

波浪-흐름 相互作用을 考慮한 不規則波의 屈·廻折 模型
Refraction and Diffraction Model for Irregular Waves
including Wave-Current Interaction

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1. Introduction

Waves propagating near a tidal inlet will be transformed due to currents and irregular water depths. The wave-current interaction is one of the most interesting and important phenomena for the prediction of wave climate and resultant sediment transport in coastal area. Monochromatic waves may deviate by as much as 50 to over 100 % from irregular waves with typical spectral shapes and directional spreads(Vincent and Briggs, 1989).

Recently, a number of studies have been made for the analysis of wave-current system. Booij(1981), Liu(1983), and Kirby(1984) proposed hyperbolic equations governing the propagation of waves in water of varying depth and currents in the mild-slope approximation. They used parabolic approximation in order to circumvent the difficulty in calculation of elliptic equations for regular waves.

Most of existing models employ parabolic or hyperbolic-type differential equations which are in general not so efficient to use in large area(order of hundreds wave length). In shallow water they need fine grid resolution to meet sufficient accuracy of numerical results. There is a definite need for an efficient method for the calculation of irregular wave transformation over large coastal area.

2. Governing Equations

The mild-slope equation has been used successfully as a model equation for describing surface water waves propagating over a seabed of mild slope(Berkhoff, 1972). For a wave-current interaction Kirby(1984) derived a general equation. Recently Chae et al.(1990) and Jeong(1990) have rederived the mild-slope equation using variational principle and Green's theorem for linear water waves following Booij's method(1981). The equation can be written as

$$\frac{D^2\phi}{Dt^2} + (\nabla \cdot \mathbf{U}) \frac{D\phi}{Dt} - \nabla \cdot (CCg \nabla \phi) + (\sigma^2 - k^2 CCg)\phi + W \frac{\partial \phi}{\partial t} = 0 \quad (1)$$

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where $D/Dt = \partial/\partial t + \mathbf{U} \cdot \nabla$, $\nabla = [(\partial/\partial x)i, (\partial/\partial y)j]$, and $\mathbf{U}=(u,v)$, ϕ the complex velocity potential at the mean surface level, σ the intrinsic angular frequency, k wave number, C and Cg are the phase and group velocity respectively, which are defined according to $C = \sigma/k$, $Cg = \partial \sigma / \partial k$, $\sigma^2 = gk \tanh kh$, and W dissipation coefficient. The final forms of the wave equation for this numerical model study are below.

$$\nabla \cdot \left[\mathbf{U} \frac{a^2}{\sigma^2} (\omega - \mathbf{U} \cdot \nabla S) + CCg \frac{a^2}{\sigma^2} \nabla S \right] + W \frac{a^2}{\sigma} = 0 \quad (2)$$

$$CCg \frac{a}{\sigma} (\nabla S)^2 - (\mathbf{U} \cdot \nabla S - \omega)^2 \frac{a}{\sigma} + (\sigma^2 - k^2 CCg) \frac{a}{\sigma} - \nabla \cdot (CCg \frac{a}{\sigma}) = 0 \quad (3)$$

$$\frac{\partial (|\nabla S| \sin \theta)}{\partial x} = \frac{\partial (|\nabla S| \cos \theta)}{\partial y} = 0 \quad (4)$$

3. Calculation of Wave Spectral Changes

The input directional spectrum is defined as

$$S_o(f, \theta) = S(f) G(f, \theta) \quad (5)$$

where $S_o(f)$ is the Bretschneider-Mitsuyasu(B-M hereafter) frequency spectrum, and $G(f, \theta)$ is the Mitsuyasu type directional spreading function(Goda, 1985).

The input wave amplitude for a particular frequency-directional component is $a_o = \sqrt{2S_o(f, \theta) \Delta f \Delta \theta}$. The resulting wave amplitude at any location can be computed using the model, and then the transformed spectrum $S(f, \theta)$ can be obtained as

$$S(f, \theta) = \sqrt{a/a_o} S_o(f, \theta) \quad (6)$$

Applying the governing equations to each component of directional spectrum transformed one can easily be obtained.

4. Computation Results and Discussions

Some results of the computations are compared with analytical solutions(Jeong, 1990), and to demonstrate the applicability of the equations and methods, numerical computations are made for two cases. The first case is for the refraction-diffraction due to rip-current in a mild sloping beach as shown in Figure 2(studied by Arthur, 1950).

The computational domain is divided into square grids ($\Delta x = \Delta y = 10m$) and numerical calculations are performed. Normal incident waves of $H_o = 1m$, $T = 8s$ are used as an incident wave condition at the offshore boundary. The dimensionless wave heights H/H_o for two transections are plotted in Figure 3. For the purpose of comparison,

parabolic model results(Kirby, 1984) are also shown in the same figure. A comparison of the figures shows that they are in good agreement.

The second case is for irregular wave propagation over a shoal as shown in Figure 4, which was recently simulated on a hydraulic laboratory equipped with multi-directional random wave generators(Hiraishi, 1991). The shoal is similar to that used in the experiments of Ito and Tanimoto(1972) with a minimum water depth of 0.05 m at the center of the shoal and constant depth(0.15 m) in the region outside the shoal. B-M spectrum is used for the input spectrum for which $H_{1/3} = 0.1m$, $T_{1/3} = 1.5s$, and $S_{max} = 75$ (narrow directional spectrum) are used. The grid sizes used are $\Delta x = \Delta y = 0.1m$. The results are presented in Figure 5, in the form of normalized wave height against the input wave height. The computations agree very well with experimental data which are for the case of non-breaking waves. As the frequency and directional spectra are not available, the comparison for those spectra between computation and experiment are not be made. However, the spectrum can be simulated by linear superposition of monochromatic wave components(eg. Panchang et al. 1990). From those comparisons, the present model appears to be used effectively for the calculation of irregular wave propagation with respect to computation accuracy and time(26 min. with IBM 386 PC).

5. Conclusions

A set of elliptic type mild-slope equations has been derived for wave-current interactions over a slowly varying topography. Numerical computation method to solve the equations has been presented. The model solves the elliptic equations in a way similar to an initial value problems. Accuracy of numerical computation does not greatly depend on grid size. It can be said that the present model is efficient for wave propagation problems in a large coastal area. Numerical results are shown for transformation of the waves propagating on a rip-current in a mildly sloping beach. They are in good agreement with published ones(Kirby, 1984). It is also shown that spectral transformation of irregular wave can be satisfactorily simulated by summing up the results from a monochromatic refraction-diffraction model for component waves of a spectrum.

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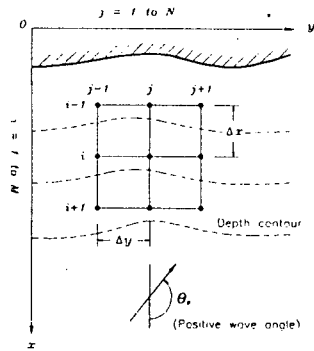


Figure 1. Definition of coordinate system, grid cell and wave angle conventions.

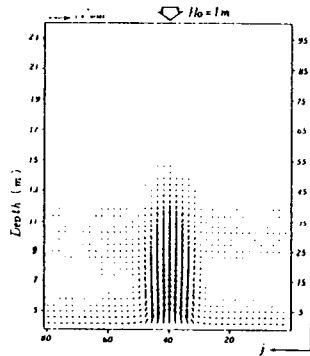


Figure 2. Rip-current field.

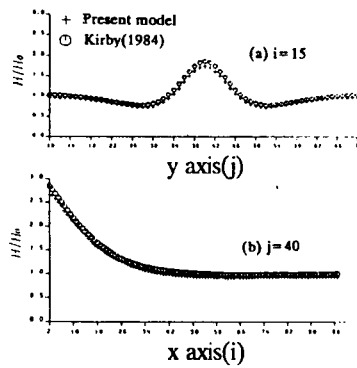


Figure 3. Wave height relative to incident wave for waves interacting with rip current.

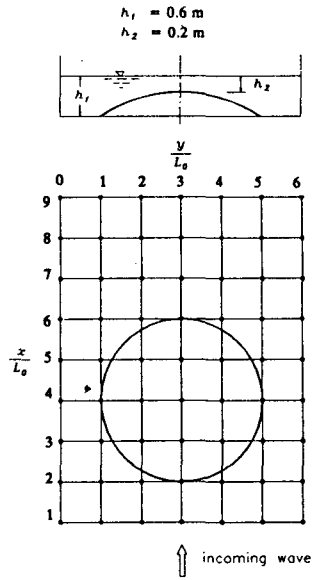


Figure 4. Experimental configuration(Hiraishi, 1991).

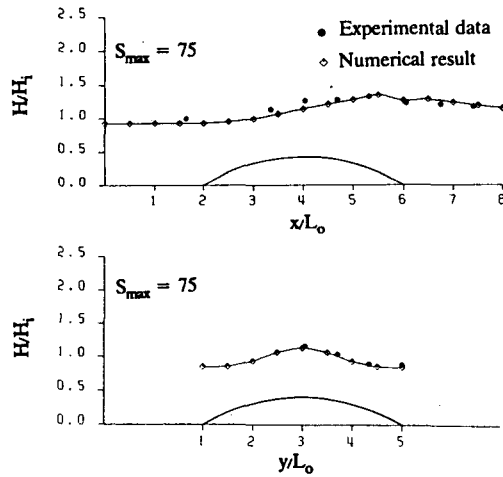


Figure 5. Comparisons between present model results and observed data.