波・流れ共存場での砂漣上の流況

STUDY OF FLOW FIELD OVER A SAND RIPPLE

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I-INTRODUCTION

Mechanics of sediment transport under wave-flow combination over sand ripples is subject of study. Flow field have vortex structures either on both sides of the ripple or on one side; depending on wave-flow combination and therefore ripple shape. Sand particles are set in motion by the effect of shear and drag forces acting on the bottom. Some of the moving sand particles are captured by the vortex structure and moved together with it. Observations show that these vortex structures control the direction of net sediment transport. Understanding of transport mechanism requires analysis of flow field.

Results of hot-wire measurements and a numerical modeling of the flow field by vortex method are presented.

II-EXPERIMENTS

Hot-wire measurements are carried on a wind tunnel of cross-section 12x40 cm. with the following wave-flow characteristics:

wave period,	T=1.48 sec.
wave amplitude,	U_w=70 cm/sec.
flow velocity,	U_c=40 cm/sec.
ripple length,	L=40 cm.
ripple heigth,	h=5.7 cm.
particle size,	d_{50}=0.13 cm.

(For more details of experimental set-up see [1].)

Response signals of a X-wire are recorded at 379 test points. Data is digitised with a sampling frequency of 100 Hz. Mean velocities and turbulence quantities are computed by ensemble averaging over 80 wave cycles. Examples are given in figures Fig.2-a,b~ Fig.6-a,b.

III-VORTEX METHOD

The vortex method adopted here is known as the cloud-in-cell (CIC) method. The idea is to retain the Lagrangian treatment of vorticity field but to solve the Poisson equation for the velocity field on a fixed Eulerian mesh. Computational steps are as follows:

1. Create vortices and place them at an initial distance from the wall. Circulation of each vortex is computed from,

$$\Gamma_n=\Gamma(x,t)=-|U_d|U_d\frac{\Delta t}{2} \tag{1}$$

where $U_d=U(x,d,t)$ is the tangential velocity at the *normal distance* d, Δt is the time increment for each computational step and Γ_n is the circulation of the n^{th} vortex. Computatuonal experience show that d/3. is a good approximation to the initial distance from the wall.

2. Compute vorticity of each vortex assuming a uniform distribution.

$$\omega_n=\frac{\Gamma_n}{\pi r_n^2} \tag{2}$$

where $r_n=r(\tau_n)$ is a radial distance which can be obtained from the decay law given for a vortex [5].

$$V(r,\tau)=\frac{\tau_0}{2\pi r}[1-\exp(-\frac{r^2}{4\nu\tau})] \tag{3}$$

$$r_n=cr' \tag{4}$$

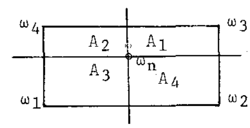
$$r=r' \quad \text{when} \quad \tau=\tau_n \quad \text{and} \quad V=V_{max} \tag{5}$$

where V is the tangential velocity τ is the age of the vortex, ν is the kinematic viscosity and c is a constant.

4. Distribute vorticity to four mesh points at the corners of the cell according to area weighting scheme(Fig.1).

$$\omega_k=A_k\omega_n/A \tag{6}$$

Fig.1 Area weighting scheme



Repeat steps 2 and 3 for all vortices which resides in the *same* cell and sum up the vorticity contributions at each corner.

4. Solve Poisson equation for the stream function Ψ

$$\frac{\partial^2\Psi}{\partial x^2}+\frac{\partial^2\Psi}{\partial y^2}=-\omega \tag{7}$$

In this study the successive overrelaxation (SOR) method is used.

5. Find the velocities at the mesh points by the central differences,

$$u_{i,j}=\frac{\Psi_{i,j+1}-\Psi_{i,j-1}}{\Delta y_i} \qquad v_{i,j}=\frac{\Psi_{i-1,j}-\Psi_{i+1,j}}{\Delta x} \tag{8}$$

6. Compute velocity of vortex n by bilinear interpolation,

$$\underline{u}_n=\sum_{k=1}^{4}\underline{u}_k\frac{A_k}{A} \tag{9}$$

7. Simulate diffusion normal to wall by

$$(U_{dif})_n=(\frac{dr}{dt})_n \tag{10}$$

Add $(U_{dif})_n$ to $\underline{u}_n$. Move vortices to new positions and go to step 1. Diffusion is simulated by dr/dt because r is a measure of the vortex growth.

IV-RESULTS AND DISCUSSIONS

From experimental results five important stages can be discerned.

1. Wave is in the flow direction. Velocities at the ripple crest are maximum of one cycle and vorticity production is also expected to be at maximum level (Fig.2-a).
2. After accumulation of sufficient vorticity flow is seperated and a vortex structure is formed on the right hand side of the ripple (Fig.3-a).

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3. Flow is decelerating but vortex structure still keeps its strength. As a consequence, sand particles moving with the structure may not find any chance to fall down (Fig.4-a).
4. Flow is reversed, vortex structure is altered by a subflow in the reversed direction (Fig.5-a).
5. Subflow reaches to left end of the ripple carrying the sand particles which were within the vortex structure (Fig.6-a).

Turbulence quantities vary between 5 cm/sec.- 25 cm/sec. in a wave-cycle. High fluctuations are observed within the vortex structure (Fig.2-b~ Fig.6-b).

The vortex method is successfull to follow the evolution of the vortex structure in a wave-cycle. Results presented here are obtained with 8880 vortices on a 40X35 mesh by a time increment Δt=0.02 sec., with d=2.5 mm., c=3. Flow field can be obtained with an overall agreement with experimental results. This may help integration of suspended sediment transport. However, method requires development of some rules to control vortex creation rate, decay, diffusion and cut-off frequencies. Experimental data can be used for development of such rules.

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REFERENCES:

[1] Tanaka,H. and N. Shuto:Experiments of oscillatory flows accompanied with steady flow on wavy bottom. Proceedings of 31th japanese conference on coastal engg. pp 301-305 (1984)

[2] Leonard,A.:Vortex methods for flow simulation. Journal of computational physics vol 37, pp 289-335 (1980)

[3] Kiya,M. Sasaki,K. Arie,M.:Discrete vortex simulation of turbulent separation bubble Journal of fluid mech. vol. 120 pp 219-244 (1982)

[4] Christiansen,J.P.:Numerical simulation of hydrodynamics by the method of point vortices. Journal of computational physics vol. 13, pp 363-379 (1973)

[5] Schlichting, H.:Boundary Layer Theory pp 89-90 Mc Graw-Hill (1955).

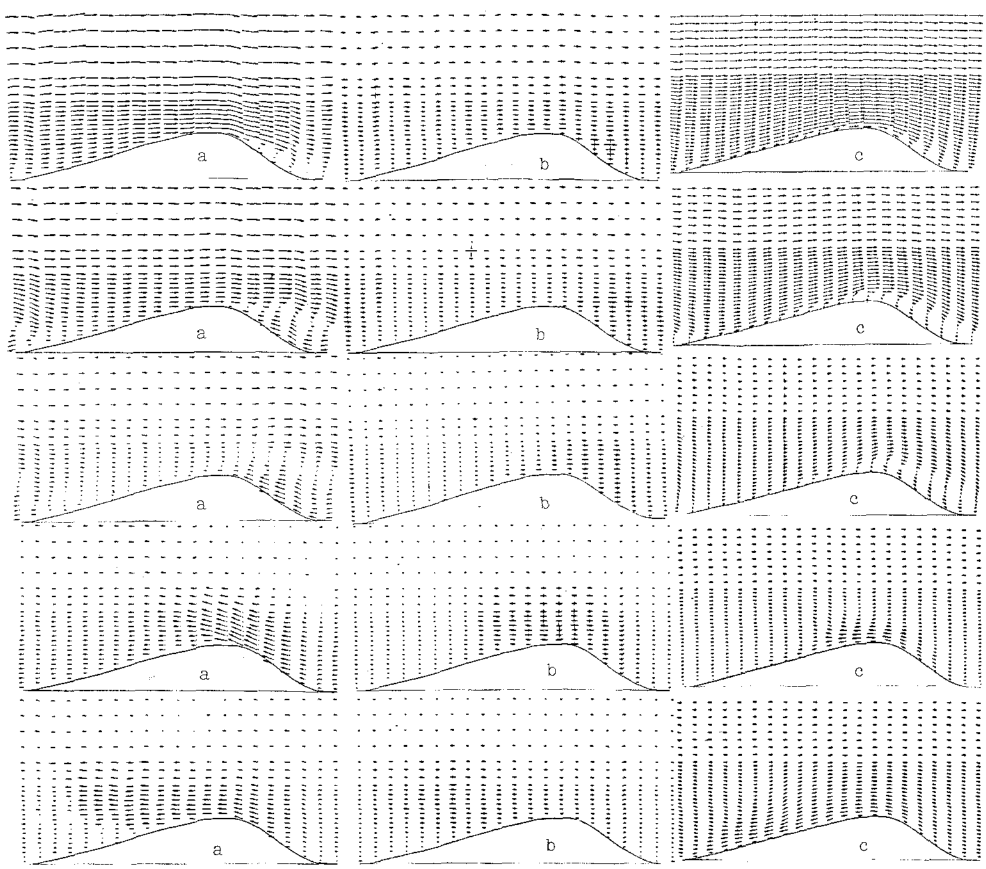
Fig 2 t=0.40 s

Fig 3 t=0.64 s

Fig 4 t=0.76 s

Fig 5 t=1.00 s

Fig 6 t=1.24 s



Figures 2-6: a) Experiment,velocity field → 1 m/s.
b) Experiment,turbulence field, ↔ $U_{r.m.s.}$, ↕ $V_{r.m.s.}$, – 20 cm/sec.
c) Computation,velocity field, – 1 m/s.