CHAPTER 214

LOCAL SCOUR AROUND A LARGE CIRCULAR CYLINDER ON THE UNIFORM BOTTOM SLOPE DUE TO WAVES AND CURRENTS

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1. Introduction

In recent years, many kinds of coastal structure, such as man-made island, large-scale piers, marinas and so on, are constructed in the coastal area. Local scour occur around a coastal structure due to waves and currents. The scouring around a structure is important in the estimation of stability of the structures. However, there are no standard of judgement of measures against scour around coastal structures. There are few investigations for mechanism of local scours around a large-scale structures. The dimension of large-scale structure is comparable to the wave length, and the wave field around them is complicated owing to the presence of diffracted waves. The mechanism of sand movement around a large circular cylinder were first investigated experimentally by Toue and Katui(1985). Saito et al.(1990) presented a numerical model for the bottom topography changes around a large circular cylinder. The model consisted of three submodels, that is, wave model,current model and sand transport model. In the model, the wave field was evaluated by using the linear theory derived by McCamy and Fuchs(1954). The current field was evaluated as sum of the depth-integrated current induced by the spatial variation of the radiation stress and the mass transport velocity in the vicinity of the bed. The sand transport rate was calculated in terms of the

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bottom shear stress and near-bottom current velocity. The change of bottom topography was calculated by using the mass conservation equation of the sand. Later, Katsui and Toue(1992) improved the model by using the wave-current friction factor. These investigations, however, were performed under uniform water depth conditions. Since real sea bottom has a slope, wave breaking and additional current appears. The mechanism of sand movement seems to be different. The purpose of the present study is to investigate the mechanism of the local scour around a large circular cylinder installed on the uniform bottom slope due to waves and currents by both laboratory experiment and numerical simulation.

2. Laboratory Experiment

Experiments were performed in a 9 times 9m wave basin with a 1/20 slope. About 2.5 times 2.3m test bed was made in the basin. A circular cylinder with a diameter of 52.2cm was installed at the center of the test bed. Two types of test beds, fixed and sand, were used in the experiment. Well-sorted sand with a median diameter of 0.2mm were put in the test section. Experimental equipment is shown in Fig.1, and experimental conditions are listed in Table 1.

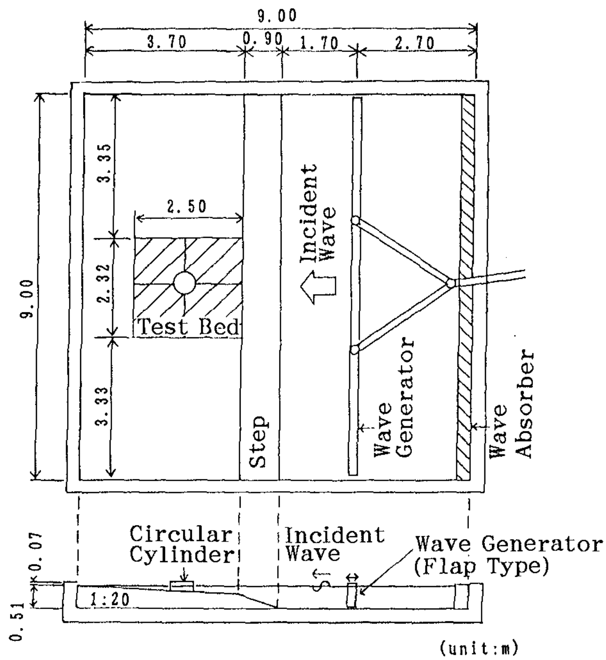


Fig.1 Experimental Set-up(Fixed Bed)

Table 1 Experimental Conditions

Case	1	2
Test Bed	Fixed	Sand
Incident Wave Period $T(s)$	1.02	
Incident Wave Height $H_0'(cm)$ (at uniform water depth)	9.4	
Deepwater Wave Height $H_0(cm)$	9.1	
Water Depth at Cylinder $h_c(cm)$	11.5	
Diameter of Circular Cylinder $D(cm)$	52.2	
Measured Values	·Wave Height ·Steady Current	·Wave Height ·Change of Bottom Topography

In the case of fixed bed (case1), the distribution of wave height and the variation of steady current velocities around a cylinder were measured with a horizontal spacing of 10cm. Steady current were measured by using ultra-sonic type current meter or electromagnetic current meter at both upper level and lower level for one measuring point. We set the upper level at 8cm below the mean water level to prevent the current meter from being exposed to the air when the wave trough comes. And we set up the lower level at 1cm above the bottom. In the shallow water area, steady current only at lower level was measured. Measuring points are shown in Fig.2. The whole pattern of current direction was also observed by using dye injection.

In the case of sand bed (case2), the development of sand ripples and change of bottom topography during experimental run were measured by using a bottom profiller. Measuring points are the same with those in Fig.2. The measurements were carried out at 1,2,4 and 6 hours after wave generation. The scouring depth and the depositing height along the cylinder surface were also measured by using scales printed on the cylinder surface. The distribution of wave height were also measured at same point as case 1. The measurements were carried out from 0 ~ 2 hours and from 5 ~ 7 hours upon the initiation of wave action to estimate the influence of the change of bottom topography on the wave height distribution. In this study, the physical meaning of large circular cylinder is considered to be the

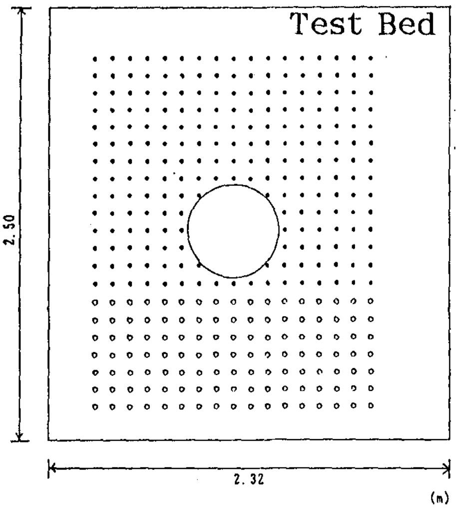


Fig.2 Measuring Points

cylinder which causes obvious diffracted waves. In this experiment, diffracted waves, which passed around behind the cylinder, were observed obviously. Jo(1986) proposed the criteria of large cylinder by using the parameter D/L and K.C.number(K.C.=$u_b \cdot T/D$), where D is the diameter of the circular cylinder, u_b the orbital velocity amplitude near the bottom, T the wave period. The criteria of large cylinder is listed in Table 2. When we calculate these parameters by using the experimental conditions listed in Table 1, we obtained D/L=0.52 and K.C.=0.70. As a result, the circular cylinder with a diameter of 52cm is considered to be a large circular cylinder in the present experiments.

Table 2 Criteria of Large Cylinder

D/L	Small Diameter< 0.2 <Large Diameter
K. C. Number	Small Diameter>4.0~5.0>Large Diameter

The experiments were carried out with the scale of 1/50. Prototype according to the Froude law are listed in Table 3.

Table 3 Prototype Conditions

Case	1	2
Incident Wave Period $T(s)$	7.21	
Incident Wave Height $H_0'(m)$ (at uniform water depth)	4.70	
Deepwater Wave Height $H_0(m)$	4.55	
Water Depth at Cylinder $h_c(m)$	5.75	
Diamerer of Circular Cylinder D(m)	26.1	

3.Numerical Model

A numerical model was developed to predict bottom topography changes around structures. The model consists of three sub-models, that is, wave model,current model and sand transport model. The outline of each sub-model is described below.

3.1 Wave Model

The wave field was evaluated by using the time dependent mild slope equation derived by Watanabe and Maruyama(1986). It is possible to calculate wave fields around structures on the bottom slope accurately. The equation is as follows:

$$\left.\begin{aligned}
&\frac{\partial \eta}{\partial t} + \frac{1}{n}\cdot\frac{\partial n Q_x}{\partial x} + \frac{1}{n}\cdot\frac{\partial n Q_y}{\partial y} = 0\\
&\frac{\partial Q_x}{\partial t} + C^2\frac{\partial \eta}{\partial x} + f_D\cdot Q_x = 0\\
&\frac{\partial Q_y}{\partial t} + C^2\frac{\partial \eta}{\partial y} + f_D\cdot Q_y = 0\\
&\text{where}\\
&Q = \sqrt{Q_x^2+Q_y^2},\quad Q_r = 0.25\sqrt{g h^3}\\
&f_D = 2.5\tan\beta\sqrt{(g/h)(Q/Q_r - 1)}\\
&\qquad (: Q > Q_r)
\end{aligned}\right\} \quad (1)$$

where η : the water elevation, Q_x, Q_y:the components of the flux in the x-direction and y-direction, C:wave phase velocity, n:the ratio wave group velocity to wave phase velocity, tan β : bottom slope, h:water depth, g:acceleration of gravity

3.2 Current Model

The steady current,that is, time averaged and depth-integrated current induced by the spatial variation of the radiation stress, was calculated through numerical calculation by using depth-integrated continuity equation and momentum equation expressed as follows:

$$\left.\begin{aligned}
&\frac{\partial \zeta}{\partial t}+\frac{\partial U(h+\zeta)}{\partial x}+\frac{\partial V(h+\zeta)}{\partial y}=0\\
&\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+F_x-M_x+R_x+g\frac{\partial \zeta}{\partial x}=0\\
&\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+F_y-M_y+R_y+g\frac{\partial \zeta}{\partial y}=0
\end{aligned}\right\} \tag{2}$$

where ζ the mean water level elevation, U,V:the components of steady current in the x-direction and y-direction, F_x, F_y:the components of bottom friction term, M_x, M_y:the components of lateral diffusion term, R_x, R_y:the components of radiation stress term.

3.3 Sand Transport Model

In the experiments, a large quantity of suspended sand movement and obvious steady current were observed near the cylinder. It seemed from experiments that the sand transport direction agreed with the steady current direction in particular near the cylinder. Therefore, the net sand transport rate Q was calculated by using the following equation under the wave-current field obtained by Shibayama et al.(1989):

$$Q=\frac{\Phi\omega d}{(1-\lambda)} \tag{3}$$

$$\Phi=0.9\Theta^{1.2} \tag{4}$$

$$\Theta=\frac{(\tau_m-\tau_c)u}{\rho(sgd)^{1.5}} \tag{5}$$

where τ_m the maximum value of bed shear stress, τ_c the critical value of bed shear stress for initial sand movement, **u** the steady current velocity, λ the porosity, d the diameter of sand, w the fall velocity of sand, ρ the water density, and s the specific gravity of sand in water. The change of bottom topography was calculated by using the sand mass conservation equation of sand:

$$\frac{\partial z_b}{\partial t} = -\mathrm{div}\ Q \tag{6}$$

where z_b is the bed level.

By using the three sub-models described above, the quantity of local scour and deposition was calculated by using finite difference method with a rectangular calculation grid with a size of 2cm under the same conditions as laboratory experiment.

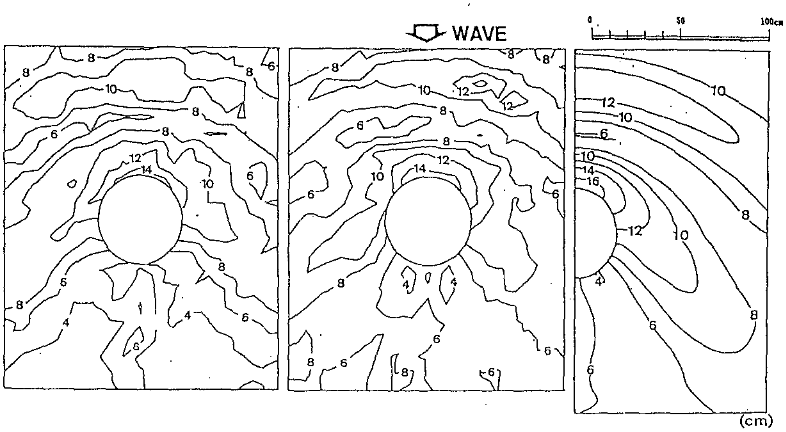
4. Laboratory Results and Comparison with Numerical Results

4.1 Wave Field

In the experiments, wave breaking was observed at an onshore side of the cylinder. Fig.3 shows the comparison of the distribution of wave height. Fig.3(a) is measured on the fixed bed and Fig.3(b) is measured on the sand from 5 to 7 hours after the wave generation. The numerical results by the time dependent mild slope equation is shown in Fig.3(c). Scour and deposition around 3 to 4cm was observed around a cylinder 6 hours after the wave generation. Therefore, Fig.3(b) shows the distribution of wave height after the bed topography changed in some degree. No significant change exists between Fig.3(a) and Fig.3(b),which means that no great variation in the wave field was developed in this case, even when the bed topography changes with time. Since calculated value,which was shown in Fig.3(c),was a little small compared with two measurements, the overall agreement between the measurements and the calculations is obtained. It is confirmed that the wave field around a large circular cylinder could be evaluated in a good accuracy by the time dependent mild slope equation.

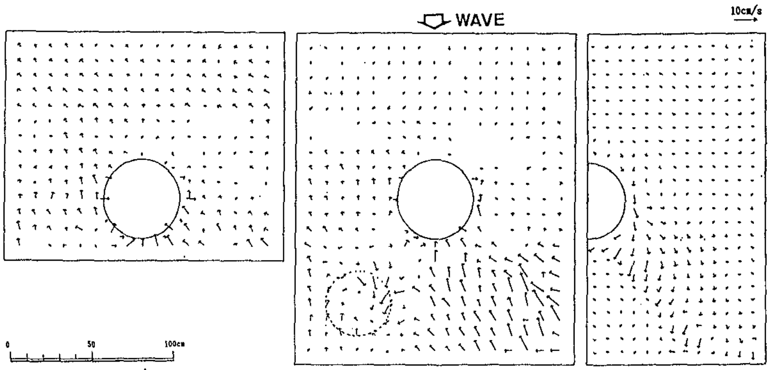
4.2 Current Field

Fig.4 shows comparison of the steady current velocity distribution between experimental results and calculated results. Fig.4(a) shows the distribution of measured steady current at upper level and Fig.4(b) at lower level. The calculated current field is also shown in



(a)Measured (Fixed Bed) (b)Measured (Sand Bcd,from 4 to 6 hours after wave generation.) (c)Calculated

Fig.3 Distribution of Wave Height (H_0=9.4cm,T_0=1.02s)



(a)Measured (Upper level) (b)Measured (Lower level) (c)Calculated

Fig.4 Steady Current Velocity Field (H_0=9.4cm,T_0=1.02s)

Fig.4(c). According to Fig.4(a) and Fig.4(b), the experimental steady currents were generally offshore directed. In particular, strong offshore currents occurred oblique behind the cylinder, where conspicuous wave breaking were observed. On the contrary, however, calculated steady currents have a tendency to be onshore directed on behind the cylinder. The reasons for the discrepancy will be discussed below. In the experiments, it is very difficult to measure onshore currents perfectly by using current meter. In the surf zone, generally, a mass of water at upper level is transported by breaking,bore-like waves. It causes onshore current at upper level and offshore current at lower level,that is, undertow. Therefore, it is impossible to measure steady currents above the wave trough because the current meter will be exposed to the air at the phase of trough. The steady current in the present numerical model is depth-integrated velocity calculated by assuming that the velocity is uniform over entire water depth. Therefore,undertow was not included in the model.

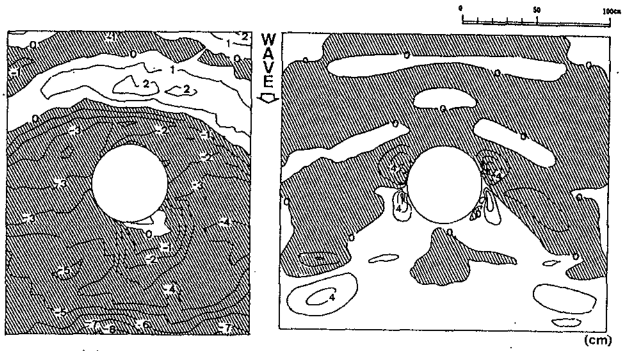
According to Fig.4(a) and Fig.4(b), steady current vectors direct generally from the right to the left. These longshore currents were generated by wave breaking and energy dispersion. The effect of longshore current is not included in the present model.

A cell of steady current, as shown by the dotted circle line in Fig.4(b), were observed. It indicates the existence of the vortex. In the experiments on sand bed, the bottom topography was considerably scoured in the vortex area. The vortex observed here is the separation vortex induced by the steady currents. In present experiments, however, it was impossible to investigate the vortex mechanism in detail due to the limitation of the measuring device.

4.3 Bottom Topography

Fig.5 shows a comparison of the bottom topography between the laboratory experiment and numerical model. The hatched areas in the figure indicate the eroded area. Since it took approximately 5 to 6 hours for bottom topography to reach equilibrium condition, both measured result and calculated result in Fig.5 are for 6 hours after the wave generation. It can be observed that the calculated results agree qualitatively with experimental results especially near the cylinder. However, some discrepancies exists in the area at a short distance from the surface of the cylinder. The experimental bottom topography shows that the bottom was mainly scoured in the onshore area of the cylinder, conversely, the bottom in the calculation was mainly scoured in the offshore area. Furthermore, the pattern of the experimental bottom topography is not symmetrical. The reasons for the discrepancy will be discussed below.

As was stated previously, undertow and longshore current were observed around a circular cylinder in the experiments. It seems that these currents gave significant effect on the bottom topography. In the experiments, a large quantity of suspended sand, which was transported under the effect of undertow and longshore current, were observed near the cylinder and in the surf zone. For



(a)Measured (b)Calculated

Fig.5 Bottom Topographies
(6 hours after wave generation)

this reasons, bottom topography in the surf zone, that is, onshore area of the cylinder, and near the cylinder was scoured and bottom topography in the offshore area was deposited. Furthermore, bottom topography change was asymmetric. According to the experiments carried out by Saito et al.(1990), under the uniform water depth condition, no significant undertow was observed. Saito et al.(1990) concluded that the effects of mass transport velocity and standing waves are important for the sand movement. The mechanism of the sand movement under the uniform water depth condition was different from that of under uniform slope condition. Numano et al.(1989) suggested the importance of the effect of the undertow for the bottom topographical changes by using numerical model. Here also we can conclude that the effect of undertow is important for the case of sloping bottom.

According to the experimental results of the steady current field, the separation vortex due to steady current was observed oblique behind the circular cylinder. Fig.5(a) shows that bottom topography at the vortex generation area shown in Fig.4(b) was considerably scoured. It indicates that in order to estimate the bottom topography change around the cylinder, it is necessary to consider the effect of the separation vortex due to steady currents. Shibayama and Win(1992) indicated the scouring effect of the vortex under steady current field in the surf zone by using a numerical model.

Since effects of undertow, longshore current and vortex are not included in the present numerical model, it is necessary to include these important effects as a next step.

5. Conclusions

Investigation for the mechanism of the local scour around a large circular cylinder installed on the uniform bottom slope due to waves and currents were performed experimentally and numerically. Major conclusions are summarized as follows:

① Undertow, longshore current and separation vortex due to longshore current were observed in laboratory experiment around a large circular cylinder on an uniform slope in the surf zone. It appeared that these currents and vortex give strong effects on the bottom topography.

② A numerical model was proposed for the local scour around a large circular cylinder on an uniform slope. To improve the model prediction, it is necessary to include the effect of undertow and vortex.

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