COMPUTATION AND MEASUREMENT OF OSCILLATORY FLOW
OVER SAND RIPPLES

砂レン上の流れの数値計算および測定

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I-INTRODUCTION In oscillatory flows on the sea bed a correct computation of flow phenomena (such as velocity, bed shear stress and wave energy dissipation) requires correct prediction of the time-dependent turbulence structure. Since the flow is oscillatory and mostly reversing, viscous and turbulent stresses may alternately dominate the 'wall layer' on the sea bottom. Bottom geometry and roughness introduce additional complexities to the turbulence structure.

An improved version of the k-ε model of turbulence is applied to the wave-current combined flow over sand ripples. Transport equations of vorticity, turbulence kinetic energy and turbulence energy dissipation rate and the Poisson equation for the stream function are solved over fine computational meshes extending from the ripple surface to the outside of the boundary layer. Results are compared with the LDV measurements in a wind tunnel.

II-TURBULENCE MODEL The system of equations for two dimensional, unsteady, turbulent motion can be written as,

$$\frac{\partial^2\Psi}{\partial x^2} + \frac{\partial^2\Psi}{\partial y^2} = -\frac{\omega}{J} \tag{1}$$

$$\frac{D\omega}{Dt} = \frac{\partial^2}{\partial x^2}[(\nu+\nu_t)\omega] + \frac{\partial^2}{\partial y^2}[(\nu+\nu_t)\omega] + 2J\left(\frac{\partial^2\nu_t}{\partial x^2}\frac{\partial^2\Psi}{\partial y^2} + \frac{\partial^2\nu_t}{\partial y^2}\frac{\partial^2\Psi}{\partial x^2} - 2\frac{\partial^2\nu_t}{\partial x\partial y}\frac{\partial^2\Psi}{\partial x\partial y}\right) \tag{2}$$

$$\frac{Dk}{Dt} = \frac{\partial}{\partial x}\left[\left(\nu+\frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right] + \frac{\partial}{\partial y}\left[\left(\nu+\frac{\nu_t}{\sigma_k}\right)\frac{\partial k}{\partial y}\right] + G - \frac{\varepsilon}{J} - \frac{2\nu k}{Jy^2} + \frac{\xi}{J} \tag{3}$$

$$\frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x}\left[\left(\nu+\frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x}\right] + \frac{\partial}{\partial y}\left[\left(\nu+\frac{\nu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial y}\right] + C_1 G\frac{\varepsilon}{k} - C_2 f_2\frac{\varepsilon^2}{kJ} - f_3\frac{2\nu\varepsilon}{Jy^2} \tag{4}$$

$$\nu_t = C_\mu f_1 k^2/\varepsilon_t \quad , \; \varepsilon_t = \varepsilon + 2\nu k/y^2 \tag{5}$$

$$\frac{D}{Dt} = \frac{1}{J}\frac{\partial}{\partial t} + \frac{\partial\Psi}{\partial y}\frac{\partial}{\partial x} - \frac{\partial\Psi}{\partial x}\frac{\partial}{\partial y} \quad ; \quad G = \nu_t J\left[\left(\frac{\partial^2\Psi}{\partial x^2} - \frac{\partial^2\Psi}{\partial y^2}\right)^2 + 4\left(\frac{\partial^2\Psi}{\partial x\partial y}\right)^2\right]$$

J is Jakobian of the coordinate transformation $C_\mu=0.09$ $\sigma_k=1.$ $\sigma_\varepsilon=1.3$ $C_1=1.35$ $C_2=1.8$

The damping functions f_1, f_2, f_3 are expressed as functions of turbulence Reynolds number R_t. F_1 is modified to take into account the bottom roughness effects on the viscous sublayer.

$$f_1 = \exp[\,-C_r\,/\,(R_* - 0.17R_*^2 + 0.01R_*^3\,)\,] \tag{6.1}$$

$$f_2 = 1. - 0.22\exp[\,-R_t^2\,/36.\,] \tag{6.2}$$

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$$f_3 = \exp[\ -0.3\sqrt{R_t}\ ] \tag{6.3}$$

$R_t = k^2/\nu\varepsilon_t$; $R* = 1.+R_t/20.$

The constant C_r in f_1 is a function of the roughness of the bottom. The last term ξ in Eq'n-3 is the source function of turbulence kinetic energy due to bottom roughness when the laminar sublayer is completely pressed into the roughness elements. The source function ξ is given as,

$$\xi = \phi\ \mathrm{sech}[5(y/k_s - 1.)] \tag{7}$$

Then C_r and ϕ are determined as ,

For smooth bottom $C_r = 5.9$, $\phi = 0.$ (8.1)

For rough bottom $e^+<24.$; $C_r = -1.65\ \ln[e^+/24.]-2\exp[-e^+]$; $C_r \leq 5.9$, $\phi=0.$ (8.2)

$e+>24.$; $C_r=0.0$, $\phi = (\ U*^2\nu\ /k_s^2)\ 0.19\ (e^+)^{1.79}$ (8.3)

where $e^+=k_sU*/\nu$ and $U*$ is the shear velocity

Eq'ns-1∿4 are solved by ADI (alternating direction implicit) method using a hybrid skew upwind difference scheme, and Eq'n-1 is solved by SOR (successive overrelaxation) method. Boundary conditions are;

on the ripple surface $\Psi = k = \varepsilon = 0.$, $\omega = -2\Psi(\Delta y_1)/(J\Delta y_1^2)$

outside the boundary layer δ $\psi = [U_c+U_w\cos(2\pi t/T)]\delta$, $\omega = \partial k/\partial y = \partial\varepsilon/\partial y = 0.$

where U_c is the current velocity U_w is the wave amplitude and T is the wave period. There is no specific boundary condition for the upstream and downstream of the ripple. Equations are enforced until the same boundary conditions on upstream and downstream are obtained.

III-RESULTS AND DISCUSSIONS A comparison of computational and experimental results are shown in Fig-1. The vortex structure on the ripple is smaller than experimentally found. Since the vortex structure cannot grow enough, the subcurrent in the reverse direction, created by the the vortex is weaker. High turbulence intensity region, in the computational case is concentrated to a smaller area, whereas it covers a larger area in the experimental case, being proportional to the size of the vortex structure. However, it should be noted that the measured turbulence kinetic energy is always overestimated due to ensemble averaging errors.

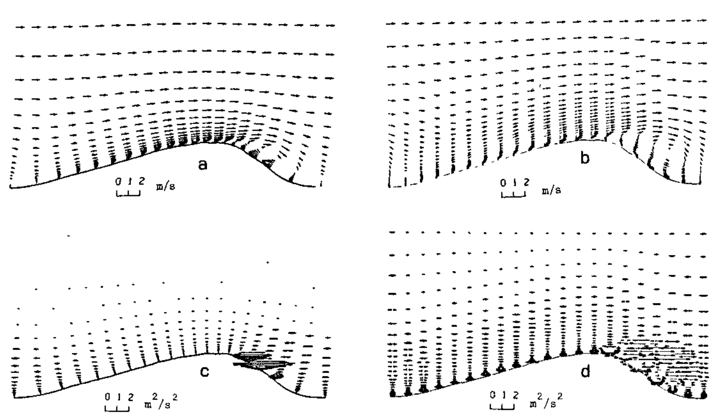

Fig.1 Velocity Field;
a) computed
b) measured
Turbulence Kinetic Energy
c) computed
d) measured