector, respectively; ζ is the water level; λ is the porocity of the artificial reef, which equals 1 for the region outside the artificial reef; A_l is the eddy viscosity; K is the coefficient for the friction at the rock surface; C is the COD concentration; D is the diffusion coefficient for the pollutant; K_r is the purification coefficient; and Q is the source term.

A half-day-period tidal change of the water level is given at the offshore boundary together with a fixed concentration of COD. The solid surface boundary condition is non-slip and zero gradient for COD. The initial condition is zero velocity and concentration of COD every where equals to the offshore value.

The system of partial differential equations (1-4) are integrated using a finite volume scheme on a staggered grid to get the velocity components u, v, water level ζ and concentration of COD C at nodal points. A explicit scheme is used for time discretization. Since static pressure assumption is employed, even with small time step required by the explicit scheme, the computational time is relatively small.

Figure 2 depicts the flow field and distribution of the organic matter during ebb tide. In the figure, a dark region inside the artificial reef represented a region with low COD concentration. As seen, COD concentration inside the artificial reef is significantly reduced compared with that of the outside water. Since the offshore boundary condition for COD is taken as constant COD concentration and flow velocity is relatively small, the back-wards diffusion of COD makes the difference in the COD concentration outside the artificial reef not distingishable. However, since the water has to flow the artificial reef, its COD concentration is reduced and it is significantly purified.

The purification efficiency of the artificial reef is clearer shown in Figure 3, which depicts the time variation of COD concentration before entry to the artificial reef and after leaving the artificial reef. It is clear that both during the flood tide and ebb tide, the concentration of the exited COD is much smaller than the entry one.

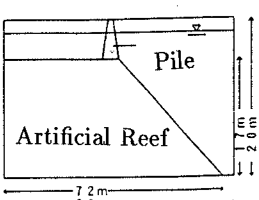

Figure 1. Sketch of the artificial reef

Figure 2. Flow velocity and COD concentration

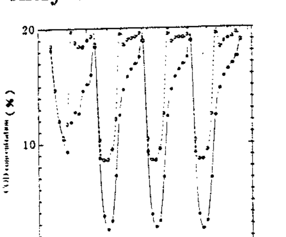

Figure 3. COD concentration at the entry and exit of the artificial reef

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References

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