CHAPTER 31

A Model for Long Waves at Grazing Angle to a Rubble-Mound Jetty

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Abstract

The main features of a model proposed recently by the authors for the propagation of long waves at grazing angle to a rubble-mound jetty are reviewed. Model results for a single jetty and for a jettied channel are shown.

1 Introduction

The behavior of ocean waves normally incident upon a rubble-mound breakwater has received considerable attention. Models describing wave reflection and transmission, the stability of the breakwater, energy dissipation, wave run-up and so on, are available for normal incidence. The case of oblique wave approach is less studied. Recently Melo & Guza (1990 a,b) proposed a linearized model for the propagation of long waves at grazing angle to a rubble-mound jetty. The model combines earlier work on waves normally incident on permeable breakwaters [Sollitt & Cross (1976), Madsen & White (1976)] with the localized dissipation diffraction model of Dalrymple, Kirby & Hwang (1984). Model results for a channel bounded by jetties compared favorably to an extensive data set obtained at the Mission Bay entrance channel in San Diego, California. This paper reviews the main features of the grazing angle model and briefly illustrates its applications.

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2 Model Description

Following the idea of Madsen & White's (1976) model for normally incident waves, the grazing angle model also divides the dissipation of wave energy in the rubble-mound jetty into "external" and "internal" components. The "external" dissipation is associated with fluid motion over the sloped face, and the "internal" dissipation with fluid motion within the pores of the structure. Internal dissipation is modeled with a permeable, surface piercing, homogeneous core of rectangular cross-section. External dissipation caused by run-up over the rough, sloped face is simulated with a surrounding region of comparable *bottom* roughness (Figure 1). The dimensions of the core and external dissipation regions and the representative stone size are estimated from the actual (usually trapezoidal and multi-layered) structure. Incident waves are assumed to be long, linear (nonbreaking), monochromatic and to approach the jetty at grazing angle with respect to the jetty axis (Figure 1).

The key model equation is the Helmholtz equation

$$\nabla^2\phi + \overline{k}^2\phi = 0 \tag{1}$$

where ∇ is the horizontal (x, y) gradient, and $\phi(x, y)$ the wave potential, proportional to the free surface displacement. Energy dissipation is accounted for in the model by allowing $\overline{k}$ to be complex.

$$\overline{k} = \sigma(gh)^{-\frac{1}{2}}(1 - if)^{\frac{1}{2}} \tag{2}$$

where σ is the wave frequency, g the acceleration of gravity, h the water depth and f a linearized dissipation coefficient discussed in section 3.

As opposed to the normal incidence situation, the grazing angle case has a wave crest propagating *simultaneously* over three distinct regions: "open" water, the external dissipation region and the permeable core. The portion of the wave within the dissipative zones will be locally damped; gradients in wave height will be generated and a diffraction pattern will appear. Plane wave solutions (with a fixed amplitude and propagation direction) are not possible. Dalrymple, Kirby & Hwang (1984) were the first to study wave diffraction caused by areas of energy dissipation and their solution method is also utilized here (section 4).

3 Linearized Dissipation Coefficients

The linearized dissipation coefficient quantifies the amount of dissipation taking place in each region. In "open" water, dissipation is usually negligible compared to that associated with the jetty, so $f = 0$ away from the jetty.

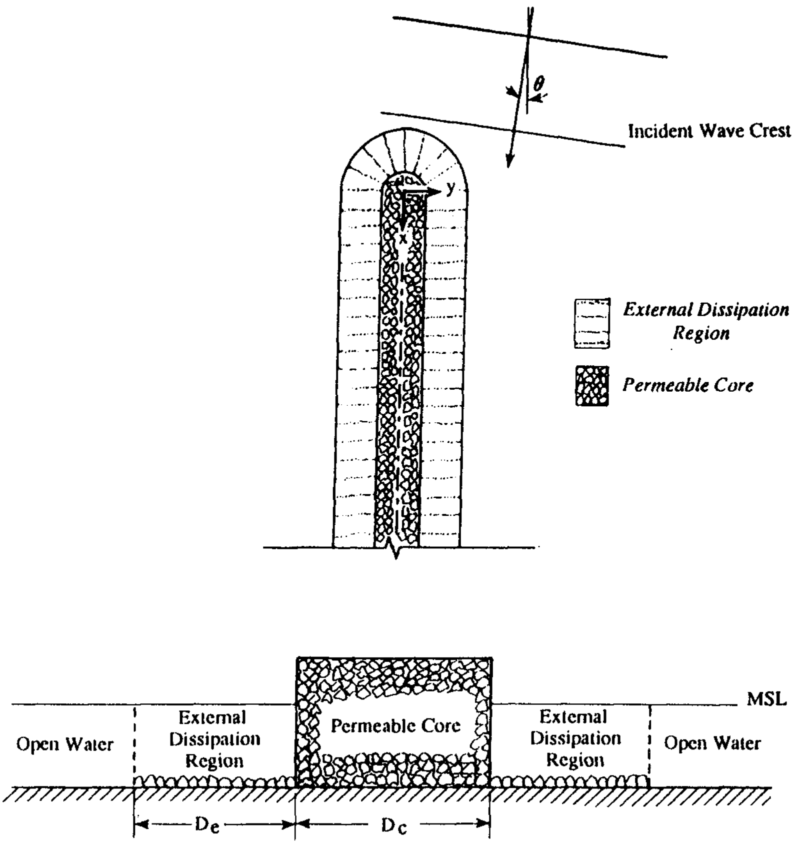

Figure 1: Plan view (upper) and cross-section (lower) of model breakwater.

The evaluation of f in the external region (f_{ext}) requires an estimate of the energy dissipated over a rough, steep slope by a wave at an arbitrary incidence angle. Until more is learned about this very complex problem, a representative value of f_{ext} is obtained from Madsen & White's (1976) reflection measurements of long waves *normally incident* on an impermeable, rough slope

$$f_{ext} \approx \frac{1 - R^2}{kD_e} \tag{3}$$

where R is a reflection coefficient, D_e is the width of the external dissipation region and k is the wavenumber. Madsen & White (1976) found that R was nearly independent of the incident wave height when $kl_s < 2$, where l_s is the length of the sloped face. The above condition is usually satisfied for swell waves in relatively shallow water and steep jetty faces, and makes f_{ext} indeed linear.

Nonlinear turbulent dissipation in the permeable core is included in the linearized model by means of the Lorentz principle of equivalent work [Sollitt & Cross (1976), Madsen & White (1976), Madsen (1983) and others]. In the general case, the internal dissipation coefficient, f_{int}, takes different values at different positions within the core (i.e. $f_{int}(x, y)$). The present model uses the fact that the core width is small compared to the wavelength (for relatively long waves) and assumes f_{int} to be constant in the transverse direction (y-dir). However, (slow) variations in the wave height within the core in the direction of wave propagation (x-dir.) make f_{int} a function of x. The iteration procedure used to calculate f_{int} and the parameterization of the porous medium are exactly the same ones utilized for normally incident waves (see, for example, Madsen (1983)).

4 Solution Method

The solution method suitable here is the parabolic approximation [Radder (1979), Booij (1981), Dalrymple, Kirby & Hwang (1984), Liu, Yoon & Dalrymple (1986), Kirby (1986)]. The governing Helmholtz equation (1) is split into parabolic equations for the transmitted and back-reflected fields. The back-reflected field is neglected and the resulting parabolic equation for the transmitted part is solved numerically. The equation to be solved, if the lower-order parabolic approximation is used, is

$$2i\bar{k}\frac{\partial A}{\partial x} + \left[2\bar{k}(\bar{k} - k) + i\frac{\partial \bar{k}}{\partial x}\right] A + \frac{\partial^2 A}{\partial y^2} = 0 \tag{4}$$

where A is the complex amplitude of the forward scattered wave field (ϕ^+)

$$\phi^+(x, y) = A(x, y)\, e^{ikx} \tag{5}$$

The applicability of the parabolic method relies on two assumptions:

(i) That the wave propagates nearly along the axial direction of the jetty.

(ii) That the back reflected (i.e. in the $-x$-dir) wave field is negligible.

Assumption (i) is in accordance with the grazing angle requirement. For assumption (ii), the jetty head is the only place capable of producing strong back scattering. Elsewhere, x-variations in the medium of propagation are slow and no significant back reflection should occur. However, the effect of head scattering is expected to be small in the area of interest (i.e. for $x > 0$, Figure 1). Of course, assumption (ii) also implies the existence of a nonreflective boundary at the down-wave side (like a dissipative beach for example).

Numerical solutions are obtained by the Crank-Nicolson finite-difference scheme for a given initial condition. Solutions in the different regions must satisfy continuity of pressure and mass flux at the separating interfaces. This is straight forward at the interface between "open" water and the external dissipation region. However, at the permeable core interface there is a change in the porosity of the medium; a discontinuity in the normal velocity is required to assure mass conservation, and special matching conditions are necessary. Note also that the marching forward nature of the parabolic method is very convenient for the calculation of f_{int} by the Lorentz principle. The correct value of f_{int} is obtained after about 5 iterations.

5 Application Examples

In this section we illustrate the model results with two examples: a single jetty and a jettied channel.

Figure 2 shows the solution for a wave incident at 0^o on a crib-style (rectangular cross-section) permeable jetty. In this particular application, all dissipation takes place in the permeable core and there is no external dissipation region. The opposite case of a virtually impermeable, sloped face structure can be treated by considering only external dissipation in the model. It is clear that the presence of the jetty alters significantly the wave field around it, even for a 0^o incident wave. Even though the net effect of the jetty is to dissipate wave energy, the diffraction-reflection pattern can result in normalized wave heights greater than 1 (Figure 2). The solution for f_{int} is shown in Figure 3. The current example is for water of constant depth. However, this is *not* a constraint of the model, depth variations of mild slope can also be included. Preliminary tests show satisfactory results for incidence angles as large as 30^o. More detailed studies of the single jetty case are under

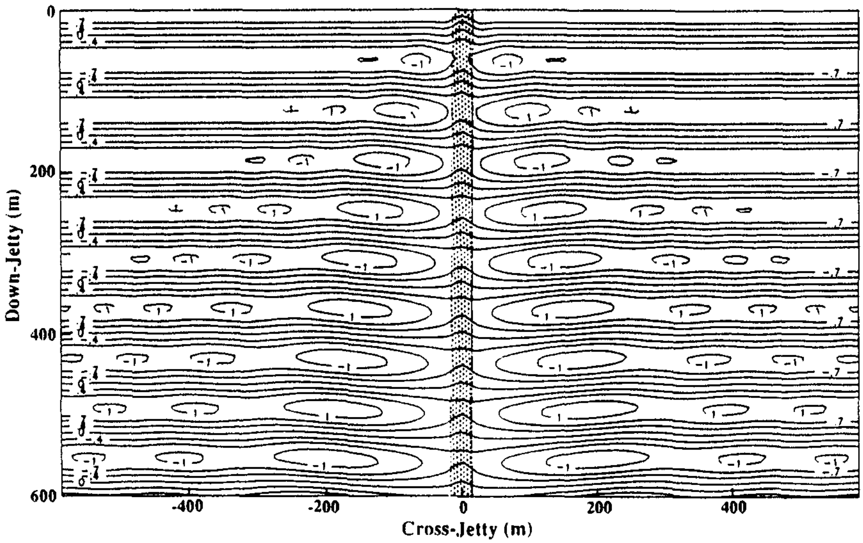

Figure 2: Normalized, instantaneous surface elevation field. Incoming wave: incidence angle = 0°, period = 14 sec, height = 0.8 m, lenght = 120 m. Model jetty: core width = 32 m, stone diam. = 1.25 m, porosity = 0.45. The origin of the semi-infinite jetty is at (0,0).

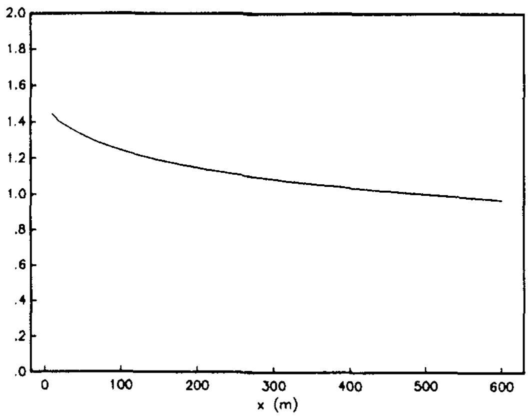

Figure 3: Corresponding f_{int} for Figure 2.

way and will be presented in a forthcoming paper.

Figure 4 shows the solution for a wave propagating in a constant depth channel bounded by nontransmitting (sealed) rubble-mound jetties. The wave is initially at 0° to the channel axis and the model jetties have both external and internal dissipation. As we anticipated, energy dissipation occuring along the jetties generate cross-channel gradients in wave height and the initially plane wave is deformed by diffraction. A damped plane wave is not possible in a wide channel with strong energy dissipation localized at the edges. The solution is a modulated wave with bent crests in spite of the constant water depth. The down-channel variation in f_{int}, shown in Figure 5, corresponds to regions of higher and lower wave heights within the permeable cores.

Model results for a jettied channel compared favorably to an extensive data set obtained at the straight, 1-km long, 250-m wide, 8-m deep Mission Bay entrance channel. The model predicted both the observed rapid wave height decay on the channel centerline and the observed insensitivity of the normalized rate of decay to variations in wave conditions (Figure 6). In the Mission Bay study, the linearized dissipation coefficients were evaluated with the methodology summarized in this paper, *not* by fitting to the data. A complete account of the jettied channel application can be found in Melo & Guza (1990 a,b).

6 Concluding Remarks

The linearized model proposed by Melo & Guza (1990 a,b) for the propagation of long waves at grazing angle to a rubble-mound jetty has been reviewed. Although a crude approximation to the full problem of a directional spectrum of waves propagating about a permeable, multi-layered, sloped structure, we believe it realistically captures the main physical mechanisms of dissipation in the jetty and diffraction in the wave. The model may be a useful engineering tool and, with further refinements, may serve as a basis for dealing with obliquely incident waves on many types of dissipative structures.

Acknowledgements

This work was supported by the Coastal Sciences Branch of the Office of Naval Research, contract N00014-89-J-1055. The California Department of Boating and Waterways (CDBW) supported the Mission Bay data analysis as part of its continuing program of studies to enhance boating safety and access

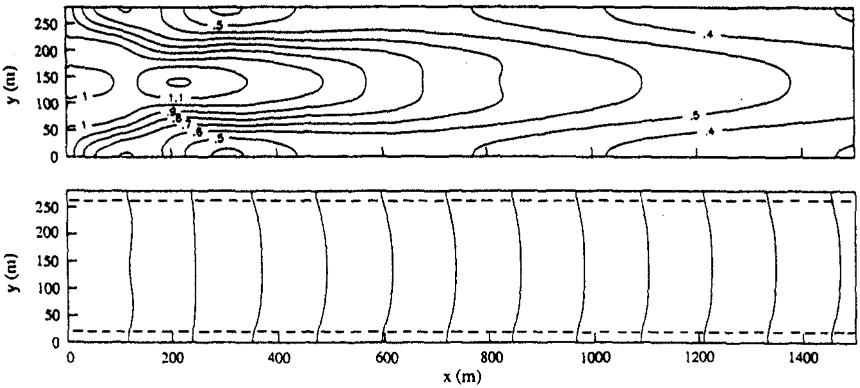

Figure 4: Normalized wave height contour (upper) and wave crests (lower) for a jettied channel. Non-transmitting model jetties are indicated by dashed lines. Incoming wave: same as in Figure 2. Model jetties: permeable core width = 10 m, external diss. width = 10 m, stone diam. = 1.25 m, porosity = 0.45.

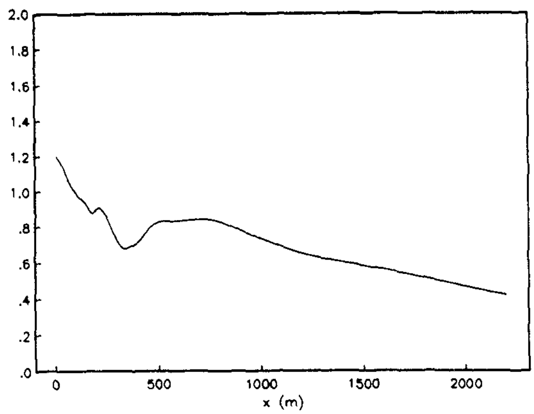

Figure 5: Corresponding f_{int} for Figure 4; $f_{ext} = 0.5$ (constant).

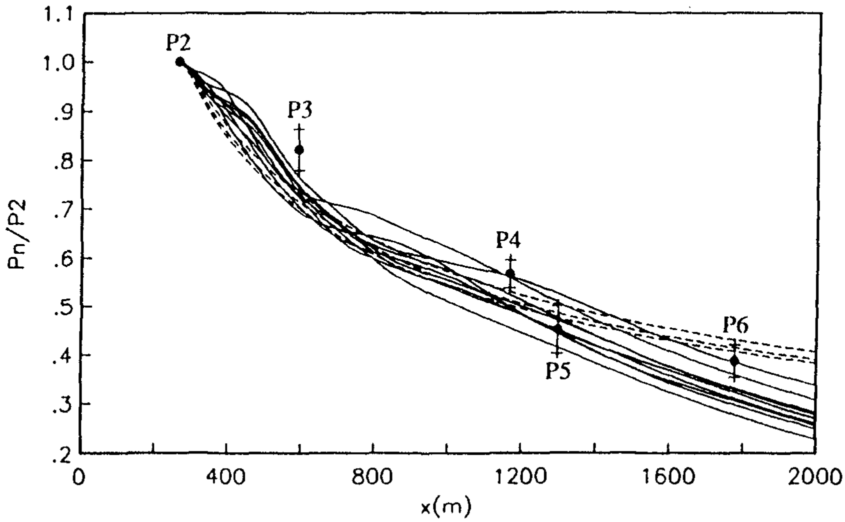

Figure 6: Full lines: model results for the wave height on the channel centerline at location Pn normalized by the height at P2, the sensor located nearest the channel mouth ($x = 0$), for a range of initial conditions including: $0.5 \leq H_o \leq 2.0\,m$, $-10^o \leq \theta \leq 10^o$ and $14 \leq T \leq 20\,sec$. Dashed lines: gap diffraction solutions with gap width equal to the waterway width, $-10^o \leq \theta \leq 10^o$ and $14 \leq T \leq 20\,sec$. Also shown are the observed mean (circle) and standard deviation (brackets) of the Pn/P2 (n=2,3,4,5,6) wave height ratio for runs when energy in the period range $13.5 \leq T \leq 23.3\,sec$ was at least 70% more than at higher frequencies where the model assumption of long waves is violated.

in California. E.M. received personal support from "Conselho Nacional de Desenvolvimento Cientifico e Tecnologico" (CNPq, Brazil) and from CDBW.

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