

CHAPTER 150

NEARSHORE CIRCULATIONS DUE TO WAVE INDUCED CURRENTS BY OFFSHORE BREAKWATER IN FINITE ELEMENTS

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1. INTRODUCTION

The objective of the present study is concerned with the numerical prediction of wave patterns and wave induced currents adjacent to a breakwater. The wave theory used is that of Berkhoff's (1972) mild slope wave equation with effects of diffraction, refraction and reflection described as Bettess, Liang and Bettess (1984). A finite element model is applied with appropriate boundary conditions. The singularity in the velocity at the tip of the breakwater is modelled effectively using the technique of Henshell and Shaw (1975), originally developed for elasticity. In the case of waves induced currents a potential representation of velocity in the fluid has been used to derive a set of radiation stress expressions based on the theory of Longuet-Higgins (1964, 1970a,b), which are for an arbitrary wave pattern and the bottom variation. These expressions used account for the mean sea level and satisfy Mei's (1973) static balance of momentum flux.

The radiation stress is applied to obtain forcing terms for use in a shallow water equation in conjunction with limiting ratio wave breaking where wave height, wave period, wave steepness and beach slope may be considered. Finally, an offshore breakwater on a beach for shore protection has been applied in a complete finite element model to predict both wave pattern and nearshore currents. Two angles of wave incidence are chosen. A series result has been produced.

2. THEORIES

2.1. WAVES

The wave equation of Berkhoff (1972,1975) is used as

$$\nabla \cdot (c c_g \nabla \phi_0) + \frac{\omega^2 c}{c} \phi_0 = 0 \quad (1)$$

with ω : angular frequency,

c : wave celerity and $c = \omega/k$, k is a wave number,

c_g : group velocity by $c_g = nc$ and $n = \frac{1}{2}(1+2kh/\sinh 2kh)$

ϕ_0 : velocity potential in deep water. ²

For shallow water due to kh is small and $\tanh kh = kh$ Eq. (1) becomes

$$\nabla \cdot (h \nabla \phi_0) + \frac{\omega^2}{g} \phi_0 = 0 \quad (2)$$

For deep water, kh is large and so $\tanh kh = 1$, this leads to $c = g/\omega$ and $n = 1/2$, so that

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$$\nabla^2 \phi_0 + \frac{\omega^4}{g^2} \phi_0 = 0 \quad (3)$$

The boundary conditions of Eq. (1) must be satisfied and specified. On a solid boundary the velocity must be zero and hence $\partial \phi / \partial n = 0$, with n : outward normal to the surface. This implies a total reflection of a wave. In a real problem the reflection will be partial as energy absorption will occur on a beach due to wave breaking, or on a real breakwater where the porous nature of the boundary does not result in a zero boundary velocity. For such a boundary the condition can be written as

$$\frac{\partial \bar{\phi}}{\partial n} = \frac{\alpha}{c} \frac{\partial \bar{\phi}}{\partial t} \quad (4)$$

where $\bar{\phi}$: velocity potential for periodic wave, and

$\bar{\phi}(x, y, z, t) = \phi(x, y, z) \exp(i t)$

α : a real dimensionless damping coefficient, as

$\alpha = 0$: total reflection

$\alpha = 1$: total absorption

$0 \leq \alpha \leq 1$: any partial reflection.

Where the energy absorption is due largely to inertia terms, such as occur in wave breaking, α could be given a complex value.

2.2. WAVE BREAKING

Waves break in different ways depending on wave height, wave period, steepness and beach slope. The determination of the initial line of breaking is a purely empirical matter. Breaking criteria are based on three important aspects of the breaking theories which are solitary wave, Airy wave theories and similarity parameter introduced by McCowan (1891) etc., Komar and Gauphan (1972) and Iribarren and Nogales (1949) respectively.

Lacking direct empirical data for waves with varying amplitude, a plausible criterion to waves with longshore modulation is extended as

$$\phi(x, y, t) = - \frac{i g}{\omega} \eta'(x, y, t) \quad (5)$$

where $\bar{\eta}$ is the local wave amplitude. Approximating for shallow water and invoking along with breakerline

$$\eta'(x, y) = \gamma(\bar{\eta} + h) \quad (6)$$

with γ is an empirical breaking criterion, obtain from previous ideas.

Inside the surfzone wave energy is dissipated due to the generation of turbulence in wave breaking and bottom friction. The local wave amplitude decreases towards the shore and becomes negligible along the mean shoreline. Using three different breaking criteria to find the waves inside the surfzone, the variations of radiation stresses are obtained in two channel meshes of slope = 1/10 and 1/50, as shown in Figs. (1) and (2). There are no significant differences among three criteria in mild slope case but for the steeper of slope = 1/10, we would prefer to use one of the criteria of Iribarren and Nogales or Komar and Gauphan, which considers more factors, such as bottom slope and wave steepness.

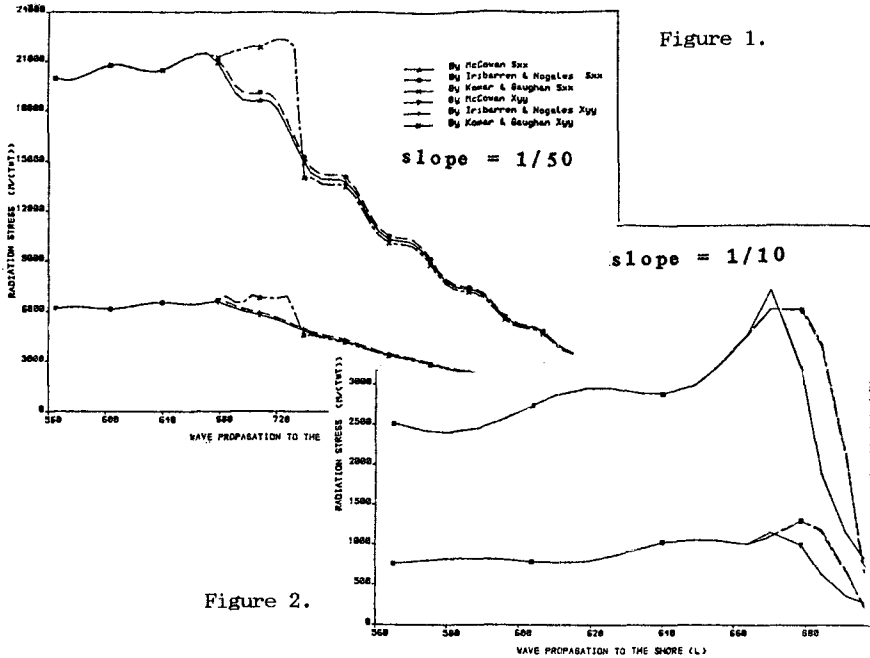


Figure 2.

2.3. RADIATION STRESSES

Based upon Longuet-Higgins and Stewart (1964) and Mei (1973), a finite element model of radiation stress has been developed by Liang (1983) to generalize the radiation stress for arbitrary wave patterns and bottom variations. Mei (1973) mentioned that the equation of a static balance of momentum is given as

$$\bar{P}_h \frac{\partial h}{\partial x_\alpha} - \rho g h \frac{\partial \bar{\eta}}{\partial x_\alpha} - \frac{\partial S_{\alpha\beta}}{\partial x_\beta} = 0 (ka)^2 \quad (8)$$

For constant depth ($h = \text{constant}$) the equation becomes

$$-\rho g h \frac{\partial \bar{\eta}}{\partial x_\alpha} - \frac{\partial S_{\alpha\beta}}{\partial x_\beta} = 0 \quad (9)$$

where $\alpha, \beta = 1, 2$, $S_{\alpha\beta}$ is the radiation stress tensor and $\bar{\eta}$ is the time average of mean sea level. For slowly varying depth, due to higher derivatives of h are small comparing with other two terms, therefore the first term is usually insignificant. The static balance is also as Eq. (9) shown.

The next step is to determine the expressions of $S_{\alpha\beta}$ and $\bar{\eta}$ in Eq. (9). The radiation stress tensor is defined as

$$S_{\alpha\beta} = S_{\alpha\beta}^{(1)} + \delta_{\alpha\beta} S^{(2)} \quad (10)$$

where $\delta_{\alpha\beta}$ being the kronecker delta and to the second order of the approximation these expressions are equivalent to

$$S_{\alpha\beta}^{(1)} = \rho \int_{-h}^0 \overline{u_{\alpha} u_{\beta}} dz + O[(ka)^2] \quad (11)$$

$$S_{zz}^{(2)} = \int_0^{\eta} \overline{p} dz + \int_{-h}^0 \overline{p} dz - \frac{1}{2} \rho g (\bar{\eta} + h)^2 + O[(ka)^2] \quad (12)$$

In the first term of Eq. (12), the pressure is taken as hydrostatic

$$p = \rho g (\eta - z), \quad 0 < z < \eta(x, y, t). \quad (13)$$

In the second term of the equation, P can be obtained from the time averaged as

$$\bar{p} = \rho g (\bar{\eta} - z) + \rho \int_{-h}^0 \frac{\partial}{\partial x_i} (\overline{u_i w}) dz - \rho (\bar{w})^2 \quad (14)$$

with $x_i = x, y$ and $u_i = u, v$. Therefore components of radiation stress tensor can be written as:

$$\begin{aligned} S_{xx} = & \int_{-h}^0 \rho (\bar{u}^2 - \bar{w}^2) dz + \frac{\partial}{\partial x} \int_{-h}^0 \int_{-h}^0 \rho \overline{uw} dz' dz \\ & + \frac{\partial}{\partial y} \int_{-h}^0 \int_{-h}^0 \rho \overline{vw} dz' dz + \rho g h \bar{\eta} + \int_0^{\eta} \bar{p} dz \end{aligned} \quad (15)$$

$$S_{xy} = \int_{-h}^{\eta} \rho \overline{uv} dz \quad (16)$$

S_{yy} and S_{yz} can be found by interchanging x and y everywhere in Eqs. (13) and (14).

The mean sea level of Eq. (9) is derived from Longuet-Higgins (1967) and Mei (1973) as

$$\bar{\eta} = -\frac{1}{g} \frac{\partial \bar{\theta}}{\partial t} - \frac{1}{2g} \left[\left(\frac{\partial \bar{\theta}}{\partial x} \right)^2 + \left(\frac{\partial \bar{\theta}}{\partial y} \right)^2 - \left(\frac{\partial \bar{\theta}}{\partial z} \right)^2 \right] \quad z = 0 \quad (17)$$

or

$$\bar{\eta} = -\frac{1}{g} \frac{\partial \bar{\theta}}{\partial t} - \frac{1}{2g} \left[\bar{u}^2 + \bar{v}^2 - \bar{w}^2 \right] \quad z = 0 \quad (18)$$

If set

$$\theta(x, y) = A(x, y) + iB(x, y) \quad (19)$$

and

$$\bar{\theta} = \text{Re} [\theta(x, y) \cosh k(z+h) \exp(-i\omega t)] \quad (20)$$

Where A and B are real and $i = \sqrt{-1}$, then the velocities, such as u, v and w and their square or time-averaged values etc., are easy to derive in terms of A and B . That means if we can find the values of A and B and their higher order derivatives through velocity potential of wave in the technology of finite element simulations, we can find the tensor straightwards.

The major interest for us is to find the tractive forces which induce currents and set-up. These are

$$\tau_x = - \left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right) \quad (21)$$

$$\tau_y = - \left(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y} \right) \quad (22)$$

The gradients can be found in terms of A and B as

$$\begin{aligned} \frac{\partial S_{xx}}{\partial x} = & \frac{\rho}{8} \left[\left[2 \left(\frac{\partial A}{\partial x} \frac{\partial^2 A}{\partial x^2} + \frac{\partial B}{\partial x} \frac{\partial^2 B}{\partial x^2} \right) - \frac{1}{2} \frac{\partial F}{\partial x} \right] \left(\frac{\sinh 2kh + 2kh}{k} \right) \right. \\ & + \left[\left(\frac{\partial A}{\partial x} \right)^2 + \left(\frac{\partial B}{\partial x} \right)^2 - \frac{F}{2} \right] \frac{\partial}{\partial x} \left(\frac{\sinh 2kh + 2kh}{k} \right) \Big] \\ & + \frac{\rho}{4} \left[\frac{\partial F}{\partial x} h \cosh^2 kh + F \frac{\partial h}{\partial x} \cosh^2 kh + Fh \frac{\partial}{\partial x} (\cosh^2 kh) \right. \\ & + (A^2 + B^2) \frac{\partial}{\partial x} (k^2 h) + 2k^2 h \left(A \frac{\partial A}{\partial x} + B \frac{\partial B}{\partial x} \right) \Big] \\ & + \frac{\rho}{8g} \left[\left[\left(\frac{\partial A}{\partial x} \right)^2 + \left(\frac{\partial B}{\partial x} \right)^2 + \left(\frac{\partial A}{\partial y} \right)^2 + \left(\frac{\partial B}{\partial y} \right)^2 \right] \cosh^2 kh \right. \\ & - k^2 (A^2 + B^2) \sinh^2 kh \Big] \left[\left[\left(\frac{\partial A}{\partial x} \right)^2 + \left(\frac{\partial B}{\partial x} \right)^2 + \left(\frac{\partial A}{\partial y} \right)^2 \right. \right. \\ & + \left. \left. \left(\frac{\partial B}{\partial y} \right)^2 - k^2 (A^2 + B^2) \right] \cosh kh \sinh kh \frac{\partial(kh)}{\partial x} \right. \\ & + \left. \left[\left(\frac{\partial A}{\partial x} \frac{\partial^2 A}{\partial x^2} + \frac{\partial B}{\partial x} \frac{\partial^2 B}{\partial x^2} \right) + \left(\frac{\partial A}{\partial y} \frac{\partial^2 A}{\partial x \partial y} + \frac{\partial B}{\partial y} \frac{\partial^2 B}{\partial x \partial y} \right) \right] \cosh^2 kh \right. \\ & - \left. k \left[k \left(A \frac{\partial A}{\partial x} + B \frac{\partial B}{\partial x} \right) + \frac{\partial k}{\partial x} (A^2 + B^2) \right] \sinh^2 kh \right] \end{aligned} \quad (23)$$

$$\begin{aligned} \frac{\partial S_{xy}}{\partial x} = & \frac{\rho}{8} \left[\left(\frac{\partial A}{\partial x} \frac{\partial A}{\partial y} + \frac{\partial B}{\partial x} \frac{\partial B}{\partial y} \right) \frac{\partial}{\partial x} \left(\frac{\sinh 2kh + 2kh}{k} \right) \right. \\ & + \left. \left(\frac{\sinh 2kh + 2kh}{k} \right) \left(\frac{\partial A}{\partial x} \frac{\partial^2 A}{\partial x \partial y} + \frac{\partial B}{\partial x} \frac{\partial^2 B}{\partial x \partial y} + \frac{\partial A}{\partial y} \frac{\partial^2 A}{\partial x^2} + \frac{\partial B}{\partial y} \frac{\partial^2 B}{\partial x^2} \right) \right] \end{aligned}$$

$$\frac{\partial S_{xy}}{\partial y} = \frac{\rho}{8} \left[\left(\frac{\partial A}{\partial y} \frac{\partial A}{\partial x} + \frac{\partial B}{\partial y} \frac{\partial B}{\partial x} \right) \frac{\partial}{\partial y} \left(\frac{\sinh 2kh + 2kh}{k} \right) \right. \quad (24)$$

$$\left. + \left(\frac{\sinh 2kh + 2kh}{k} \right) \left(\frac{\partial A}{\partial y} \frac{\partial^2 A}{\partial x \partial y} + \frac{\partial B}{\partial y} \frac{\partial^2 B}{\partial x \partial y} + \frac{\partial A}{\partial x} \frac{\partial^2 A}{\partial y^2} + \frac{\partial B}{\partial x} \frac{\partial^2 B}{\partial y^2} \right) \right]$$

where

(25)

$$F = -\frac{1}{h} \left[\frac{\partial h}{\partial x} \left(A \frac{\partial A}{\partial x} + B \frac{\partial B}{\partial x} \right) + \frac{\partial h}{\partial y} \left(A \frac{\partial A}{\partial y} + B \frac{\partial B}{\partial y} \right) + (A^2 + B^2) k \tanh kh \right]$$

$$+ \left(\frac{\partial A}{\partial x} \right)^2 + \left(\frac{\partial A}{\partial y} \right)^2 + \left(\frac{\partial B}{\partial x} \right)^2 + \left(\frac{\partial B}{\partial y} \right)^2 \quad (26)$$

$$\begin{aligned} \frac{\partial F}{\partial x} = - \left[\frac{\partial}{\partial x} \left(\frac{A}{h} \frac{\partial h}{\partial x} \frac{\partial A}{\partial x} \right) + \frac{\partial}{\partial x} \left(\frac{B}{h} \frac{\partial h}{\partial x} \frac{\partial B}{\partial x} \right) + \frac{\partial}{\partial x} \left(\frac{A}{h} \frac{\partial h}{\partial y} \frac{\partial A}{\partial y} \right) \right. \\ \left. + \frac{\partial}{\partial x} \left(\frac{B}{h} \frac{\partial h}{\partial y} \frac{\partial B}{\partial y} \right) + \frac{\partial}{\partial x} \left(\frac{A^2 k}{h} \tanh kh \right) + \frac{\partial}{\partial x} \left(\frac{B^2 k}{h} \tanh kh \right) \right] \\ + \frac{\partial}{\partial x} \left[\left(\frac{\partial A}{\partial x} \right)^2 + \left(\frac{\partial A}{\partial y} \right)^2 + \left(\frac{\partial B}{\partial x} \right)^2 + \left(\frac{\partial B}{\partial y} \right)^2 \right] \quad (27) \end{aligned}$$

The expression for $\frac{\partial F}{\partial y}$ is analogous to that $\frac{\partial F}{\partial x}$ just change x to y everywhere in Eqs. (22) and (26).

2.4. NEARSHORE CURRENTS

The finite element program to be used to calculate currents in the whole nearshore system is based upon the penalty form of shallow water equations of Zienkiewicz (1978) for a steady state which are similar in form to the Navier - Stokes equations for turbulent flow. These are

$$\frac{\partial}{\partial x} (h \bar{u}) + \frac{\partial}{\partial y} (h \bar{v}) = \frac{\eta}{\lambda} \quad (28)$$

$$\begin{aligned} \rho \left[\frac{\bar{u} \bar{u}}{\partial x} + \frac{\bar{v} \bar{v}}{\partial y} - f \bar{v} \right] - \rho g \lambda \left[\frac{\partial}{\partial x} (h \bar{u}) + \frac{\partial}{\partial y} (h \bar{v}) \right] \\ = 2 \frac{\partial}{\partial x} \left[\mu_h \frac{\partial \bar{u}}{\partial x} \right] + \mu_h \frac{\partial}{\partial y} \left(\frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial x} \right) + \frac{\tau_x}{h} - \frac{C \bar{u}}{h} \quad (29) \end{aligned}$$

$$\begin{aligned} \rho \left[\frac{\bar{u} \bar{v}}{\partial x} + \frac{\bar{v} \bar{v}}{\partial y} + f \bar{u} \right] - \rho g \lambda \left[\frac{\partial}{\partial y} (h \bar{u}) + \frac{\partial}{\partial x} (h \bar{v}) \right] \\ = 2 \frac{\partial}{\partial y} \left[\mu_h \frac{\partial \bar{v}}{\partial y} \right] + \mu_h \frac{\partial}{\partial x} \left(\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} \right) + \frac{\tau_y}{h} - \frac{C \bar{v}}{h} \quad (30) \end{aligned}$$

Where μ_h is a horizontal mixing length (eddy) viscosity coefficient and f is an angular rotation of coriolis acceleration and c is a friction coefficient. λ is a very large number called penalty parameter. τ_x and τ_y are wave tractive forces. u and v are represented the mean transport velocity component.

The equations are discretized using the method of weighted residuals. The choice of a penalty parameter, λ is fairly critical although empirical. If it is too large machine error will dominate the results, while if it is too small the condition is not enforced. A value of λ in the order of 10^6 was suggested for this shallow water problems.

Longuet-Higgins (1970a,b) reasoned that the eddy viscosity effects should tend to zero at the shoreline and suggested

$$\mu_h = N\rho |x|(gh)^{1/2} \quad (31)$$

N is a dimensionless constant. μ_h is horizontal viscosity. From studies of the effects of littoral friction on the velocity profile using field data, the range of N was found to be between 0.0024 and 0.0096. Many authors also had introduced their expressions for eddy viscosity. James (1974) summarized some available values of N were between 0.009 and 0.064. $N = 0.01$ is used in this computation.

Longuet-Higgins assumed a similar quadratic law which similar to standard quadratic law for turbulent river for bottom stress, would apply to the oscillatory flows encountered under waves in the surfzone. He suggested that if there were longshore currents bottom friction under a wave would be given by

$$\tau_b = F_{LH} |u_{orb}| u_{orb} \quad (32)$$

where u_{orb} was the orbital velocity and F_{LH} was the Longuet-Higgins friction coefficient. The coefficient is given as

$$F_{LH} = \frac{g}{C_z^2} \quad (33)$$

where C_z is Chezy's coefficient. If there is a range of Chezy's coefficients of 60 - 100, there is a range of Longuet-Higgins' coefficients of 0.003 - 0.001. Longuet-Higgins' suggested value for $F_{LH} = 0.01$. Liu and Mei (1976a,b) adopted two values of 0.01 and 0.09 in their nearshore current computations.

Longuet-Higgins etc. supposed that the radiation stress was a crucial driving force in the nearshore current. Inside the surfzone the wave energy decreases shoreward, leading to a decrease in the radiation stress. Outside the surfzone because of no wave energy dissipation the longshore gradient of the radiation stress is always zero, and the flow is therefore driven only inside the surfzone. The radiation stress terms τ_x and τ_y are given as Eqs. (21) and (22).

2.5. LONGSHORE BOUNDARY CONDITIONS

When waves and currents are predicting numerically in a region adjacent to a long coastline, there are four boundaries enclosing the region of interest: the coastline, two roughly normal to the coast and a seaward boundary. When waves are incident from deep water upon the coastline at some angle, θ , due to shoaling effects they refract and diminish the angle of incidence as they travel into the shallow water. In the region, the problem can be complicated by wave reflections leading to partial standing waves, diffraction resonance effects. Incorrect treatment of these artificial boundaries of the model will induce chaos in the problem. Some damper and repeatability boundaries are introduced in the present model.

Shoreline - A finite depth and smoothing the depth profile near shoreline is given to prevent infinite number of elements in the mesh

due to wave number k tending to infinity. Then we apply boundary damper by Sommerfeld's (1896) radiation condition to absorb the incident wave.

Boundary parallel to the shoreline - The model is simply terminated at this boundary.

Boundaries normal to the shoreline - Dampers and Snell's law have been used. The dampers absorb and generate the longshore component of the incoming wave.

In the case of current model it is assumed the flow profile at one artificial boundary is the same as the flow profile at the second boundary and a repeatability condition is applied as

$$\begin{aligned} u(x,0) &= u(x,L) \\ v(x,0) &= v(x,L) \end{aligned} \quad (34)$$

The condition is restrictive in that the beach slope and water depth need to be identical at each end of the model.

3. GEOMETRY, DATA AND RESULTS

3.1 GEOMETRY

The geometry chosen here is that of an offshore breakwater at Santa Monica, California which has been described by Liu and Mei (1976a,b). These are as Fig. (3) shown,

breakwater

length : 700 m
thickness : 0 m
wall : vertical and perfectly reflective
position : 350 m from shoreline
domain : $x = 350$ m, $350 \text{ m} \leq y \leq 1050$ m parallel to the shore
depth : 7 m

beach profile

uniform slope : slope = 1/50 for all y .

3.2 DATA

In order to model the wave accurately four elements per wavelength rule is maintained. Wider spacing is used in y direction, except at the tips of the breakwater where singularities occur. Restricted by the computation time for the fact that the numbers of the element will become enormous for covering all the describing region after the mesh is finer, a little bit longer wave period will be set to match the rule instead of subdividing the mesh in this computation. The wave climates are as

periods : $T = 10$ sec and 20 sec
incident wave amplitude : $a = 0.5$ m
angular frequency : $\omega = 0.62832$ and 0.31416 (1/sec)
gravity : $g = 9.81 \text{ m/sec}^2$
mass density of water : $\rho = 1000 \text{ kg/m}^3$
incident angles : $\theta = 0$ and 10 degrees.

Empirical data are

breaking criterion : McCowan's value $\gamma = 0.8$
eddy viscosity : $\mu_h = 10.0 \text{ kgf.s/m}$
friction coefficient : $F_{LH} = 0.0015, 0.01$ and 0.09
penalty parameter : $P = 100000$ and 1000000
coriolis coefficient : $f = 0$.

3.3 RESULTS

3.3.1 DIFFRACTION AND REFRACTION

In Fig. (4) contours of absolute values of wave elevation around offshore breakwater in the case of normal wave incidence of $T = 10$ sec are shown. It is could be seen that a strong reflection effects has resulted in standing waves in front of the breakwater. The peak of the wave elevation was at 1.2 m, compared with an incident wave amplitude of 0.5 m. Meanwhile some diffracted waves had intruded into the sheltered area of the breakwater. Similar situation is shown in Fig. (5) of $T = 20$ sec but wave penetrations are more profoundly because of longer wavelength. Fig. (6) is shown an oblique incident wave of 10 degrees attacks on the breakwater. A standing waves were form obliquely in front of the breakwater and more intruded waves In the upstream part.

3.3.2 NEARSHORE CURRENTS

As shown in Figs. (7), (9) and (11) which are in normal wave incidence of $T = 10$ sec there are two symmetrical counter - rotating cells found behind the breakwater in the case of friction coefficients, $F_{LB} = 0.0015, 0.01$ and 0.09 respectively. The variations of alongshore mean velocity component, V , through the centres of the circulation cell of constant y are shown in Figs. (8), (10) and (12) respectively. Two features can be seen immediately. First, the values of the velocity are decreasing as friction increasing. The maximum mean alongshore velocity component decrease from 1.911 m/sec, 1.310 m/sec to 0.568 m/sec. Second, the centres of the circulation cells shift outward about 50 m in each case apparently. This show the velocity is strongly affected by the friction which is a very difficult quantity to ascertain in the field. The two cells theoretically should be symmetrical but because of different distances from the boundaries chosen the unsymmetrical are found.

In the cases of a normal wave incidence of $T = 20$ sec, two more compact circulation cells are induced as shown in Figs. (13). The maximum alongshore mean velocity components, V , is 0.831 m/sec as Fig. (14) shown. In a 10 degree wave incidence of $T = 20$ sec because the wave force acts obliquely a strong circulation cell is found on the upstream of the surfzone. However on the other end, downstream, it is much weak comparatively. The maximum mean alongshore velocity is 0.845 m/sec on the upstream and much weak on the downstream. These are as Figs. (15) and (16) shown.

3.3.3 COMPARISONS

Because of the restriction of the available values of longshore current in the field or laboratory, only two references can be used for comparison. Firstly, Sauvage etc. (1955) has carried out a laboratory studies with sandy bottoms for an offshore breakwater and current directions. The observed trend of current and particle movement is sketched in Fig. (17). It is consistent with the present results above. Secondly, Liu and Mei (1976a,b) have developed a finite different model based on ray theory and ignoring that of convective inertia and viscosity. The comparisons between Liu and Mei and present results have been made in Fig. (18) and describe as:

Normal wave incidence, $F_{LH} = 0.01$

1. Position of the circulation centres

y - direction

Liu and Mei : $y = 1125$

present : $y = 1200$

x - direction

Liu and Mei : $x = 60$

present : $x = 135$

2. Max. mean alongshore velocity components, V

Liu and Mei : 0.48 m/sec

present : 1.365 m/sec

The above comparisons show good agreement in the general form of the circulation pattern, although there are some differences of detail.

4. CONCLUSIONS

An offshore breakwater on a beach for shore protection has been considered in the complete finite element model to study the wave variations due to diffraction, refraction and reflection, and nearshore current due to breaking wave inside or near surfzone with the considerations of convective inertia, eddy viscosity and bottom friction. A quite pleased result has been produced in this research.

Figure 3.

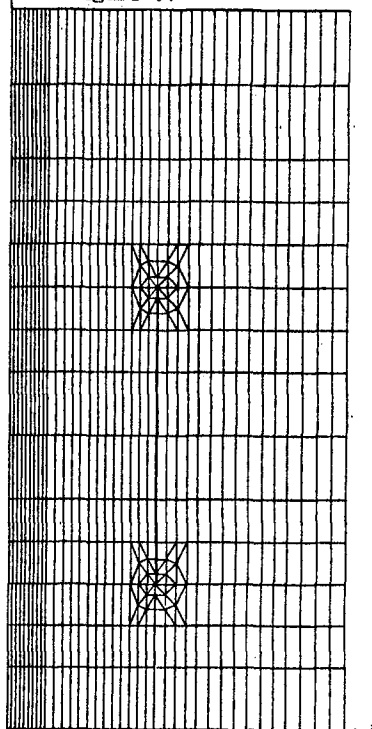
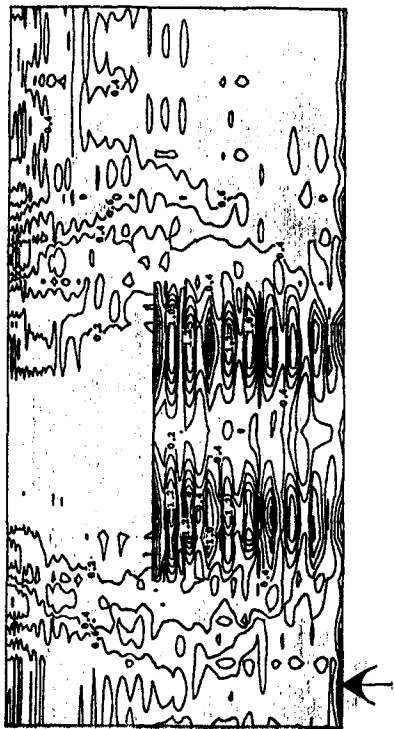


Figure 4.



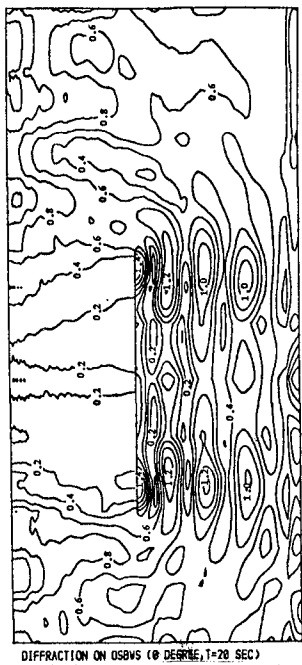


Figure 5.

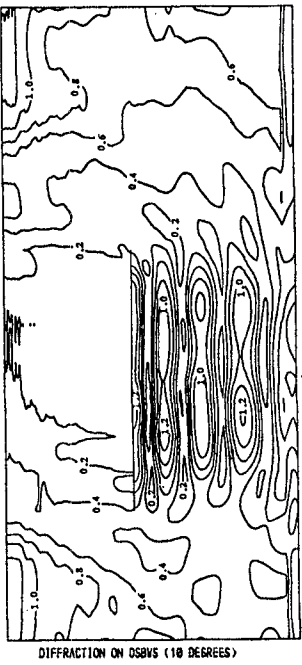


Figure 6.

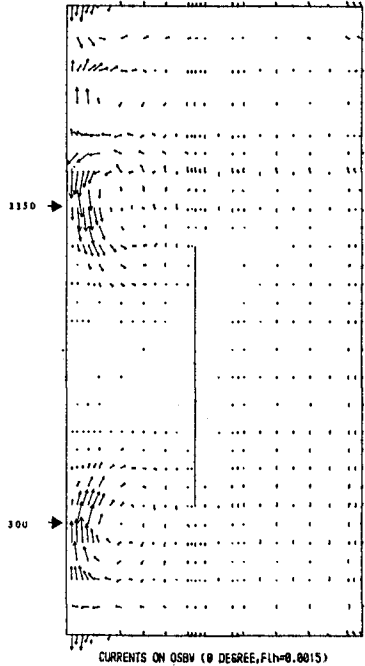


Figure 7.

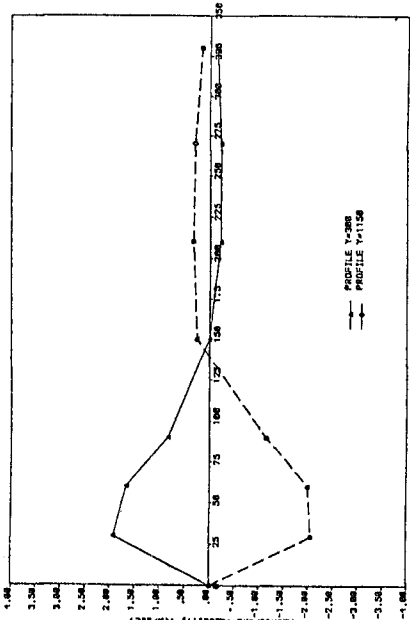


Figure 8. DISTANCE FROM SHORE, Miles

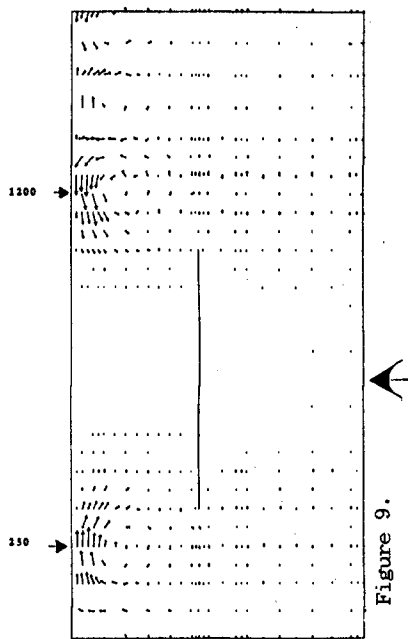


Figure 9.

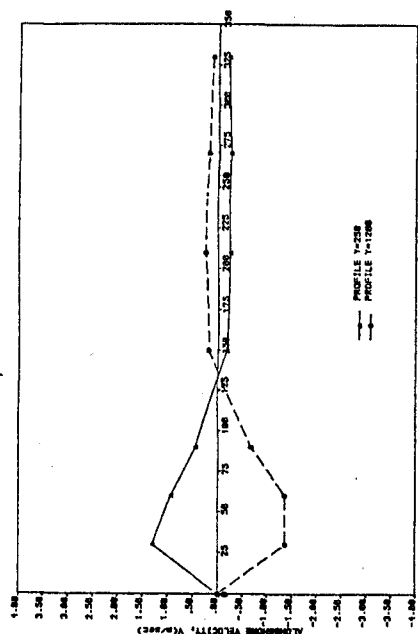


Figure 10. DISTANCE FROM SHORE, X(m)

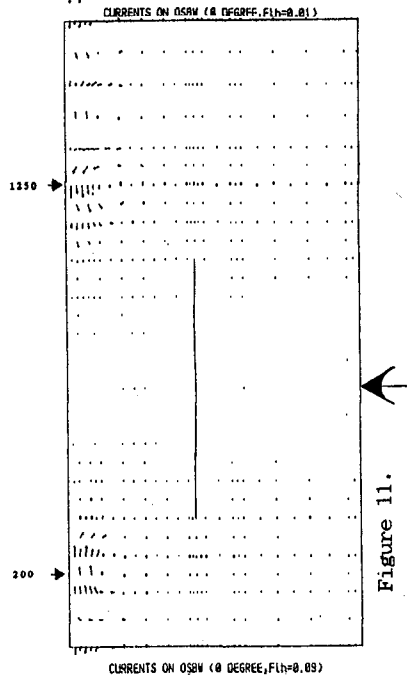


Figure 11.

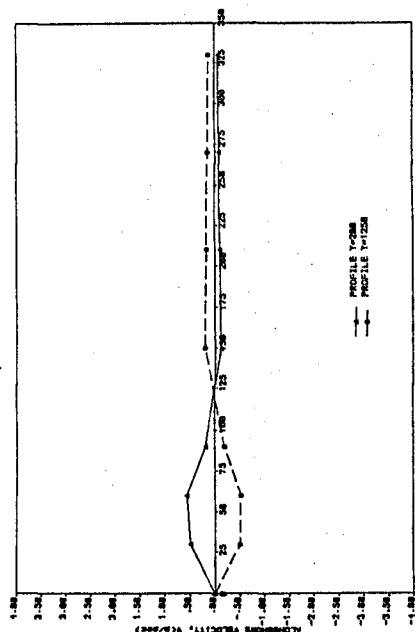


Figure 12. DISTANCE FROM SHORE, X(m)

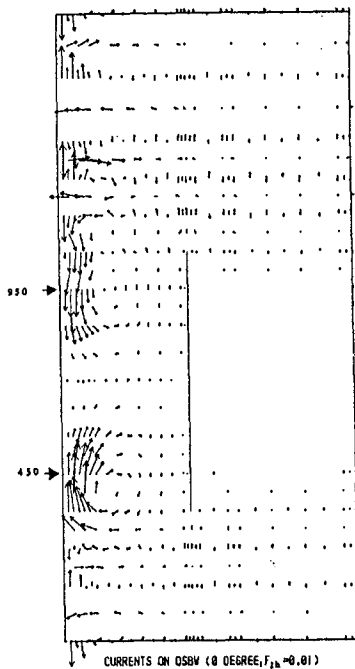


Figure 13.

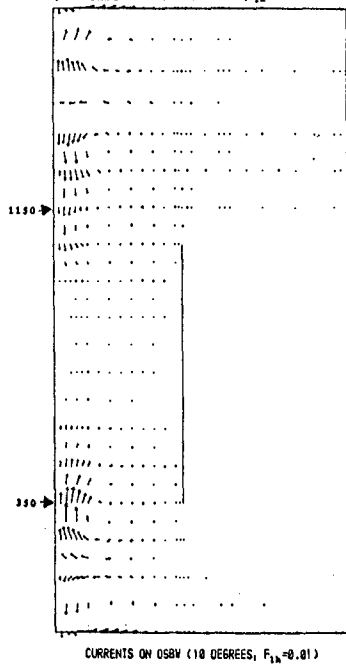


Figure 15.

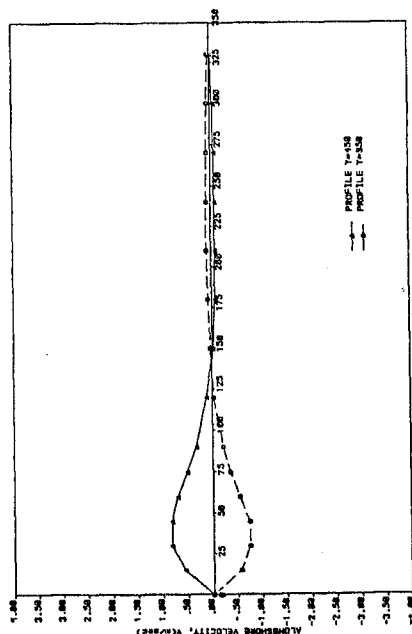


Figure 14.

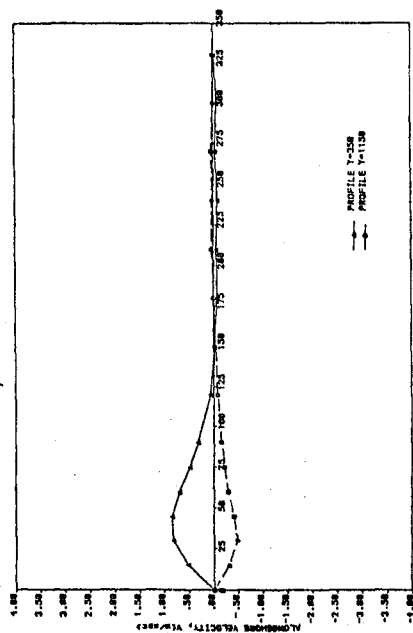


Figure 16.

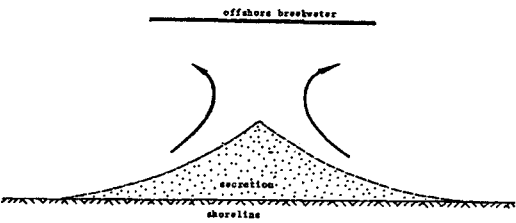


Figure 17.

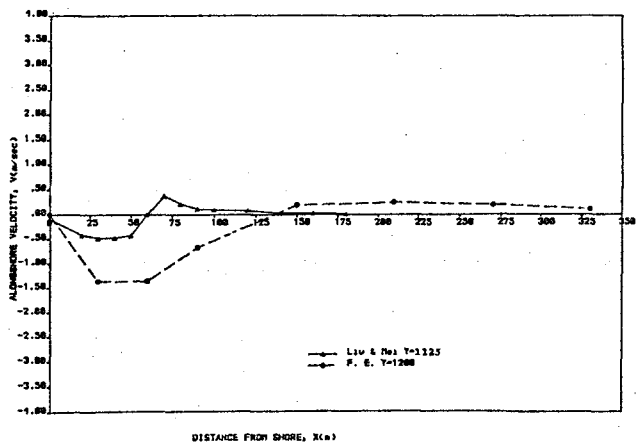


Figure 18.

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