CHAPTER ONE HUNDRED FIFTY NINE

REPRODUCTION OF NEARSHORE CURRENTS BY A MATHEMATICAL MODEL

Hiroyoshi Tanaka* and Akira Wada**

ABSTRACT

In order to cope with such environmental problems as shoreline change and diffusion of discharged warm water and contaminations in the surf zone, it is necessary to predict velocity vector field due to nearshore currents accurately.

The present study is aimed at establishing a mathematical model applicable to the prediction of nearshore currents on actual coasts which have complicated bottom configurations. First, to investigate the mechanism of nearshore current generation hydraulic experiments were carried out. By the experiment it was made clear that the generation of a longshore current depends mainly upon a difference in mean water level in the longshore direction. After investigating estimation of radiation stress terms on the basis of the information obtained from the basic experiments a mathematical model of nearshore currents was developed and validity of the model was verified by both hydraulic model tests and field survey.

I. INTRODUCTION

On a coast having a gentle slope the surf zone is relatively wide, and consequently physical phenomena such as breaking of waves, nearshore currents, etc. may have some effects on the diffusion and shoreline change in and near the surf zone. In the case where the nearshore currents fluctuate as wave condition changes hourly, the currents may exert a great effect on the advective diffusion of small time-scale. Meanwhile, in case that nearshore current pattern doesn't change very much even if wave condition varies to some extent, the currents may also have some effects on the shoreline change of long-term scale.

To cope with the aforementioned environmental problems in and near the surf zone, therefore, it is necessary to accurately predict the velocity vector field due to nearshore currents. Many mathematical models of nearshore currents[1),2),3),4),5)] have been proposed so far, but they have applied the small amplitude wave theory even to the estimation of physical phenomena in and near the surf zone. Consequently, none of the existing models may reproduce well the nearshore currents on actual coasts which have complicated bottom configurations. Recently, field surveys on nearshore currents have been carried out positively. Although those are very important from the standpoint of understanding the

* Senior Research Engineer, Environment Department, Central Research Institute of Electric Power Industry, Abiko, Chiba Pref., Japan

** Manager of Environment Department, Central Research Institute of Electric Power Industry, Abiko, Chiba Pref., Japan

actual phenomena it is very difficult to minutely grasp the mechanism and main characteristics of nearshore currents from complicated phenomena on a real coast.

In the present study, first, the mechanism of nearshore currents was clarified by hydraulic experiments. Especially, this experimental study attached great importance to the grasp of transient phenomena, regarding it as a clue for elucidating the physical processes and mechanisms.

Next, a mathematical model was developed for the prediction of nearshore currents in the field. In this model, estimation of radiation stress terms was mainly studied so that it was compatible with the mechanism of nearshore current generation. Then, validity of the present mathematical model was examined by comparing the results of the numerical simulation with those of the hydraulic model tests and the field survey.

II. MAIN CAUSE OF NEARSHORE CURRENT GENERATION

2.1 Contents of the hydraulic experiments

The basin used for the present hydraulic experiments has dimensions of 50m × 22.6m × 1.5m. On one end of the basin three units of wave generators are installed and on the other end there is a 1/150 non-distorted model of a certain actual sea region. Regular waves were used in the experiments. The normally incident waves were generated by the wave generator and the obliquely incident waves were made by a simple wave maker installed temporarily. As for the wave condition used in the experiments the ranges of the average breaking wave height and the wave period were 2.5~3.6cm (3.8~5.4m in the prototype) and 1.25~2.5s (15.3~30.6s in the prototype) respectively. Thus, the wave height and the wave period were exaggerated in the experiments compared with those appearing in the field, in order to grasp clearly the physical phenomena and processes in the surf zone.

Measurement of water surface level was made by using capacitance type wave gauge, and velocity and direction of nearshore currents were measured with ultra sonic current meters. Great precision was required in measuring wave set-up. Hence, after confirming that no zero drift took place during the measurement, one or several cycles of analog time series data of the water surface level written on pen recorder charts were traced on section papers and the elevation due to wave set-up was estimated by counting the area put between the time variation curve of the water surface and the still water level by means of 1mm section.

2.2 Experimental results and discussion

For the purpose of making clear the cause of nearshore current generation, the experiment was at first carried out by applying waves whose average breaking wave height and period were 3.6cm and 2.5s (5.4m and 30.6s in the prototype). Figure 1 shows the horizontal distribution of wave set-up in a steady state with the velocity vector field due to nearshore currents under the offing condition of normal incidence of waves. From the figure it can be seen that longshore currents are governed mainly by a difference in mean water level in the longshore direction. A result of the field survey[6] carried out by Tokyo Electric Power Company is shown in Fig. 2. This result also tells the directions of longshore currents correlate with a difference in mean water level

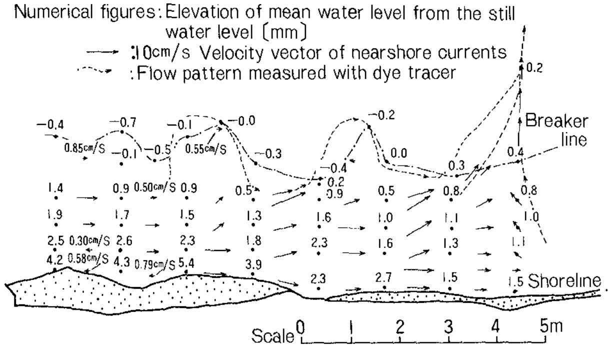


Fig.1 Relation between velocity vector field due to neashore currents and horizontal distribution of mean water level (Experimental result)

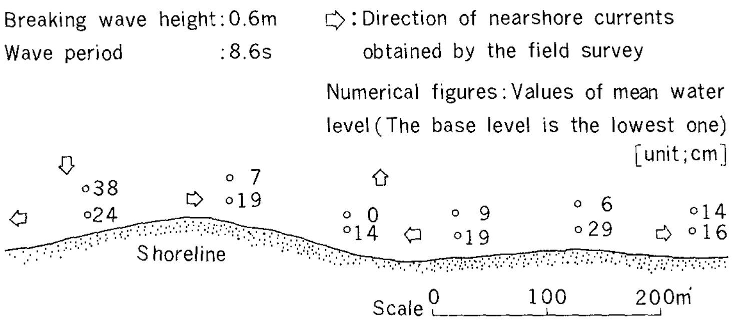


Fig.2 Relation between longshore current directions and horizontal distribution of mean water level (Result of field survey)

in the longshore direction.

The above investigations were performed in steady state conditions. Another kind of experiment was carried out in a transient state to examine the cause of longshore current generation. In this experiment the relation between the acceleration of a longshore current and the longshore gradient of mean water level was examined at the beginning of wave action, that is, at the time when the effects of friction force, eddy viscosity and inertia can be ignored. The several kinds of regular waves used in the experiment have 2.5~3.6cm in average breaking wave height, 1.25~2.5s in period and 0°~54° in incident angle. An example of the experimental results is shown in Fig. 3. Figure 3(a) shows how to obtain an initial acceleration $\partial v/\partial t$ from the velocity change of a long-shore current in a transient state and Fig. 3(b) shows how to obtain the initial force $-g\cdot\partial\bar{\eta}/\partial y$ from the initial difference in mean water level at two points near the velocity sampling point. From these figures it is found that the acceleration $\partial v/\partial t$ coincides with the value $-g\cdot\partial\bar{\eta}/\partial y$ fairly well in the initial state. Figure 4 shows the relation between $\partial v/\partial t$ and $-g\cdot\partial\bar{\eta}/\partial y$ at the beginning of the action of various kinds of normally and obliquely incident waves. These data were obtained at various points in the surf zone to the exclusion of the region near breaking points. The experimental result clearly shows that even if waves have any incident angle the initial acceleration $\partial v/\partial t$ agrees fairly well with the initial force $-g\cdot\partial\bar{\eta}/\partial y$ based upon a difference in

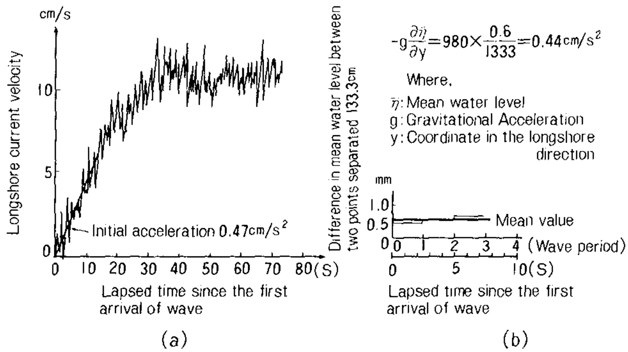


Fig.3 Velocity change of a longshore current and a difference in mean water level in the longshore direction at the beginning of wave action

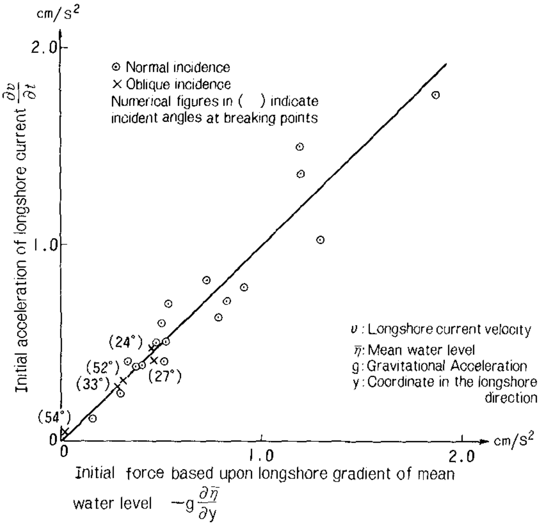


Fig.4 Relation between acceleration of a longshore current and force based upon a difference in mean water level in the longshore direction at the beginning of wave action.

mean water level. Also from this result it can be inferred that the generation of a longshore current depends mainly upon a difference in mean water level in the longshore direction.

III. FEATURES OF MATHEMATICAL MODELS

3.1 Mathematical model of wave field

The distribution of wave directions is calculated by using the following wave direction equation:

$$C\cdot\vec{i}\cdot\nabla\theta = -\vec{j}\cdot\nabla C \tag{1}$$

where C, θ, $\vec{i}$ and $\vec{j}$ are wave celerity, wave direction, unit vector in the direction of wave ray, and unit vector in the direction of wave crest line, respectively. This equation shows that the wave direction varies with the spatial change of wave celerity determined by the distribution of water depths. However, as the wave ray method ignores the effects of reflection, diffraction, and energy transfer in the direction of wave crest line, it can be inferred that wave direction as well as wave height cannot be correctly estimated at the places where a space between neighbouring wave rays is very small or where wave rays cross. Hence, wave directions at such places are obtained by interpolating those in the surrounding area where the wave ray method is valid. Such handling as mentioned above removes an unnatural scattering of wave directions.

The plane distribution of wave heights is dealt with independently of wave direction, and the numerical simulation of wave heights is carried out on the basis of the following mathematical model.

Regarding the outside of the surf zone, basic equations are obtained by integrating the continuity equation and the momentum equations in the vertical direction and by applying the small amplitude wave theory. If the two-dimensional momentum equations are applied as it is, numerical instability is liable to occur because variables (water surface elevation and flow rate per unit width) widely fluctuate in a short period. From a physical viewpoint it can be considered that in the actual fluid momentum of waves is diffused due to eddy viscosity. Therefore, the momentum equations should be modified as follows.

$$\partial Q_x/\partial t = -C^2\cdot\partial\eta/\partial x + K\cdot(\partial^2 Q_x/\partial x^2 + \partial^2 Q_x/\partial y^2) \tag{2}$$

$$\partial Q_y/\partial t = -C^2\cdot\partial\eta/\partial y + K\cdot(\partial^2 Q_y/\partial x^2 + \partial^2 Q_y/\partial y^2) \tag{3}$$

where t is the time, x and y the horizontal co-ordinates, η the water surface elevation, Q_x and Q_y the flow rates per unit width in the x-and y- directions respectively, and C the wave celerity. K is the apparent horizontal eddy viscosity under the action of waves. By using the continuity equation $\partial\eta/\partial t + \partial Q_x/\partial x + \partial Q_y/\partial y = 0$ and the momentum equations (2) and (3), Q_x, Q_y and η are calculated from the offshore boundary to the breaking points. Since the result of calculation on the change in wave height is not based on the group velocity but on the wave celerity the actual wave height should be modified as shown below by introducing the coefficient f_s :

$$H = (\eta_{max} - \eta_{min})\ (f_s/f_{so}) \tag{4}$$

where η_{max} and η_{min} are the maximum and minimum of η respectively in a wave period. The modifying coefficient f_s is defined by the following equation :

$$f_s = (1+2kh/\sinh 2kh)^{-1/2} \tag{5}$$

where k is the wave number and h the water depth. The subscript o in Eq.(4) indicates the value of f_s for the offshore boundary.

The above argument cannot be applied to waves after breaking since it depends on the small amplitude wave theory. In this model, the wave height in the surf zone H was assumed as follows.

$$H = \gamma h \tag{6}$$

where γ is the ratio of wave height to water depth after breaking. To estimate the ratio γ, an experiment was carried out by using a non-distorted model of scale 1/150. Figure 5 shows the experimental results. The waves used in the experiment had frequencies extending over 0.4~1.2 Hz. The following information is obtained from Fig. 5.

1) The ratio of breaking wave height to breaking water depth γ_b (shown by the mark ●) is about 0.8 even against any wave period.
2) γ immediately after breaking (shown by the mark ◑) is smaller than γ_b and when the waves advance farther in the surf zone the ratio (shown by the mark ○) becomes much smaller.

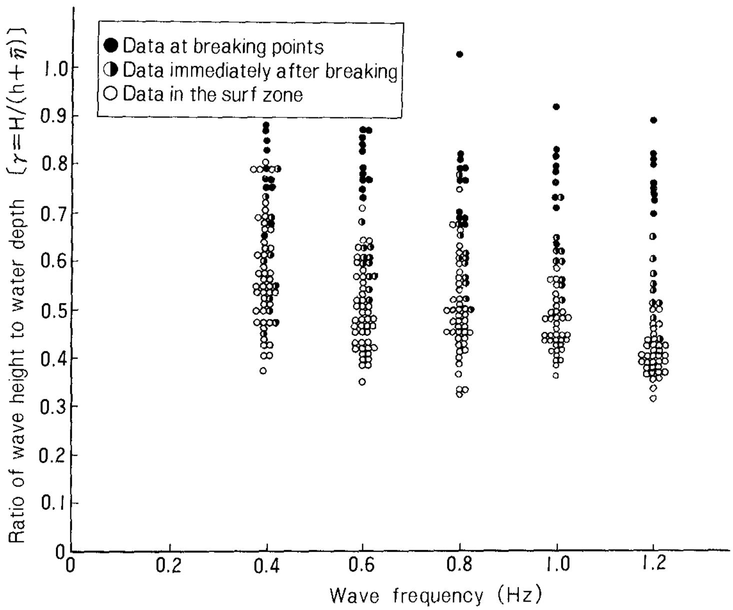


Fig.5 Ratio of wave height to water depth in the surf zone (Experimental Result)

3) In the frequency range of 0.4~1.2 Hz, the shorter the wave period, the smaller γ (shown by the mark o) is.

In the present study on nearshore currents, the waves concerned are regular waves (wave period 10.2s) and irregular waves (average wave period 7.3s). With regard to the regular waves, 0.4 is used as the ratio after breaking γ on the basis of Fig. 5 since the wave period 10.2s almost corresponds to the wave frequency 1.2 Hz on the hydraulic model of scale 1/150. In the present study, wave set-up $\bar{\eta}$ has not been determined yet at the stage of calculating the wave field because the model of wave field is dealt with independently of that of nearshore currents. Ignoring the effect of $\bar{\eta}$, therefore, the wave height after breaking H is approximated by the following equation :

$$H = 0.4h \tag{7}$$

Regarding the irregular waves, 0.55 is used as the ratio of root mean square wave height to water depth in the surf zone and the value is selected based on the results of the field survey[7]. Breaking wave height is assumed to be 80% of breaking water depth.

3.2 Mathematical model of nearshore currents

Basic experiments were conducted on the mechanism of nearshore current generation in parallel to the development of a mathematical model of nearshore currents. Judging from the information obtained by the experiments, it can be inferred that the greatest problem in our previous model[5] lies in the estimation of radiation stress terms. One problem is the estimation of a wave field related to radiation stresses and another is applicablity of the small amplitude wave theory to radiation stresses in and near the surf zone. Since the former problem was discussed in the foregoing paragraph, here follows a discussion on the development of a new mathematical model of nearshore currents in consideration of the latter problem.

The basic equations of the present mathematical model are depth averaged two-dimensional equations which are also averaged over one wave period.

$$\partial\bar{\eta}/\partial t + \partial\tilde{M}_x/\partial x + \partial\tilde{M}_y/\partial y = 0 \tag{8}$$

$$\partial\tilde{M}_x/\partial t + \partial(\tilde{U}\tilde{M}_x)/\partial x + \partial(\tilde{V}\tilde{M}_x)/\partial y$$
$$= -g\cdot(h+\bar{\eta})\cdot\partial\bar{\eta}/\partial x - R_x + K_h\cdot(\partial^2\tilde{M}_x/\partial x^2+\partial^2\tilde{M}_x/\partial y^2) - \gamma_b\cdot\tilde{U}\cdot\sqrt{\tilde{U}^2+\tilde{V}^2} \tag{9}$$

$$\partial\tilde{M}_y/\partial t + \partial(\tilde{U}\tilde{M}_y)/\partial x + \partial(\tilde{V}\tilde{M}_y)/\partial y$$
$$= -g\cdot(h+\bar{\eta})\cdot\partial\bar{\eta}/\partial y - R_y + K_h\cdot(\partial^2\tilde{M}_y/\partial x^2+\partial^2\tilde{M}_y/\partial y^2) - \gamma_b\cdot\tilde{V}\cdot\sqrt{\tilde{U}^2+\tilde{V}^2} \tag{10}$$

where x and y are the coordinates in the cross-shore and longshore directions, $\bar{\eta}$ the mean water level, $\tilde{U}$ and $\tilde{V}$ the mean current velocities in the x- and y- directions, $\tilde{M}_x$ and $\tilde{M}_y$ the mean flow rates per unit width in the x- and y- directions, g the gravitational acceleration, h the water depth, R_x and R_y the radiation stress terms in the x- and y- directions, K_h the horizontal eddy viscosity coefficient, and γ_b the bottom friction coefficient.

a) Ry in the surf zone

Based on the basic experiments it is evident that in the surf zone longshore currents are generated mainly due to a difference in wave set-up in the longshore direction. It can therefore be inferred that the contribution of R_y to longshore current generation is considerably small. It can be considered that if R_y is calculated by using the small amplitude wave theory as have been done so far the contribution of R_y to longshore current generation will be overestimated and consequently the numerical simulation will result in an unrealistic nearshore current field. It can also be supposed that R_y makes a small contribution to the generation of a longshore current which has a uniform velocity profile below the still water level but that it is connected with the longshore component of mass transport above the still water level. In the present model, R_y in the surf zone is ignored from an engineering standpoint. But near the breakwater not located in the longshore direction R_y is estimated with the same weight as that of R_x. In this case R_y may make an indirect contribution to the generation of a current because the breakwater interrupts the mass transport flow due to R_y and changes the mean water level.

b) R_x in the surf zone

The major cause of nearshore current generation is summarized as follows :

Wave set-up is formed so that it is almost in harmony with the radiation stress term R_x and usually it is not uniform in the longshore direction. Such a difference in the mean water level in the longshore direction generates a current, and it is important that the above mechanism is appropriately reflected in the mathematical model.

The basic experiments revealed the followings. In the surf zone, there is a narrow range where the mean water level is lower than the still water level but the range is very short in the cross-shore direction. In a very short distance from the breaking point, the mean water level turns out to be higher than the still water level, and the nearer the shoreline the higher the mean water level is. Because, at the place where the breaker line is prominent offshore (called the prominent place), wave set-up begins on the side more offshore than at the place where the breaker line is concave onshore (called the concave place), the mean water level of the prominent place is higher than that of the concave place at the same distance from a shoreline in the surf zone. Consequently, a longshore current flows from the prominent place to the concave one.

On the other hand, since in the previous mathematical model[5] the wave height and radiation stress tensors S_{xx} and S_{xy} are overestimated after breaking, R_x is underestimated especially immediately after breaking. So, in the computational result, the gradient of the mean water level rise just after breaking is considerably small as compared with the actual phenomenon and the wave set-down range in the surf zone is long in the cross-shore direction. Hence, the model may produce a wrong phenomenon that a longshore current flows from the concave place to the wave set-down range in the prominent place and may distort the whole nearshore current system. Thus, one of the weak points of the previous model seems to be attributable to considerably overestimating radiation stress tensors S_{xx} and S_{xy}, especially near the breaking points.

From the above argument, it can be understood that the estimation of R_x in the surf zone is very important and that it governs the nearshore current pattern. In the present study, the radiation stress term R_x is estimated as follows by re-examining the existing formulas of radiation stress tensors :

The coefficient α is determined as Eq.(11) on the basis of the result of a basic experiment on the distributions of the mean water levels and wave heights in and near the surf zone under the wave condition of normal incidence. Then, R_x is approximated by multiplying R_{xs} by α. Here, R_{xs} is the value obtained according to the small amplitude wave theory.

$$-g\cdot(h+\bar{\eta})\cdot\partial\bar{\eta}/\partial x \simeq \alpha\cdot(1/\rho)\cdot(\partial S_{xx}/\partial x)s \qquad (11)$$

where ρ is the density of water. $(\partial S_{xx}/\partial x)s$ is calculated according to the small amplitude wave theory by using the distribution of wave heights. The coefficient α is inferred from a lot of experimental data related to high waves. α is assumed to be 1 very near the breaking point and it abruptly decreases to 0.1 at a little more shoreward place where waves begin to be violently deformed to the bore-shape. In the range of $1/3 \leqq S/B \leqq 1$ where the bore-shape is completely established α is assumed to be 0.8 constant. Here, S is a distance from the breaker line and B the surf zone width. α is also assumed to change in linear proportion to S between the two boundaries where α = 0.1 and α = 0.8.

c) R_y on the outside of the surf zone

In the sea region where the small amplitude wave theory is valid the whole R_{ys} may contribute to current generation, but in the area where the finite amplitude wave theory has to be applied only a certain percentage of R_{ys} is assumed to contribute to nearshore current generation. R_y is assumed to be approximated by multiplying R_{ys} by $\sqrt{(h-h_b)/(h_s-h_b)}$ because the percentage of R_{ys}'s contribution to current generation is difficult to estimate quantitatively even by an experiment. Here, h_s is the minimum water depth in the area where the existing model is applicable, h_b the breaking water depth and R_{ys} the value of R_y based on the small amplitude wave theory.

d) R_x on the outside of the surf zone

R_x needs a thinking different from the discussion on R_y because the cross-shore component always has a boundary intersecting the direction. In the present study, R_x is estimated on the basis of the small amplitude wave theory on the outside of the surf zone from an engineering standpoint.

The above discussion on the estimation of radiation stress terms is summarized as shown in Table-1.

IV. CONDITIONS AND METHOD OF NUMERICAL SIMULATION

4.1 Validity verification of the mathematical model by the hydraulic model

(1) Sea region concerned and mesh size for calculation

The numerical simulation was carried out with respect to the sea region shown in Fig. 6. This sea region is characterized by a gently sloping coast facing the Pacific Ocean and by existence of breakwaters. The results of calculations are compared with those of the hydraulic experiment. The comparison is made on the breaker line and the velocity vector field due to nearshore currents. The mesh size for calculation is 20m and the computational time step is 1/100 of wave period.

(2) Incident waves

The incident wave heights and periods are given by converting the values measured by the hydraulic model into those in the prototype. The average wave height and the wave period of usual waves are 0.77m and

Table-1 Estimation of radiation stress terms for calculating nearshore currents

	In the area where a shoreline is monotonous			Near a breakwater or a cape	
	On the outside of the surf zone		In the surf zone	On the outside of the surf zone	In the surf zone
	In the area where the small amplitude wave theory is usually applied	In the area where the finite amplitude wave theory is usually applied			
R_x	R_{xs}		$\alpha \cdot R_{xs}$ $(\alpha \leqq 1)$	R_{xs}	$\alpha \cdot R_{xs}$
R_y	R_{ys}	$\sqrt{(h-h_b)/(h_s-h_b)}$ $\times R_{ys}$	0	R_{ys}	$\alpha \cdot R_{ys}$

R_x ; Radiation stress term in the cross-shore direction

R_y ; Radiation stress term in the longshore direction

h ; Water depth

h_b ; Breaking water depth

h_s ; Minimum water depth in the area where the small amplitude wave theory is valid

α ; Coefficient determined by a basic experiment

Subscript s ; Value calculated on the basis of the small amplitude wave theory

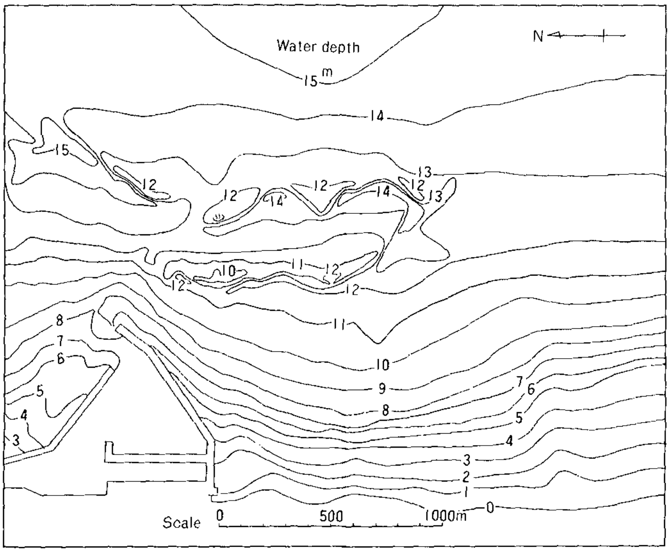


Fig.6 Bottom topography of the sea region concerned

10.2s at a distance 1 km from the shoreline. Those of high waves are 3.1m and 12.9s.

(3) Horizontal eddy viscosity coefficients $K's$ used for calculating wave fields

1 m^2/s and 2.5 m^2/s are used for calculating usual wave and high wave fields respectively on the basis of the preceding basic experiments.

(4) Horizontal eddy viscosity coefficients $K_h's$ used for calculating nearshore currents

5 m^2/s and 10 m^2/s are used for calculating nearshore currents under the action of usual waves and those under high waves respectively on the basis of the preceding basic experiments.

(5) Bottom friction coefficient γ_b used for calculating nearshore currents

On the assumption that the friction force is proportional to the square of current speed, 0.02 is taken as the non-dimensional bottom friction coefficient on the basis of the hydraulic model.

(6) Method of numerical calculation

The wave field is first solved independently of nearshore currents by assuming that the interaction between waves and nearshore currents is small. Then, the computed wave field is used for calculating the values of radiation stress tensors. As the initial conditions, the mean water level and the flow rates are set equal to zero. On the offshore boundary, the mean water level is always equal to zero. At the breakwaters, on the shoreline and on the side boundaries, $\tilde{M}_n = \partial\tilde{M}_t/\partial n = 0$, where $\tilde{M}_n$ and $\tilde{M}_t$ are the flow rates per unit width, normal and tangent to the boundaries.

In the numerical calculation, the Leap-Frog and Lax-Wendroff schemes are applied in explicit form. The flow rates per unit width $\tilde{M}_x$, $\tilde{M}_y$ and the mean water elevation $\bar{\eta}$ are calculated every time step until they become steady.

4.2 Validity verification of the mathematical model by the field survey

(1) Sea region concerned and mesh size for calculation

Although the sea region concerned is the same as that described in 4.1 the bottom configuration surveyed in December, 1978 is applied. The sea region for calculation is 12.5km in the longshore direction and 0.8km in the cross-shore direction. The mesh size is 30m in the longshore direction and 20m in the cross-shore direction.

(2) Incident waves

The applied waves were observed at almost the same time as that of nearshore current survey. The incident direction of waves is normal to the offshore boundary. Two kinds of regular waves are used for calculation. One is the significant wave whose wave height and period are 0.66m and 7.3s. The other is the root mean square wave whose wave height and period are 0.44m and 7.3s respectively.

(3) K and K_h

$K=1m^2/s$ and $K_h=5m^2/s$ are used for the numerical simulation.

(4) γ_b

Since γ_b on the actual sandy coast may be different from that on a hydraulic model covered with mortal, we use 0.00637 which has been proposed so far.

(5) Effect of the breakwater on wave energy dissipation

The energy dissipation coefficient ν_d is defined by Eq.(12), and the present mathematical model considers a decrease in wave height due to mounds of concrete armour units in front of the breakwater.

$$\partial(EC_{gx})/\partial x = -\nu_d k^2 E \qquad (12)$$

where x is the coordinate in the cross-shore direction, E the wave energy density, k the wave number, and C_{gx} the x-component of group velocity. It is assumed that $\nu_d=10^2$ cm^2/s along the breakwater normal to the shoreline, $\nu_d=0$ cm^2/s at a distance of 400m from the breakwater, and that ν_d linearly changes in the longshore direction between the two boundaries where $\nu_d=10^2$ cm^2/s and $\nu_d=0$ cm^2/s.

(6) Method of numerical calculation

The method is basically the same as that described in 4.1 (6).

V. RESULTS OF NUMERICAL SIMULATION AND DISCUSSION

5.1 Breaker line and distribution of breaking wave heights

Validity of the mathematical model of wave height distribution on the outside of the surf zone has been examined by comparing the position of the breaker lines between the mathematical and experimental results.

As an example of the comparison Fig. 7 shows the breaker lines under the action of usual waves. From this figure it can be concluded that the two breaker lines agree fairly well except for the places where the breaker line is prominent offshore. In the prominent places where shoals grow, there may be some problems with regard to the breaking condition.

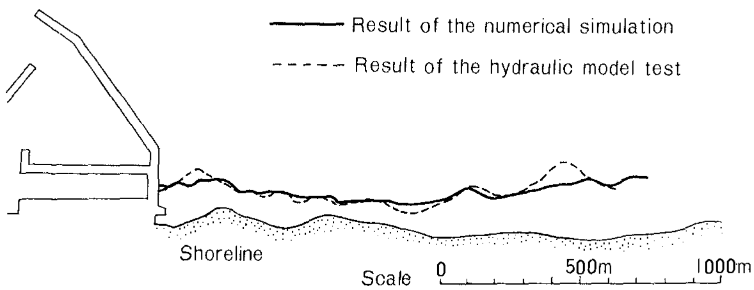


Fig.7 Comparison of the breaker line between the numerical and experimental results

Figure 8 shows comparisons between the results of the field survey and those of the numerical simulation regarding the distribution of breaking wave heights and breaker line. The significant wave trains are concerned in calculating wave field. The distribution of breaking wave heights calculated by the numerical simulation agrees fairly well with the result of the field survey at a long distance from the breakwater, but near the breakwater the calculated wave height is fairly larger than that of the field observation. It can be considered that the result of the field survey was influenced by cooling water discharge from a foot of the breakwater. The surf zone width obtained by computation is a little smaller than the result of the field survey at the places where both results are almost equal regarding the breaking wave height. This may be due to the fact that the breaker line observed with the eye in the field corresponds to that of wave trains larger than the significant wave.

In conclusion, it can be said that the present mathematical model of wave field reproduces well the distribution characteristics of breaking wave heights and breaking positions on the actual coast.

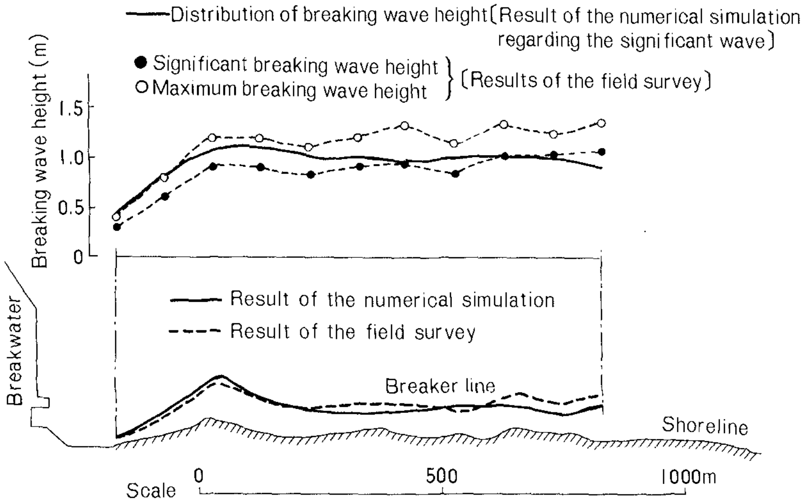


Fig.8 Comparisons of the results of breaking wave height distribution and breaker line between the numerical simulation and the field survey

5.2 Velocity vector field due to nearshore currents

Figure 9 shows a comparison of the flow pattern due to nearshore currents under the action of usual waves between the numerical simulation and the hydraulic model test. Figure 10 shows a comparison of nearshore currents under the high waves between the calculation and the experiments.

The followings are revealed from Figs. 9 and 10.

(1) The computed result reproduces the following situation often found in the field. At the place where the breaker line is prominent offshore, the shoreward current is remarkable, while at the place where the breaker line is concave onshore the rip current is predominant.

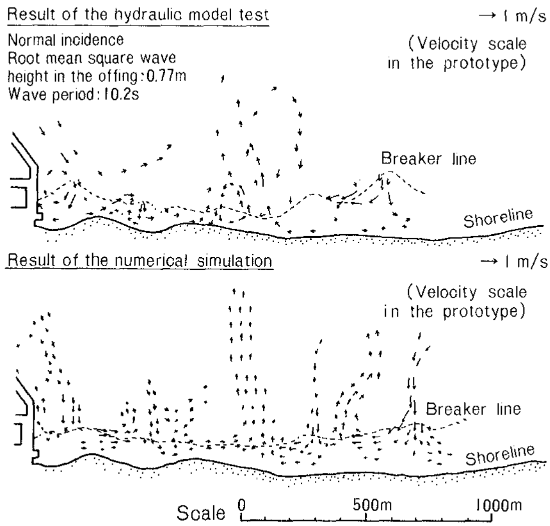


Fig.9 Comparison of the result of nearshore current pattern under the action of usual waves between the numerical simulation and the hydraulic model test

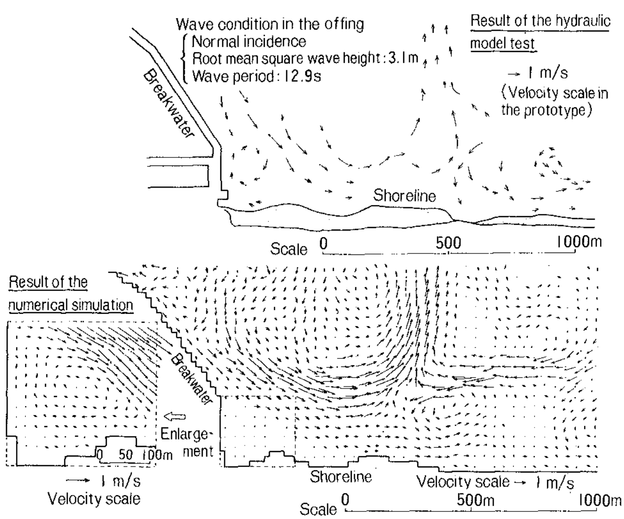


Fig.10 Comparison of the result of nearshore current pattern under the action of high waves between the numerical simulation and the hydraulic model test

(2) The mathematical result agrees fairly well with the experimental result regarding the following phenomena.

a) A notable rip current reaching the offing at a distance of 800~900m from the foot of the breakwater

b) Longshore currents in the surf zone

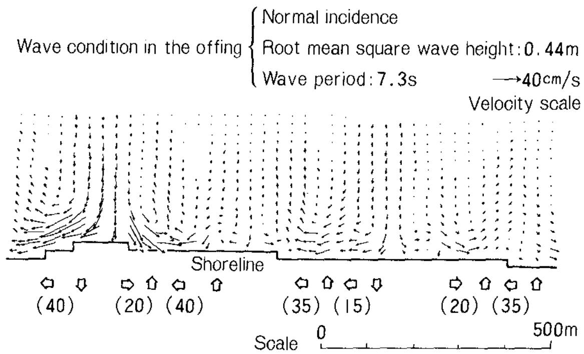
c) A circulating flow near the breakwater

Next, Fig. 11 shows a comparison of nearshore currents between the present mathematical model and the field survey. The numerical simulation was carried out by using the regular wave condition of root mean square wave obtained from irregular waves in the field. The flow pattern in the field was obtained by using ball floats. Figure 12 shows the velocity vector field due to the previous mathematical model[5] under the same computational conditions as those of the present model.

The followings are obtained from Figs. 11 and 12.

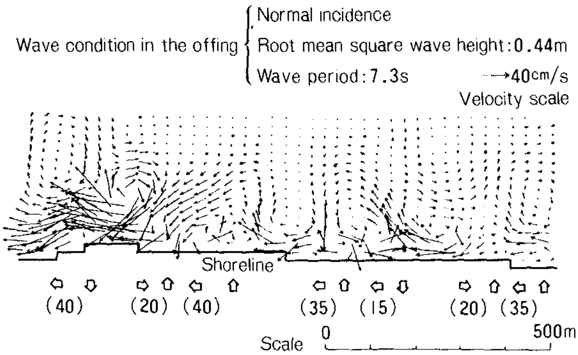
(1') Considering that a field survey cannot simultaneously grasp the whole flow pattern due to nearshore currents under irregular wave field varying from time to time and that the result may include uncertain factors, it can be said that the present mathematical model makes it possible to reproduce the characteristics of nearshore currents on the actual coast.

(2') The nearshore currents based on the previous mathematical model[5] don't agree well with those obtained by the field survey especially in the surf zone. It can be understood that the present mathematical model has attained considerable improvement in the accuracy of prediction as compared with the previous model[5].



⇨ : Direction of nearshore currents obtained by the field survey
Numerical figures in ( ) : Mean values of longshore current velocity obtained by the field survey [unit;cm/s]

Fig.11 Comparison of the result of nearshore current pattern between the numerical simulation and the field survey



⇨ : Direction of nearshore currents obtained by the field survey
Numerical figures in ( ) : Mean values of longshore current velocity obtained by the field survey (unit; cm/s)

Fig.12 Calculated result of nearshore current pattern on the basis of the previous mathematical model

VI. CONCLUSION

Main conclusions are summarized as follows.

(1) Basic experiments showed that longshore currents are generated mainly due to a difference in wave set-up in the longshore direction.

(2) The results of the numerical simulations well reproduced velocity vector fields due to nearshore currents both under the action of usual waves and under that of high waves.

(3) Validity of the present mathematical model is verified by both experiments and field survey and it is considered that the model is satisfactorily applicable to predicting nearshore currents in the field, though further study must be made to examine the validity of the model under obliquely incident waves.

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