MODEL TESTS ON THE RELATIONSHIP BETWEEN DEEP-WATER WAVE CHARACTERISTICS AND LONGSHORE CURRENTS

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INTRODUCTION

It has long been recognized that the movement of littoral material takes place, in the main, in the onshore regions of a beach where breaking of waves occurs. Waves whose crests in deep water make an angle α_0 with the shoreline, and which break at an angle α_B, are the main source of energy for the generation of the forces which manifest themselves in long-shore currents and the resulting littoral transport. This littoral material is put into motion before, during and after breaking but it is extremely difficult to separate the effects of the forces and currents in these three zones. In what follows the authors have attempted to measure the intensity of the current around the breaking zone in a highly idealized beach model in which the shoreline is straight, has a constant beach slope, Θ, and is attacked by waves of constant deep-water wave-height, H_o, and period, T.

During refraction and shoaling the angle of the wave-crests with the shore-line is reduced from α_0 to α_B and during this process some of the deep-water energy being transmitted shorewards may be dissipated by friction. The exact value of α_B is a function of α_0, H_o/L_o, and the friction loss, but will increase, both theoretically and experimentally, with increasing H_o/L_o, as shown by Brebner and Kamphuis (1963).

Based on the angle of breaking, α_B, the wave-steepness at breaking, H_B/L_B, the depth of breaking d_B, and the beach slope, Θ, it is possible to formulate relationships for the long-shore current, v_L, using the principle of conservation of energy and momentum and the principle of continuity.

Using energy considerations,

$$v_L = K_1 \left[\Theta \cdot \frac{H_B^2}{T} \cdot \sin 2\alpha_B \right]^{1/3}$$

and using momentum considerations,

$$v_L = K_2 \left[\Theta \cdot \frac{H_B^{3/2}}{T} \cdot \sin 2\alpha_B \right]^{1/2}$$

where K_1 and K_2 are empirical "constants" depending on the friction energy offered to the longshore current, the amount of energy dissipatec in the breaking process, and the amount used in maintaining on-shore off-shore motion at right angles to the longshore current.

Using continuity considerations and a random-walk distribution of wave-heights Chiu and Per Bruun (1964) arrive at a value of v_L which is apparently in reasonable agreement with field observations. However, since wave-forecasting methods give H_o, T, and α_o the authors deem it preferable in this instance to express v_L in terms of the deep-water characteristics instead of breaking characteristics, and also to deal with regular waves since these are normally used in laboratory models simulating prototype installations.

MODEL TESTS OF LONGSHORE CURRENTS

a) Procedure:- The tests were carried out in a basin approximately 2 ft. deep with a plan area of 100 ft. x 50 ft. Sixteen differing wave periods ranging from 0.78 to 1.13 seconds, five differing wave-heights from 0.075 to 0.258 feet, six differing values of α_o from 10° to 60°, and two differing impermeable fixed-bed beach slopes, 1:10 and 1:20 were used. The longshore velocities in and around the breaking zone were measured by timing coloured neutral density bubbles of trichloroethylene and benzene over known distances. About 50 such readings were taken per incident wave and a mean value of v_L established. In all about 500 values of v_L were obtained.

b) Presentation of Results:- The variables in the tests were θ, α_o, H_o and L_o (or T). In view of the form of the theoretical relationship for v_L it was decided to put v_L in the form

$$v_L = K\,\theta^a\, H_o^{\,b}\, T^{-c}\ (\text{Function } \alpha_o)$$

For given values of α_o it was possible, using a 1620 IBM computer, to perform regression analyses using values of $\underline{a}$ varying from 0.33 to 1, $\underline{b}$ from 0.5 to 1 and $\underline{c}$ from 0.33 to 1. Further, since T remains constant during refraction and the breaking height H_B is of the same order as H_o, it is possible to carry out a Fourier analysis on α_o to give (Function α_o) as a sine series.

In keeping with the theoretical results it was possible to produce two expressions for v_L, namely,

$$v_L = 2.5\left[\frac{g\theta H_o^{\,2}}{T}\right]^{1/3}\left[\sin(1.65\,\alpha_o) + 0.1\sin(3.30\,\alpha_o)\right] \qquad (1)$$

and

$$v_L = 6\left[\frac{g\theta^2 H_o^{\,3}}{T^2}\right]^{1/4}\left[\sin(1.65\,\alpha_o) + 0.1\sin(3.30\,\alpha_o)\right] \qquad (2)$$

In both these expressions the constant is dimensionless. The experimental values are shown on Figures 1 and 2. Of the total energy available prior to breaking only about 8% is used in maintaining the long-

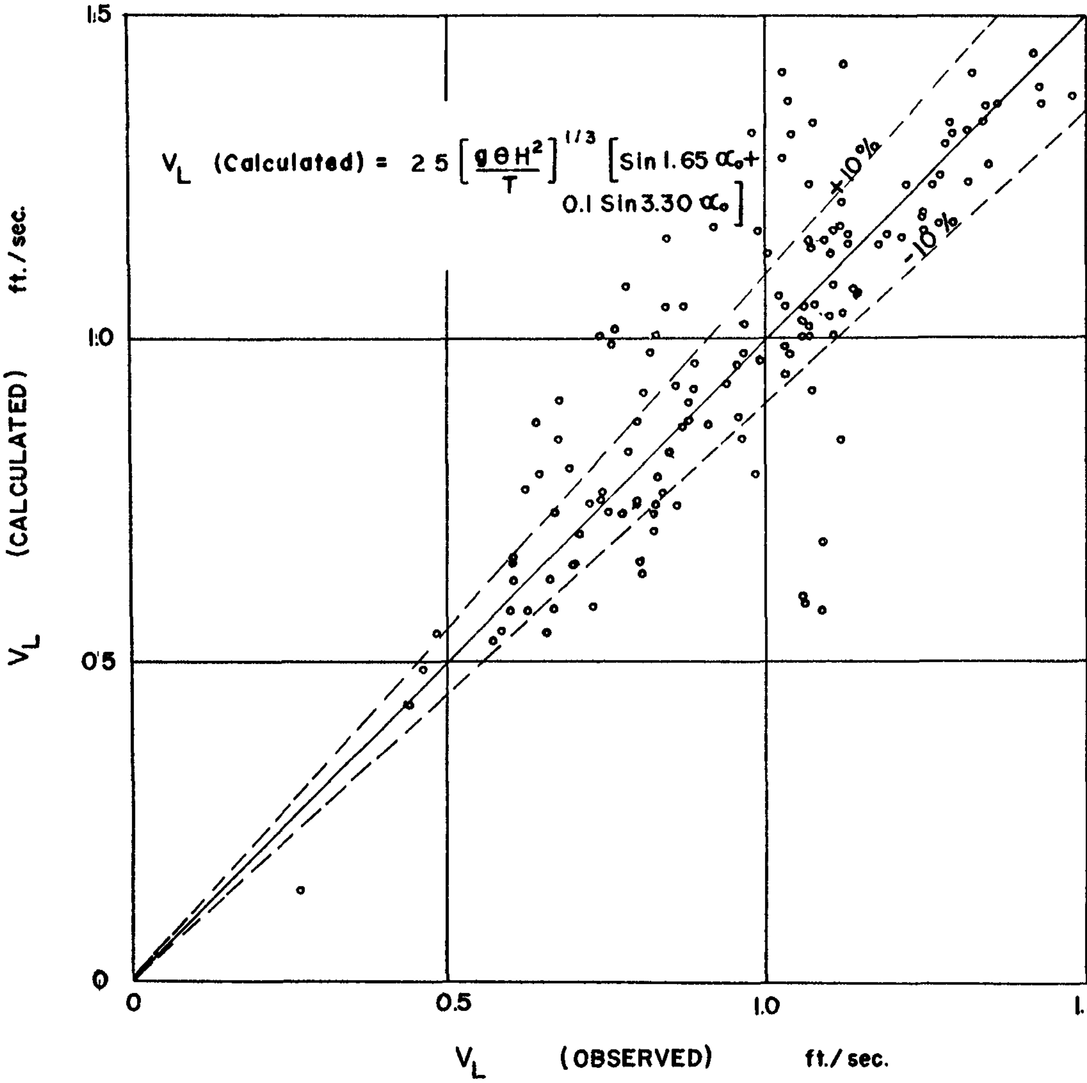
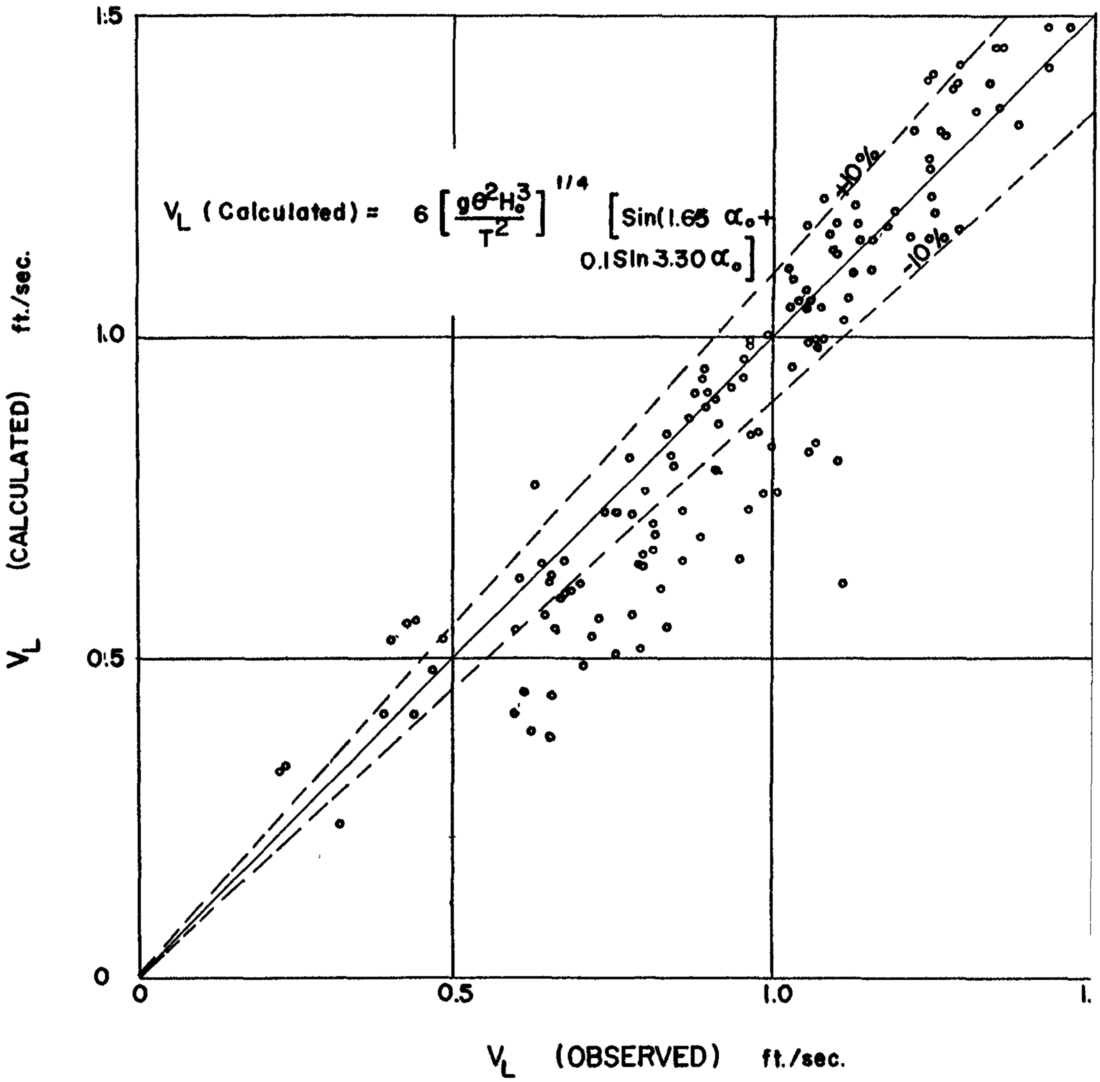

V_L (Calculated) = 2 5 $\left[\frac{g\theta H^2}{T}\right]^{1/3}$ [Sin 1.65 α_0 + 0.1 Sin 3.30 α_0]
+10%
-10%
1.5
1.0
0.5
0
0
0.5
1.0
1.5
V_L (CALCULATED) ft./sec.
V_L (OBSERVED) ft./sec.

FIGURE 1



V_L (Calculated) = 6 [ge²H₀³/T²]^(1/4) [Sin(1.65 α₀ + 0.1 Sin 3.30 α₀]
+10%
-10%
1.5
1.0
0.5
0
0.5
1.0
V_L (CALCULATED) ft./sec.
V_L (OBSERVED) ft./sec.

FIGURE 2

shore current at the intensity given by either equations 1 or 2, indicating the high energy loss in the breaking phenomenon itself and in maintaining on-shore off-shore movement of water, normal to the longshore current.

The (Function α_0) term reveals that the maximum value of v_L occurs when α_0 is about 55°, which is in good agreement with Bruun's value of 54° and Sauvage and Vincent's value of 53°.

DISCUSSION OF RESULTS

The model may be considered distorted or undistorted. If undistorted the Froude scale is about 1:100 for linear dimensions and at this scale the "Reynolds Number" damping effect, using Eagleson's (1962) theory of damping of oscillatory waves, is not marked.

If n_d is the ratio $\frac{\text{prototype depth}}{\text{model depth}}$ and if the suffix L refers to wave-length, H to wave-heights, and c to wave-speed, then for such a refraction model as this which demands homologous angles of breaking, homologous shoaling, and homologous breaking depths,

$$n_c = n_T = n_L^{1/2} = n_d^{1/2} = n_H^{1/2}$$

Referring to equations 1 and 2, if n_x is the plan length scale,

$$\text{Longshore current scale} = n_{vL} = \frac{v_{Lp}}{v_{Lm}} = \left[\frac{\frac{n_d}{n_x} \cdot n_H^2}{n_T}\right]^{1/3} = n_d^{1/2}\left[\frac{n_d}{n_x}\right]^{1/2}$$

or

$$n_{vL} = \frac{v_{Lp}}{v_{Lm}} = \left[\frac{\frac{n_d^2}{n_x} \cdot n_H^3}{n_T^2}\right]^{1/4} = n_d^{1/2}\left[\frac{n_d}{n_x}\right]^{1/2}$$

If the model is considered undistorted, $n_d = n_x$ and $n_{vL} = n_x^{1/2}$, as in a simple Froude model.

In effect equations 1 and 2 should be universally applicable if one assumes that

a) the model beach slopes are not so steep as to excessively deform the orbital paths compared with the prototype.

b) the prototype slopes are neither so flat, rough, nor permeable as to cause excessive attentuation due to friction compared with the model.

c) the exponent of the slope Θ is to be trusted in view of the fact only 2 differing slopes were used in the tests.

In conclusion, equations 1 and 2 probably give a maximum attainable envelope value of v_L when extrapolated to a prototype situation since, in nature,

a) beaches are not straight and uniform,

b) rip currents are set up which limit the longshore current,

c) due to the presence of longshore bars, energy and momentum are transferred to the longshore process at various locations,

d) waves are not regular and thus the breaking zone is not too well defined.

For use on prototype situations with non-regular waves the authors' suggest that H_o be replaced by $\frac{H_s}{1.6}$ on the argument that the mean height of all waves in a random-walk sample is the significant wave-height divided by 1.6. Thus, on a one-bar beach having a slope Θ of 0.017 radians, wave-period 8 secs., $\alpha_o = 45°$, and $H_s = 5.5$ metres, the longshore current is 1.4 m/sec. by equation 1 and 1.2 m/sec. by equation 2. A typical prototype value is about 1 m/sec. under such conditions, indicating as suggested previously that the authors' relationships probably give limiting values of the maximum longshore current for any particular situation.

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