CHAPTER 219

Mechanism of Sediment Transport around a Large Circular Cylinder

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ABSTRACT

Mean currents have impotant roles in sediment transport. The mean currents around a large circular cylinder are carefully measured. The theoretical mass transport rate is verified experimentally, and the movement of sediment on a flat and smooth bed can be numerically simulated well. On the contrary, the currents on sand ripples are quite different with the theoretical value. The currents are caused by the interaction of the return flow and the mass transport on sand ripples.

INTRODUCTION

Bathymetric changes and scouring around a large circular cylinder have been studied by Rance (1980), Saito et al (1990), and Katsui and Toue(1988). Fig.-1(a) and (b) are examples of the bathymetric changes around a large circular cylinder presented by Katsui (1992). The wave height is 10cm, and the wave periods are 1.0s and 2.0s and the water depth is 0.3m. In front of the circular cylinder, the feature of bathymetric change is same as that in front of a vertical structure, i.e., the scouring and accretion occur alternatively. The side of the cylinder is always accretion area irrespective to the wave period. According to Katsui et al(1990), this type of changes

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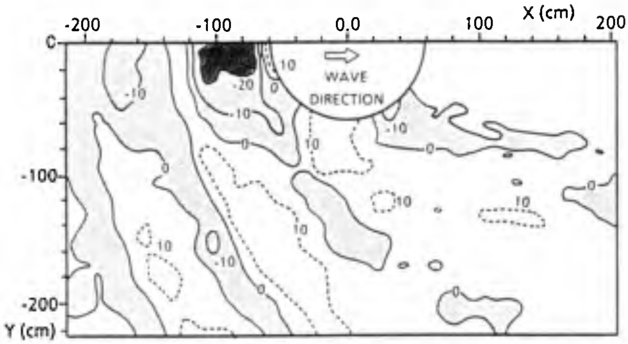
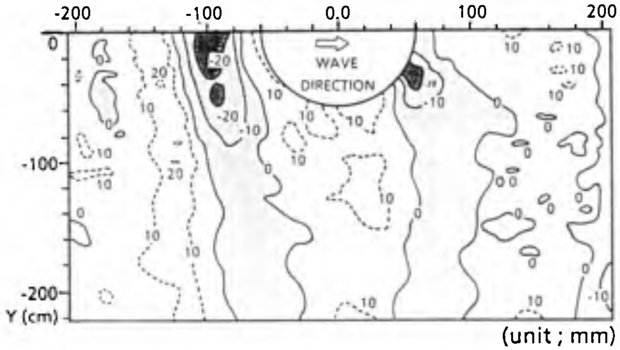


(a) T=1.0s, H=10cm and duration time =120min.



(b) T=2.0s, H=10cm and duration time =120min.

fig.-1 Bathymetric Changes around a Large Circular Cylinder

is called N' type scouring. In N' type scouring, the sediment transport rate must be maximum where the gradient of sheer stress is maximum. The mechanism of N' type scouring, however, is not understood well.

Saito et al (1988) simulated these particular changes numerically, but the simulation could not explain the experimental results well probably due to the poor understanding of the mean currents. In their simulation, the mean currents around a cylinder are consist of two different types of currents. One is the mass transport, and the other is the current due to the gradient of radiation stress. The calculated currents, however, are not verified experimentally.

To understand the mechanism of sediment transport around a large circular cylinder, the mean currents should be clarified first. The purposes of this study are to examine the mean current around a large cylinder and its influence on the sediment transport.

EXPERIMENTAL PROCEDURE

Fig.-2 is the experimental set up. The length of the wave basin is 35.5 m and width is 17m. The water depth, h, is always 0.3m. The wave height, H, is 10 cm, and

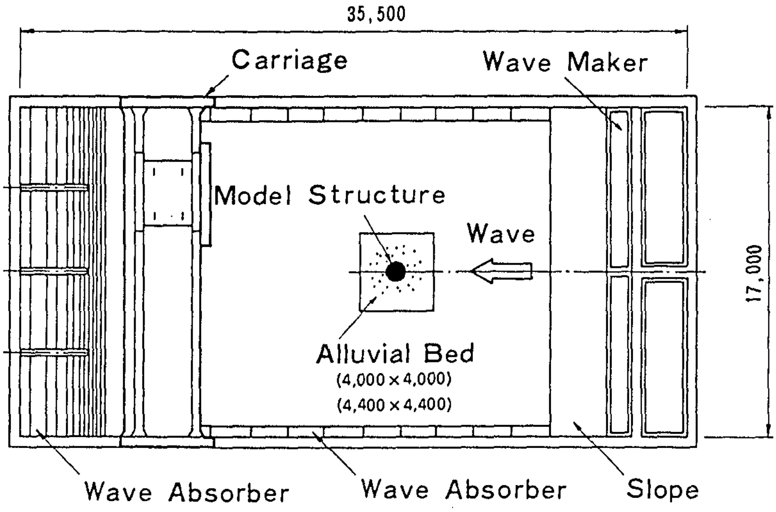


fig.-2 Experiment Set Up

wave periods, T, are 1.0s and 2.0s. The diameter of the circular cylinder, D, is 1.17m, thus the ratios of the diameter to wave length are 0.85 and 0.36. Two types of bed conditions are tested. One is a flat smooth bed and the other is the bed with sand ripples (ripple bed). In making the ripple bed, a flat movable sand layer with 5 cm thickness is formed, and then after the ripples form in the all surface by waves, the bed is fixed by cements. To measure the mean currents on the smooth bed in the boundary layer, polyethylene beads are used. Their diameter is 1 mm and the gravity ratio is 1.02. A number of beads are placed on the smooth bed, and the movements of beads are observed by the video and the photograph. The movements of sands are also observed. The sands are fine silica sands and their median diameter, d_{50}, is 0.15 mm. Mean currents are also measured by the elctro-magnetic velocity meter and LASER Doppler velocity meter. The currents are measured at every 30 cm horizontally, and 20,15,10,5,3 cm above the bottom. Table -1 summarized the experiment condition and the experiment cases.

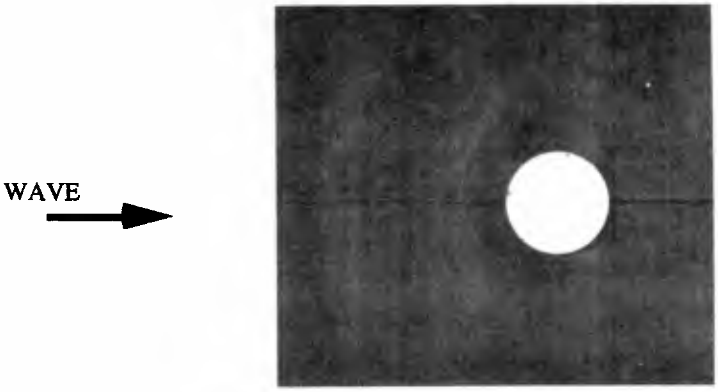
MEAN CURRENTS ON SMOOTH BED

1) Observation of Movement of Polyethylene Beads

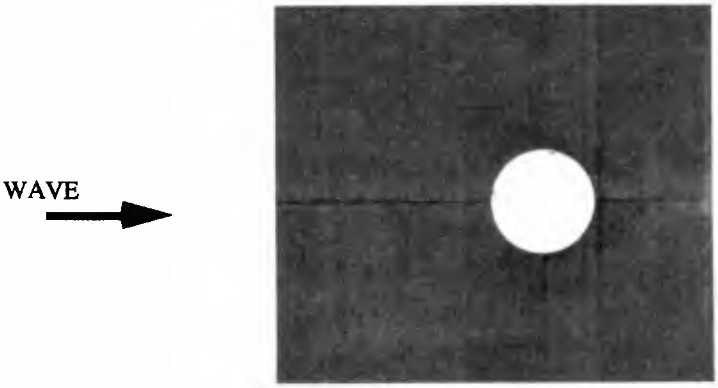
Photo -1(a) shows the movement of polyethylene beads on the smooth beds for case 1. The beads in front of the cylinder gather in semi-circular lines which are coincide to the positions of the standing waves. The beads disappear at the side of the cylinder. All particles, however, are flown to the shore ward finally. Photo -1(b) is for case 2. The beads move more dramatically. Just after the waves reach the experimental area, all beads in front of cylinder move to the direction of waves.

Table -1 Experiment Condition and Cases

case name	wave height H(cm)	wave period T(s)	water depth h(m)	bed condition
case 1	10.0	1.0	0.3	smooth
case 2	10.0	2.0	0.3	smooth
case 3	10.0	1.0	0.3	ripple
case 4	10.0	2.0	0.3	ripple



(a) T=1.0s H=10cm t=1 min.



(b) T=2.0s H=10cm t=1 min.
Photo-1 Movement of Polyethylene Beads around a Large Circular Cylinder

Simultaneously, the beads at the side of the cylinder also disappear. The shape of the disappearance is heart like. Within 3 or 4 minutes, they disappear completely.

2) Mass Transport Rate around a Circular Cylinder on the Smooth Bed

According to Carter et al (1973), the mass transport rate at the outer edge of the boundary layer is given by eq. (1) and (2) in the cylindrical coordinate.

$$U = \frac{1}{4\omega}\mathrm{Re}\left[F_5 U_w\left(\frac{\partial U_w}{\partial r}\right)^* + F_6\frac{V_w}{r}\left(\frac{\partial U_w}{\partial \theta} - V_w\right)^* + F_7\frac{U_w}{r}\left(\frac{\partial V_w}{\partial \theta} + U_w\right)^*\right] \quad (1)$$

$$V = \frac{1}{4\omega}\mathrm{Re}\left[F_5\frac{V_w}{r}\left(\frac{\partial V_w}{\partial \theta} + V_w\right)^* + F_6 U_w\left(\frac{\partial V_w}{\partial r}\right)^* + F_7 V_w\left(\frac{\partial U_w}{\partial r}\right)^*\right] \quad (2)$$

where U, V is the mass transport rate including *Stokes' drift* in the direction of r and θ respectively, Uw and Vw are the velocity of wave component at the outer edge of the boundary layer and * means the complex conjugate. F5,F6 and F7 are the complex

$$F_5 = -3 + 5i \;,F_6 = -1 + 2i \;,F_7 = -2 + 3i \quad (3)$$

constants, and given by eq. (3).

3) Numerical Simulation of Movements of Polyethylene Beads

If the beads are assumed to be moved by the mass transport rate, the movements of beads are simulated numerically. Fig. -3(a) and (b) are the results of the simulation for case 2. The simulations agree with the experimental results very well. In other words, this is the experimental verification of the theoretical mass transport rate.

MOVEMENT OF SAND PARTICLES ON SMOOTH BED

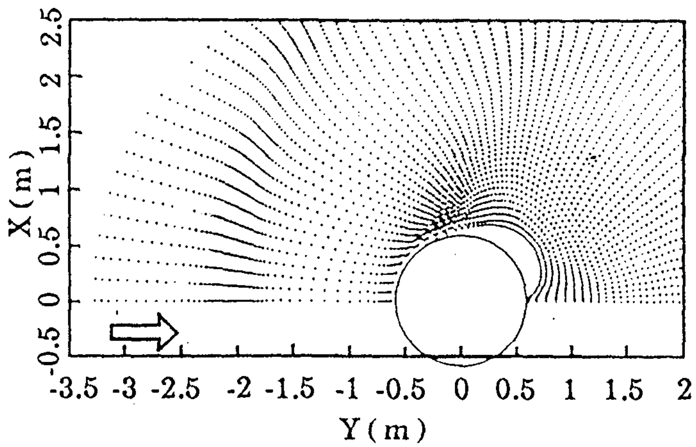
1) Observation of Sand Particles on Smooth Bed

The mass transport rate on smooth bed is clear now. Next, the movements of sand particles are examined. The same procedure as that of the experiment for polyethylene beads is used. Photo -2 (a) and (b) is the movement of sands for case 3 and case 4. In the photos, the black part is the place where sands disappear and the white part is the place where sands deposit or do not move. In other part, sand ripples form. The photos were taken after 30 minutes wave duration.

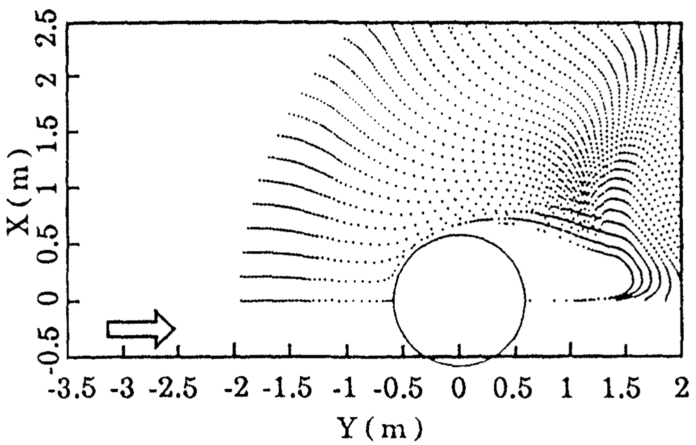
In case 3, sands in front of the cylinder gather at the position of the loop of the standing waves, and disappear at the node of the standing waves. In case 4, however, sands gather at the loop and disappear at the node. The sands at the side of the cylinder disappear for both cases.

2) Numerical Simulation of Sand on Smooth Bed

The motion of sands on the smooth bed can be given by eq. (4) and (5).



(a) T=2.0s H=10cm t=10s



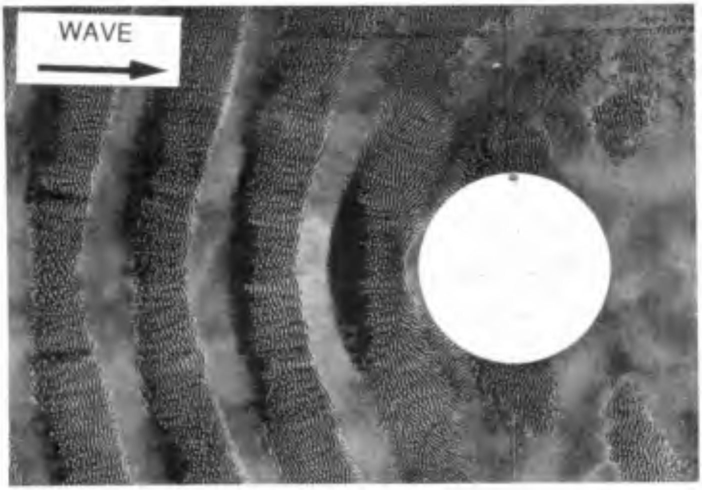
(b) T=2.0s H=10cm t=40s

Fig.-3 Numerical Simulation of Movement of Polyethylene Beads

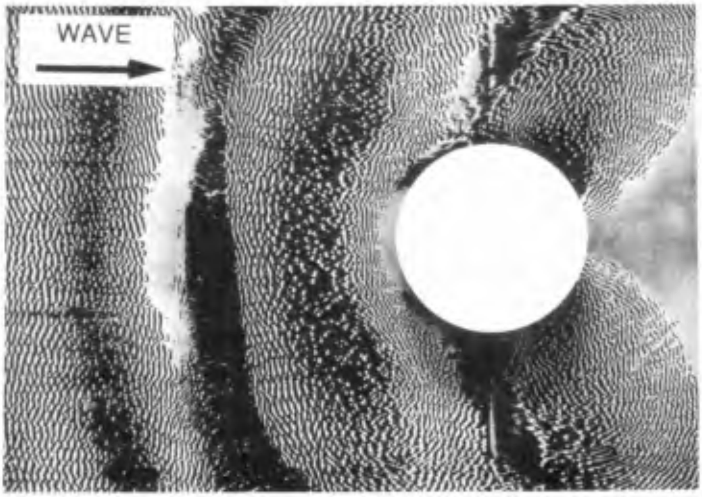
$$\frac{dx_s}{dt} = u_s \tag{4}$$

$$\frac{du_s}{dt} = \frac{3C_d}{4d(s+C_m)}|u-u_s|(u-u_s) + \frac{1}{s+C_m}\frac{dU_w}{dt} + \frac{C_m}{s+C_m}\frac{du}{dt} \pm \frac{s-1}{s+C_m}\mu_f \tag{5}$$

where u_s is the sand particle velocity, u is the velocity of the fluid and over bar means a vector quantity. Cd is the drag coefficient, Cm is the added mass coefficient and μ is the friction coefficient. Cd and Cm are 0.5. The friction coefficient at rest is 0.6 and



(a) T=1.0s H=10cm t=600s



(a) T=1.0s H=10cm t=2220s

Photo-2 Movement of Sands on Smooth Bed

changed to 0.1 when sands start to move. The height of the position ,z_0, which the fluid acts on the particles is the half of sands diameter, i.e., 0.075mm. u is given by eq.(6) and (7).

$$u = u_1 + u_2 \tag{6}$$

$$u_1 = \mathrm{Re}\left[U_w F_1(\xi)\exp(-i\omega t)\right], \xi = z_0/\delta \tag{7}$$

$$F_1(\xi) = 1 - \exp[-(1-i)\xi] \tag{8}$$

where u_2 is the mean current, δ is the thickness of the boundary layer. F_1 is given by eq.(8)

Fig.-4 is the trajectory of the sand particles in the simulation. The wave height is 10cm, and wave period is 1.0s. The initial position is x=-0.585m, y=0.676m, where the origin of the coordinates is the center of the circular cylinder. x is the positive toward the direction of the wave propagation. The sands move along the elliptic line changing the mean position toward the center of the cylinder. This movement is the same as the observation. Similar simulation was done by many researchers, such as Hino et al (1982) and Irie et al(1984) for one dimensional sands movement. In one dimensional simulation, sands stop when the velocity is very small. But, since the velocity in the both directions of x and y are not small simultaneously in three dimensional case, the sands which start to move do not stop. The simulation for all particles around a cylinder is shown in fig.-5(a) and (b). The results of the simulation agree with the experiment qualitatively. Some differences are due to the sand ripples which is not

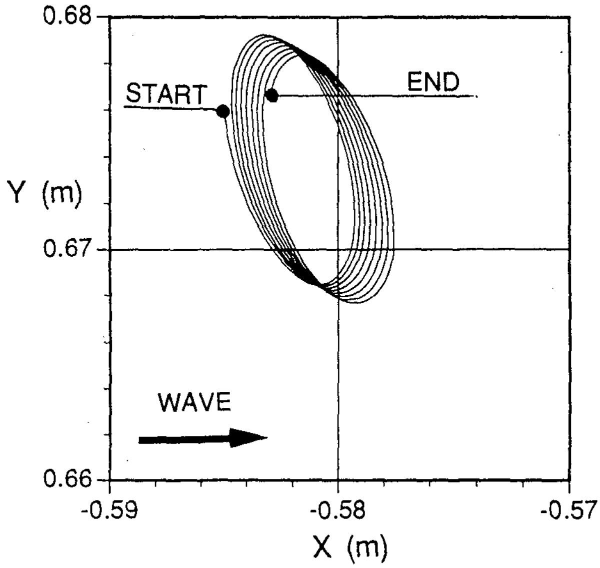
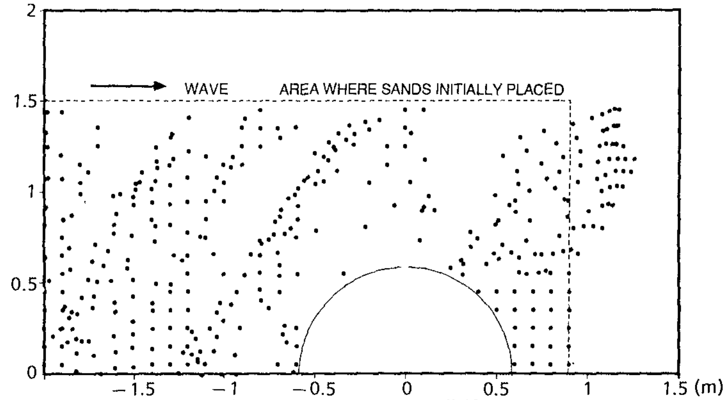
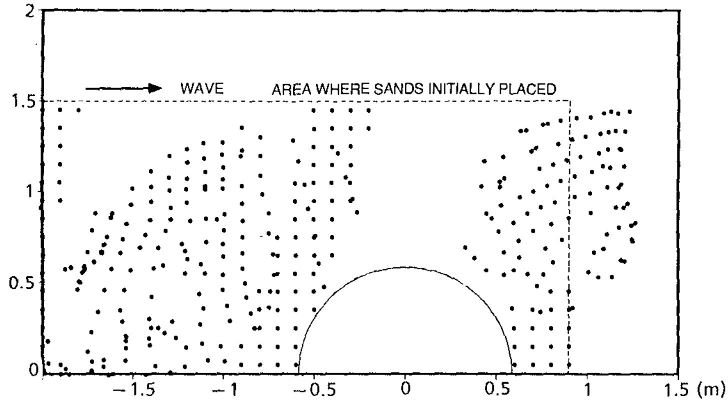


Fig.-4 Trajectory of Sands Movement in Numerical Simulation



(a) T=1.0s H=10cm t=550s



(b) T=2.0s H=10cm t=500s

Fig.-5 Numerical Simulation of Sands Movement

included in the simulation. Important findings are the sand particles disappear at the side of the cylinder both in the simulation and the experiment. In other hand, the side of the cylinder is always accretion area in the bathymetric change experiment (see fig.-1(a) and (b)).

MEAN CURRENTS ON RIPPLE BED

1) Observation of Movements of Polyethylene Beads

Photo-3 show the movements of polyethylene beads on the ripple bed after 30 minutes wave action. The difference between the movement on the smooth bed and the ripple bed is clear. In the case of the smooth bed, the beads are disappear within 3 or 4 minutes. On the contrary, the beads on the rippled bed remain there for more than 30 minutes. By careful observation, some particular movements of beads are found. The beads at the side of the cylinder move to the down drift side near the bed, but change the direction when the beads go up to the 3 to 5 cm above the bed. This imply the

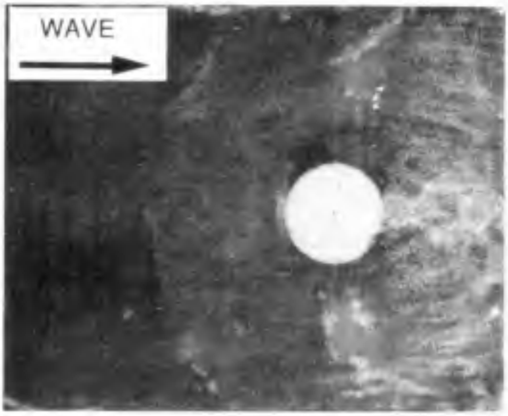


Photo -3 Movement of Polyethylene Beads on Sand Ripple (T=2.0s ,H=10cm)

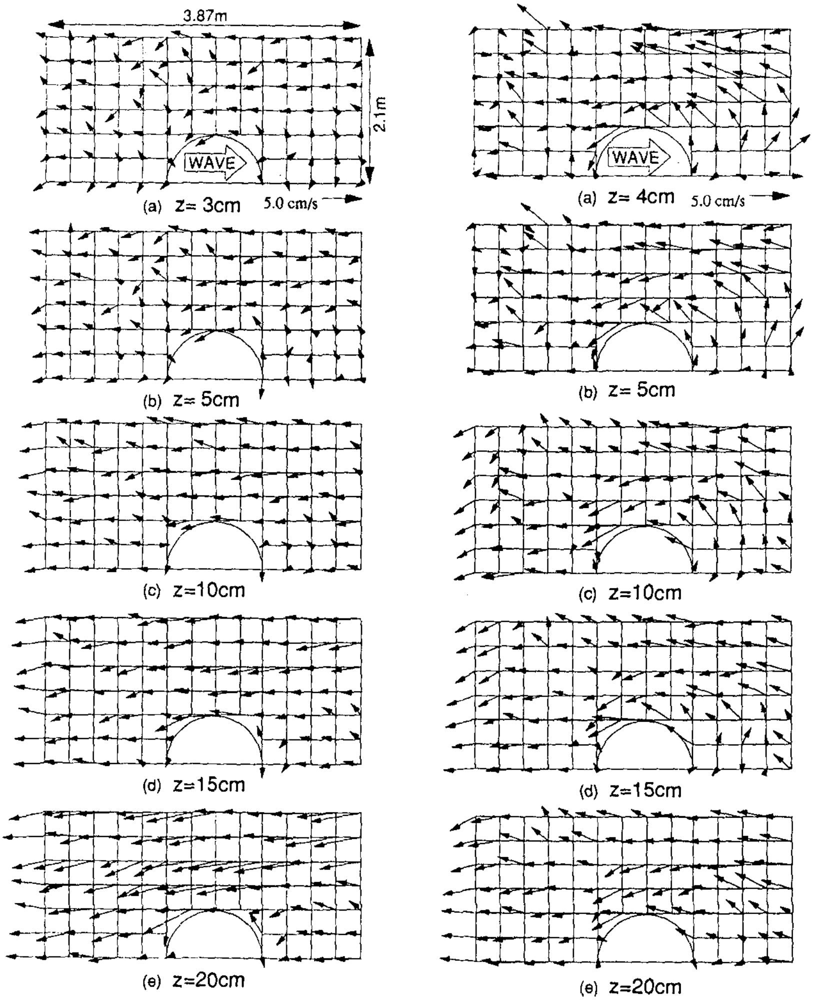
vertical distribution of the mean current might have some important role in this movement.

2) Mean Current around a Circular Cylinder

The mean currents measured by the electro-magnetic velocity meter is shown in fig-6. The currents in the upper layer go to the opposite direction of wave propagation. The currents in lower layer go from the rear of the cylinder to the side of the cylinder, therefore the beads would have gathered at the side of the cylinder in Photo 3.

The velocity of the currents is about 5 cm/s. As long as the wave basin is closed in the experiment, there must be a return flow. The order of the return flow is estimated to be about 5cm/s. Thus, the current in the upper layer might be a return flow. The current in the lower layer is more complicate. More detailed measurement by LASER Doppler velocity meter is carried out at the side of the cylinder. The vertical profile is illustrated in fig.-7 with theoretical value. The measured current is quite different with the theoretical current both its value and direction.

Since the theory is for the mass transport in the laminar boundary layer on the smooth flat bed, the differences are not surprising. Furthermore the theory does not consider any significant currents like a return flow outside the boundary layer. This is not so important when the boundary layer is very thin like that on smooth beds. When the boundary layer is considerably thick like that on sand ripples, the effects of the return flow must be considered. Consequently, to know the mean currents around a large circular cylinder, a theory for the mass transport on sand ripples must be developed taking into account of the effects of a return flow .



(a) T=1.0s H=10cm (b) T=2.0s H=10cm

Fig.-6 Mean Currents around a Large Circular Cylinder

CONCLUDING REMARKS

The following conclusions are made;

1) The mass transport around a large circular cylinder on the smooth bed are verified experimentally.

2) The sand movements around a large circular cylinder on the smooth bed are explained by the numerical simulation well.

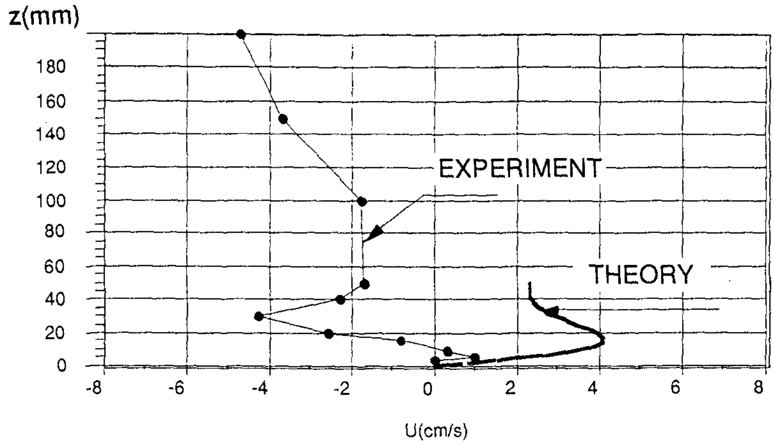


Fig.-7 Vertical Distribution of Mean Currrent

3) The mean current on the sand rippled are clarified by the experiment.

4) To know the mean current, theory for the mass transport on sand ripples must be developedtaking into account of the effects of a return flow.

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