CHAPTER 135

Field Calculations of Wave Energy Dissipation and Related Beach Profile

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Introduction

The process by which wave energy dissipates across the surf zone and its affect on the bed profile is, of course, a topic of immediate concern and debate. Various concepts of the wave energy dissipation process have been modeled, however, additional research is needed before confidence can be placed in a particular calculation scheme. In addition to the problems associated with proper model derivation a method of application and result interpretation of actual surf zone field data must be devised and understood. This is, of course, prerequisite to any realistic use of a wave energy dissipation model in an engineering project. The following study was therefore conducted in order to examine the applicability of surf zone field data to wave energy dissipation models and to investigate the bed profile relationship.

Two wave energy dissipation models were selected for comparison in this study, the 'Undertow Model'(UM) which is based on the conservation of wave energy flux across the surf zone (3), and the 'Turbulent Bore Model'(TBM) which is based on hydraulic jump theory (2). Individual waves were identified in the wave record hy employing the zero up-crossing method, and wave energy calculations were based on small amplitude wave theory, Svendsen's non-linearity parameter **Bo** (4), and the 1/3 Significant Wave classification.

Wave elevation data which was collected before, during, and after the occurrence of a storm typical to the Ogata coast, (Hmax=5.5 m.), was used for energy dissipation calculations. Lastly, an Ogata coast average cross-shore energy dissipation estimate was used in conjunction with Dean's Equilibrium Beach Profile Equation (2), to examine the stability of Ogata Coast, Japan.

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Field Measurements and Data Processing

Measurements necessary to calculate the wave energy dissipation rate were made by instruments mounted on D.P.R.I.'s T-shaped observation pier located at Ogata coast, Japan. This pier, shown in Figure 1b, is 255.6 meters in length normal to the shoreline, and 100 meters in length at the offshore T-section. A total of 14 wave gauges were positioned along the pier, as indicated in Figure 1a. In this figure, wave gauges are referred to as '**C**' for capacitance type or as '**U**' for ultrasonic type.

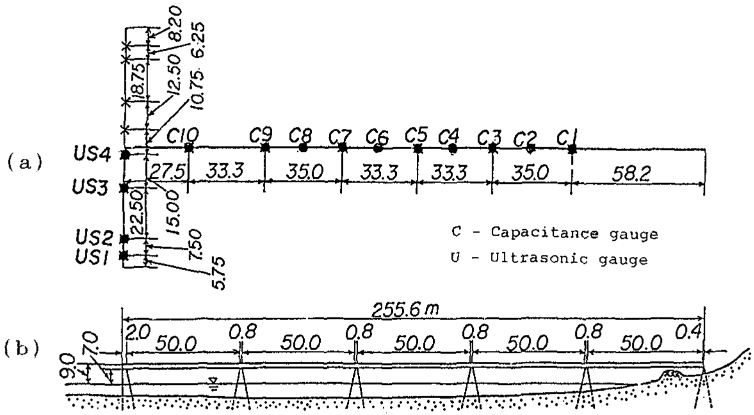


Figure 1. Ogata Coast T-shaped observation pier

Calibrations of wave gauges were continuously performed in order to determine and retain their accuracy. Wave elevation data was collected over a three day period, during which the coastal storm occurred. Wave data was stored on analogue data recorders. Digitalizing of records was accomplished by use of an A-D converter which operated at a sampling rate of 0.08 seconds. A high pass filter of 100 seconds and a low pass filter of 2.5 seconds were used to remove the long wave components and high frequency breaking wave fluctuations, respectively. Filter selection was based on record observation. The resulting wave data was then partitioned into 22 minute blocks and individual waves identified by the zero up-crossing method. Beach profile measurements were made by depth soundings conducted along D.P.R.I.'s T-shaped observation pier.

Theoretical Considerations

There are several ways by which the potential energy of irregular waves can be approximated. However, due to our data being limited to surf zone surface fluctuations, where periodic wave theories are invalid, we choose to evaluate potential energy on the basis of individual wave elevation measurements, incorporating non-linearity through Svendsen's **Bo** parameter, Equation 1. The **Bo** variation with profile shape is described in Table 1 (1). Note that if **Bo** equal 1/8 (0.125) the wave shape is of sinusoidal form and potential energy is evaluated by small amplitude wave theory.

$$B_o = \frac{1}{T}\rho g \int \frac{\eta^2}{\rho g H^2}\, dt = \frac{\eta^2}{H^2} \qquad (1)$$

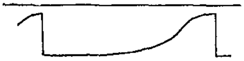
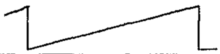
	Profiles	Bo
	Sinusoidal	0.125
	Cnoidal	< 0.125
	Parabolic	0.089
	Linear	0.083

Table 1. Nonlinearity parameter **Bo** (after Basco, 1986)

Consequently, small amplitude wave theory estimates, Equation 2, and **Bo** modified potential energy estimates, Equation 3, are employed for comparison in the energy dissipation calculations.

$$E_1 = \frac{1}{16}\rho g H^2 \qquad (2)$$

$$E_2 = \frac{\rho g}{2T}\int_0^T \eta^2\, dt = \frac{1}{2}\rho g H^2 B_o \qquad (3)$$

Where **T** is the wave period, ρ is the fluid density, g is the gravitational acceleration, η is the water surface elevation measured from the MWL, and **H** is the wave height.

The 'Undertow' model may be described as the conservation of wave energy flux across the surf zone. This relation may be expressed as:

$$\frac{\partial}{\partial x}\left(W_W + W_R \right) = D \qquad (4)$$

where W_W and W_R represent the wave and residual (turbulent) energy fluxes, respectively. The flux of externally opposing energy sources are represented by **D**. In summing the external and residual energy fluxes an expression is derived which allows us to calculate energy dissipation across the surf zone in terms of wave elevation alone, Equation 5.

$$\frac{\partial W_W}{\partial x} = D - \frac{\partial W_R}{\partial x} = -\,DISS \qquad (5)$$

Furthermore, if we make the assumption that wave energy is traveling at group velocity **Cg**, the wave energy flux may be written as:

$$W_W = E\,C_g = E\sqrt{gh} \qquad (6)$$

where **E** is the sum of both potential and kinetic energy and **h** is the water depth. By employing the small amplitude and **Bo** modified wave energy estimates, along with Equations 2 and 3, and the 1/3 significant wave height classification, three energy flux relations are derived, Equations 7-9. These three relations will each be substituted into the dissipation relation of Equation 5, to examine computational variations.

$$W_A = \bar{E}_2\,C_g = \bar{E}_2\sqrt{g\,h} \qquad (7)$$

$$W_B = (E_2)_{1/3}\,C_g = (E_2)_{1/3}\sqrt{g\,h} \qquad (8)$$

$$W_C = (E_1)_{1/3}\,C_g = (E_1)_{1/3}\sqrt{g\,h} \qquad (9)$$

The second method used to calculate the cross-shore energy dissipation rate was derived from hydraulic jump theory and is known as the 'Turbulent Bore Model' (TBM), Equation 10. This model is applicable only where the breaking wave propagates in a nearly constant form, such as that of a quasi-steady bore. Therefore, the cross-shore wave shape characteristics, described by **Bo**, must be investigated in order determine the region of model applicability.

$$DISS = \frac{\rho g h}{T}\,\frac{(d_c - d_t)^3}{4\,d_t\,d_c} \qquad (10)$$

where **h** is the mean water level, **T** is the wave period , **dc** and **dt** are the depth measurements from the crest and trough, respectively, and **DISS** is the rate of change of wave energy per unit shoreward distance expressed in the units of tons/sec/meter, Figure 2.

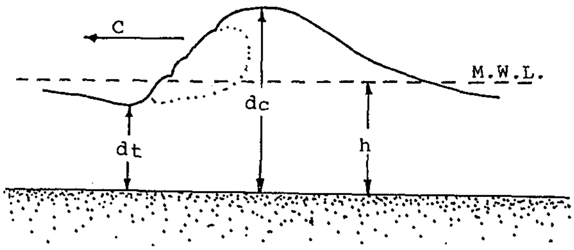


Figure 2. Turbulent Bore Model variables

The Ogata coast is best described as a high energy reflective type beach, while Dean's 'Equilibrium Profile Equation' was derived from typical low energy dissipative beaches, Equation 11. A comparison between the measured and the calculated profile will allow us to determine how unstable the profile is presently.

$$\mathbf{h} = A\,x^{2/3} \tag{11}$$

where **h** is the water depth, **A** is a parameter describing fluid and sediment properties, and **x** is the offshore distance. Furthermore, if: the 2/3 constant is replaced with the variable α , the spilling breaker assumption is adopted, Equation 12, and the energy dissipation relations described in Equations 5 and 6 are employed, an equation is derived which describes the cross-shore wave energy dissipation/beach profile relation, Equation 13.

$$H = \gamma h \tag{12}$$

$$DISS = \frac{5}{16}\,\alpha \rho g^{3/2}\,\gamma^2 h^{(3/2\,-\,1/\alpha)}\,A^{1/\alpha} \tag{13}$$

where γ is assumed to equal 0.8.

Results and Conclusions

All data collected before, during and after the coastal storm was divided into five time series, each representing a particular stage of the storm, and containing six hours of data. Data sets **N15**, **N18**, and **N19** correspond to sea state conditions best described as initial storm (steep short period waves), fully developed storm (well defined long crested waves), and post storm (swell), respectively. In Figure 3, cross-shore energy fluxes are shown for the relations described in Equations 7-9, and for the three storm stages described above. Several conclusions may be drawn from this figure, they include: 1) energy flux calculations based on the significant wave and small amplitude wave theory, are significantly larger and more scattered than results based on W_A or W_B , 2) the steep negative energy flux gradients seaward of wave gauge C8 indicates the region of rapid wave height decay, initial breaking, 3) shoreward of wave gauge C7 the energy flux gradients are slightly positive, especially for the fully developed storm, **N18**, possibly corresponding to wave rebuilding, and 4) from C3 shoreward large inflections in the energy flux gradient correspond to visual observations of incident and reflected wave interaction.

Because the W_B energy flux calculation, Figure 3, required the **Bo** parameter to be evaluated in terms of it's 1/3 significant value, it was necessary to investigate the **Bo**/wave-order relationship to clarify it's role. Therefore, in Figure 4, the variations in the **Bo** parameter with orders of increasing wave magnitude are presented at five surf zone locations.

The asterisk in the Figure 4 series indicates the locations of the 1/3 significant wave. To the left of the asterisk waves are of a greater order than the 1/3 significant and to the right the order is smaller. It is interesting to note that the wave shape parameter significantly fluctuates for wave orders less than the 1/3 significant, however, to the left of the asterisk the **Bo** parameter remains fairly constant. This observation indicates that the surf zone 1/3 significant **Bo** value may be used to approximate average surf zone energy characteristics.

As previously mentioned the TBM may be applied only where the breaking wave propagates in constant form, therefore, the **Bo** parameter must also be investigated in terms of it's cross-shore characteristics. In Figure 5 the cross-shore **Bo** variations are shown for the entire observation period, data blocks N15-N19, where an individual line within each data block represents a 22 minute **Bo** average.

In comparing each data block differences may be observed in the cross-shore **Bo** trends, however, between wave gauges C10 and C7 all data blocks show a similar **Bo** tendency. Therefore, within this zone of relatively constant **Bo** the TBM was applied and compared with dissipation results derived from the UM, Figure 6, where Diss-1 and Diss-2 represent TBM results based on 1/3 significant and individual wave measurements, respectively. The lower three curves are UM calculations based on the three previously defined energy flux relations.

Conclusions based on this figure include: 1) TBM calculations based on the significant wave component, Diss-1, are approximately 2.0-2.5 times greater than calculations based on the UM, 2) TBM calculations based on individual wave measurements are of the same order of magnitude as UM calculations (approximately 0.01 tons/sec/mm) and 3) during the initial storm stages, N15-N16, maximum wave energy dissipation values are generated by the TBM, however, because maximum storm conditions were actually observed during the period corresponding to N17 we may conclude that the TBM is inapplicable for short period waves.

Finally, a comparison is made between the calculated, Equation 10, and measured beach profiles, Figure 7. Calculation assumptions include: 1) Diss = 0.01 ton/sec/m, 2) γ =0.8, and 3) h = 5.6 m. Also, the parameters **A** and were both varied in order to determine the best fit solution to the measured Ogata Coast profile.

In this study and several others, significant differences have been noted between dissipative (α = 2/3 generated) and reflective type beach profiles, suggesting that Dean's equation may be valid only under certain undefined conditions and that additional parameters are needed to describe the reflective profile.

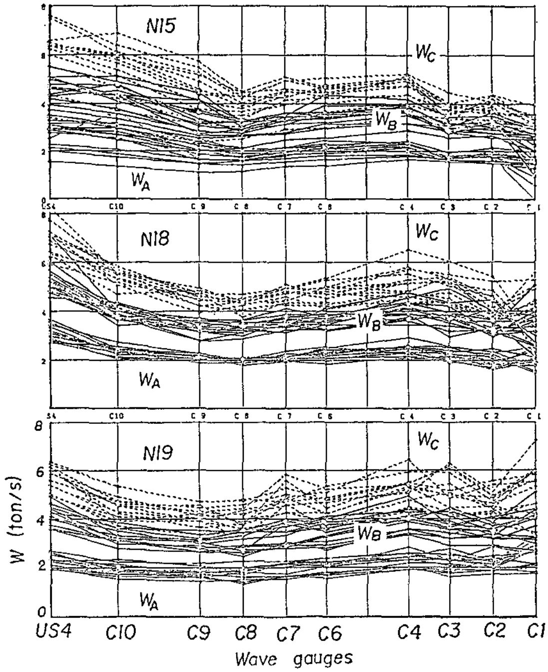


Figure 3. Cross-shore energy flux trends

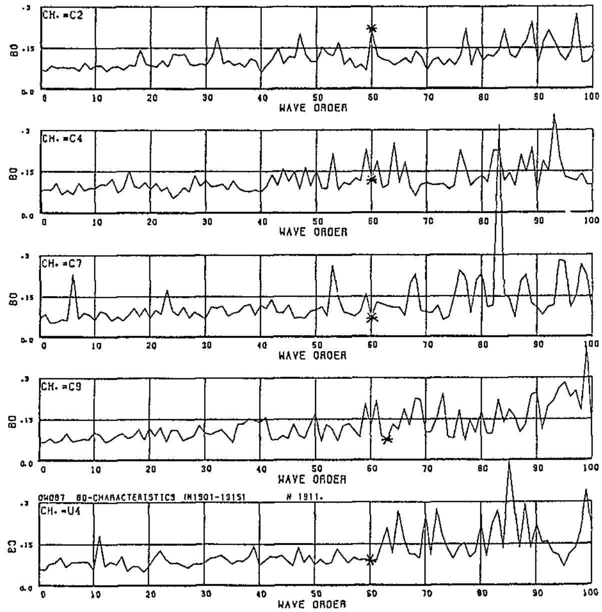


Figure 4. Ordered surf zone **Bo** characteristics

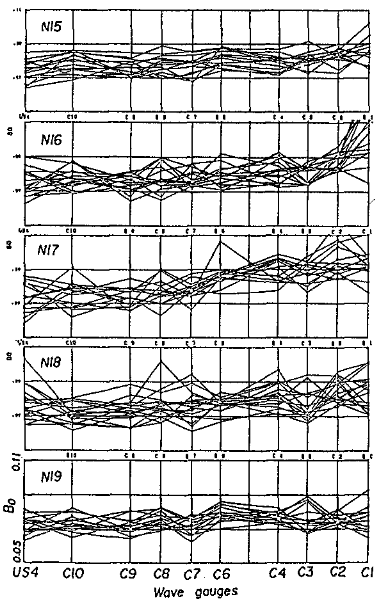


Figure 5. Cross-shore **Bo** characteristics

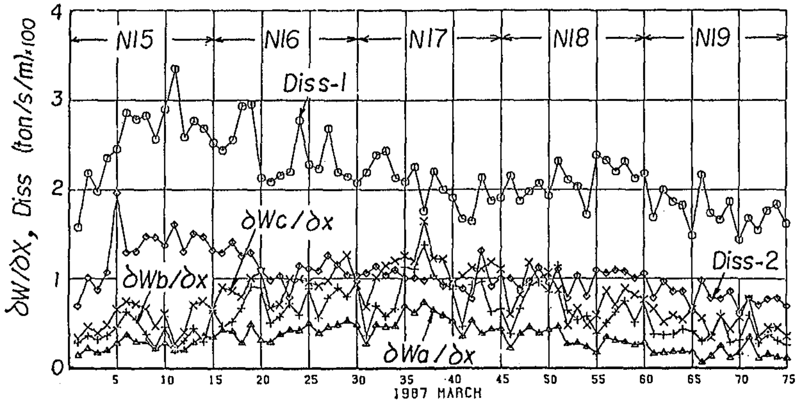


Figure 6. Wave energy dissipation comparison

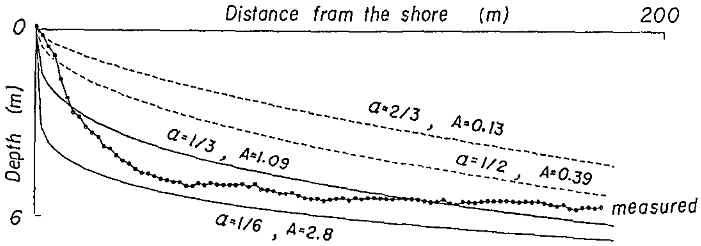


Figure 7. Comparison of measured and calculated profiles

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