CHAPTER 38

TIME DEPENDENT FLUCTUATIONS IN LONGSHORE CURRENTS

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ABSTRACT

During constant sea state conditions, longshore current velocities were monitored continuously for fifteen minute periods separated by fifteen minute periods separated by fifteen minute intervals. Three ducted impellor flowmeters were placed at equally spaced vertical positions through the water column. Sequential measurements were made with similar vertical current meter arrays at different locations across the surf zone. Simultaneous measurements of wave height, period and celerity were made at stations placed at equal intervals from the outer surf zone to the beach. The fifteen minute continuous records were subjected to spectral analysis. This analysis showed that the major power associated with fluctuations in the longshore current velocity field occurs in two major frequency bands. A significant spectral peak was coincident with the breaker period of the incident wave field, 4.2 seconds and, another dominant signature occurred at 78.8 seconds. Attenuation with depth of both the steady and fluctuating components of the longshore current flow field was relatively small. The maximum observed velocities for each station and each vertical current meter position varied from 90 to 150 percent above the observed mean longshore current velocity. However, at each station, variation of the means with depth was not appreciable and thus supports the results from time and space averaged theories of vertical uniformity in longshore currents, away from the boundary layer. Results from the field investigation of Wood and Meadows (1975) indicated that the steady state components are dominated by the fluctuating portions of the flow field. Therefore, time averaging of conservation equations in longshore current theory is a physically inappropriate procedure. In order to evaluate the magnitude of the unsteady components, a close examination of surf zone dynamics was made. The most obvious contribution to unsteadiness in longshore currents arises from the longshore component of the maximum horizontal particle velocity. However, the magnitude of observed current fluctuations is too large to be completely accounted for by this component. Spectral peaks at longer periods appear to be related to modes of edge wave phenomena. The long period spectral signature of 78.8 seconds is in direct agreement with the calculated period for a zero mode edge wave in shallow water. This agreement supports the contention that oscillatory components, other than the longshore component of the wave particle velocity,

are contributing to unsteadiness in longshore currents and are manifested throughout a wide range of frequencies.

INTRODUCTION

In the presence of an oscillatory wave field incident on a beach it is somewhat unrealistic to expect a steady or slowly varying longshore current. Unsteadiness of longshore currents has been noted for quite some time. However, the magnitude and dominance of the unsteadiness in the flow field has only recently been fully appreciated (Dette, 1974; Wood and Meadows, 1975).

Classically, field and laboratory investigations have relied on averaged results from Lagragian measurements to establish longshore current velocities. Likewise, conservation equations have been time averaged in the formation of longshore current theories. As a result, design criteria for coastal engineering structures have only considered the periodicity of the incident wave field to be important and local longshore currents have been modeled as steady state and constant with depth. Results from this investigation indicate that these assumptions are inappropriate. Field observations show at a fixed point in the surf zone variations in excess of 150 percent of the mean longshore current velocity occur over time periods from three to eighty seconds (Figure 1). These unsteady motions in longshore currents persist horizontally across the surf zone and vertically from the surface to the bottom. The dominant period of these fluctuations correspond to that of the incident breaker period; however, significant longer period fluctuations are also evident. The magnitude of the time-dependent portions of the flow field as well as their persistence horizontally across the surf zone and vertically with depth suggests that they dominate the steady component. Consequently an analytical formulation for longshore current flow must be carried out in a time dependent framework.

Longshore currents result in a net translation of fluid particles parallel to the shoreline. This fluid flow is bounded by the beach on the nearshore side, by the somewhat arbitrary limit of the surf zone on the seaward side and by the bottom. The flow velocities are hence constrained to vanish at or near these boundaries. There can be no wave generated longshore current flow beyond the maximum wetted extend of the swash zone on the beach. The seaward extent of the longshore current is located where the effects of momentum and energy fluxes, associated with breaking waves, lie beyond the range of lateral mixing in the surf zone. The lower extent of the flow field is characterized by a shear dominated zone terminating in the loosely consolidated sediment comprising the under-water portion of the beach. The flow is constrained to vanish at a sufficient depth into this underlying beach sediment. This depth is not necessarily the top of the mobile sediment layer but a depth at which percolation through the beach material is non-existent. The last remaining boundary is that of the free surface. It is at this

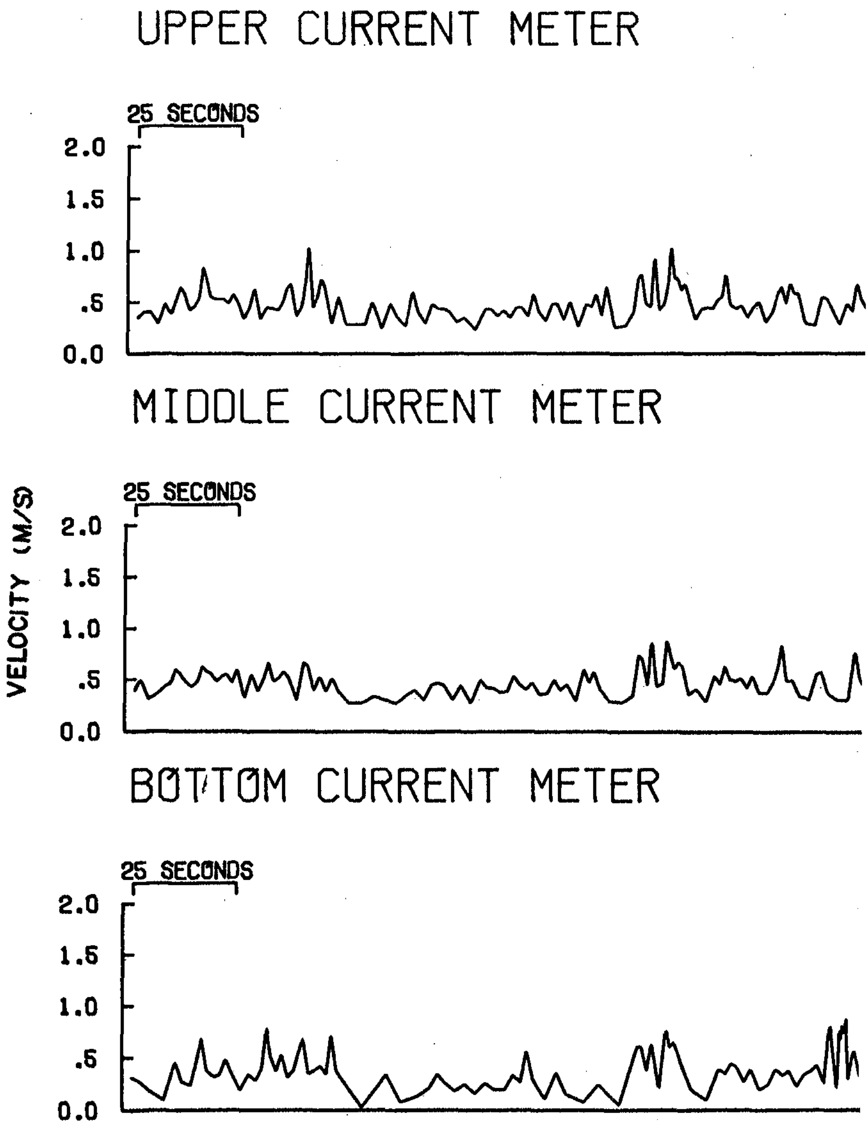

FIGURE 1. THREE REPRESENTATIVE SIMULTANEOUS TIME HISTORIES OF FLUCTUATING LONGSHORE CURRENT VELOCITIES TAKEN AT THREE DEPTH LOCATIONS THROUGH THE SURF ZONE WATER COLUMN.

boundary that the flow velocity is anticipated to be a maximum. Since the shearing stress realized at the bottom must result from a loss of momentum at the bottom boundary, the maximum velocity must be achieved at the greatest possible distance from the bottom. The longshore current flow, outside the viscous boundary layer, appears to be a weak shear flow.

Classically, longshore current velocity has been modeled as a function of wave height, period, celerity and angle of approach at breaking as well as the local water depth (Galvin, 1967). The driving forces necessary to create and sustain the longshore current are most directly related to the breaking wave height,(Putnam, Munk, and Traylor, 1949). This observation led to the development of conservation of momentum and energy approaches to the treatment of the longshore current flow field. It was assumed that in shallow water the wave celerity at breaking can be adequately represented by

$$C_b = \sqrt{g(H_b + Z)}$$

which leads to an ambiguous conclusion. Accepting the premise that energy losses exist that are not accounted for by this approximation, the driving component associated with the horizontal component of the wave particle velocity must be of greater magnitude than the resulting longshore current velocity

$$C_b \sin \theta_b > V.$$

This result is not usually observed in nature, implying that other mechanisms, not accounted for by a simple time averaged momentum balance of the longshore component of the breaking wave horizontal particle velocity, must be associated with the generation of longshore currents.

Early conservation of momentum and energy approaches have led to the investigation of longshore currents based on continuity considerations (Bruun, 1963). The basic assumption in the conservation of mass approach is that a wave breaking at an angle to the beach contributes mass to the surf zone and raises the local mean water level. This creates a slope in the water surface which generates a longshore current. Variation of still water level at different locations along the beach imparts a longshore slope to the free water surface. The differential pressure head associated with this slope initiates flow from areas of high to low pressure. Hence, the velocity of the longshore current is controlled by the frictional pressure head loss within the current itself. The non-uniformity of these conditions implies variation of the longshore current flow field in the longshore direction and forms the basis for theoretical treatments of rip-cell generation (Bruun, 1963; Bowen, 1967). Rip-channels are formed at low areas of wave and slope water set-up and flow perpendicular to the beach. This is a necessary and sufficient condition to satisfy conservation of mass in the surf zone since the continuity constraint cannot justifiably be met by imposing return flow with depth throughout the surf zone.

Perhaps the most sophisticated and least restrictive approach to longshore currents has been set forth in terms of conservation of energy considerations (Longuet-Higgins, 1970 (1) and (2)).

This approach utilizes the concept of radiation stress to relate the magnitude of the longshore current velocity to the incoming wave energy flux, given by

$$F_x = E\, c_g \sin\theta \tag{1}$$

outside the surf zone and

$$\frac{\partial F_x}{\partial x} = -D \tag{2}$$

inside the surf zone, where D is the rate of energy dissipation per unit time and horizontal area. The flux of y-momentum across a line x = constant, parallel to the shoreline is given by the radiation stress component

$$S_{xy} = F_x \left(\frac{\sin\theta}{c}\right) \tag{3}$$

and from balance of momentum flux considerations it can be shown that the waves exert a local stress

$$T_y = -\frac{\partial S_{xy}}{\partial x} \tag{4}$$

parallel to the shoreline. Substituting (3) and remembering that $\sin\theta/c$ is independent of x gives

$$T_y = -\frac{\partial F_x}{\partial x}\left(\frac{\sin\theta}{c}\right) \tag{5}$$

or from (2)

$$T_y = D\left(\frac{\sin\theta}{c}\right) . \tag{6}$$

A simple momentum balance for steady state conditions on a straight coastline can be expressed as

$$T_y - B = 0 \tag{7}$$

where B is bottom friction and lateral friction is neglected. Applying linear theory of waves in shallow water to (1) under the assumption that in the breaker zone θ is small enough that cos θ can be approximated by unity gives

$$F_x = \frac{1}{2} \rho g\ a^2 \sqrt{gz} = \frac{1}{2} \alpha^2 \rho g^{3/2}\ z^{5/2} \qquad (8)$$

where ρ is density, g acceleration of gravity, a wave amplitude, z water depth, and $\alpha = a/z$. Longuet-Higgins (1970 1, 2) assumed the Chezy Law

$$B = C\rho\ |\bar{u}|\bar{u} \qquad (9)$$

where $\bar{u}$ is the horizonaal velocity, having both a steady and oscillatory component, and C is a constant. Combining equations (5), (8), and the time averaged expression of (9) and substituting into (7) gives a longshore velocity

$$\bar{V} = \frac{5\pi}{8} \frac{\alpha s}{C}\ gz\ \frac{\sin\theta}{c}\ . \qquad (10)$$

The extension of shallow-water theory out to the breaker line and the inclusion of lateral mixing across the breaker line result in

$$V_o = \frac{5\pi}{8}\ \frac{\alpha}{C} \sqrt{gz_b}\ (s \sin\theta_b) \qquad (11)$$

and

$$V_b = \frac{5\pi}{8}\ \frac{\alpha\beta}{C}\ \sqrt{gz_b}\ \ (s \sin\theta_b) \qquad (12)$$

respectively (Longuet-Higgins, 1970 1, 2).

Longshore current velocities predicted from this approach only agree with experimental results under the conditions of a manochromatic sea surface incident at a straight planer beach of constant slope. The assumptions employed in these solutions still remain far too restrictive to produce physically realistic prediction under natural conditions. For an excellent discussion of recent developments in the predictions of steady longshore currents see Longuet-Higgins (1972).

The existence of second order effects across the surf zone with a wide range of incident periods, can add significant contributions to unsteadiness in the longshore current velocity. Wave set-up and set-down (Eagleson, 1965) across the surf zone can add slope water effects to the driving sources. The effect of short crested waves (Fuchs, 1952) and edge waves (Ursell, 1952) can also supply driving forces not accounted for by classic temporal and spatial averaged momentum theory.

Therefore, formulation of longshore current theories based on temporally or spatially averaged quantities appears to be physically inappropriate. It is unrealistic to expect a steady or slowly varying longshore current in the presence of an irregular oscillatory wave field. Although the oscillatory nature of the longshore current, due to the presence of breaking waves in the surf zone should be expected, the resulting total longshore current velocity field is a far more complex oscillatory field.

FIELD INVESTIGATION

A field investigation was carried out along a section of eastern Lake Michigan shoreline, characterized by a multiple barred configuration and nearly parallel bathymetry. Only conditions of wave breaking on the inner bar were considered for this investigation. This restriction was imposed to avoid the added complication of waves reforming and breaking at multiple locations.

Three ducted impeller flow meters oriented parallel to the shoreline were placed at equally-spaced vertical positions at each monitoring station. The upper meter was placed below the level of the lowest wave trough so that it was continuously submerged. The lower meter was placed adjacent to the bottom and the middle meter half way between the upper and lower meters (Figure 2). Sequential measurements were made with three similar vertical current meter arrays at different locations across the surf zone. The outermost current monitoring station (Station I), was located within the zone of active breaking. The inner stations (Station II and III), were located five and ten meters, respectively, shoreward of Station I. Maximum wave breaking occurred at Station II, hence, the breaker zone was bracketed by the station locations. The total surf zone width was approximately thirty meters.

Simultaneous measurements of wave height, period and celerity were made perpendicular to the shoreline at stations spaced at equal intervals from the outer surf zone to the shore. The spacing of these stations was approximately 5 meters. The incident wave angle at breaking was determined to be 21 ± 5 degrees.

During constant sea state conditions, longshore current velocities and wave characteristics were simultaneously monitored continuously for fifteen minute periods separated by fifteen minute intervals. Constant sea state was determined by requiring that the probability distributions of wave height and period at the outer most wave monitoring station remain stationary. Hydrographic surveys were conducted, at close spatial intervals, offshore to a position outside the surf zone and alongshore to a distance of one surf zone width, which is the theoretical limit of rip cell width. The average nearshore beach slope was found to be 1:40.

ANALYSIS

The most appropriate representation of the longshore current and its associated wave field should be expressed in a statistical context.

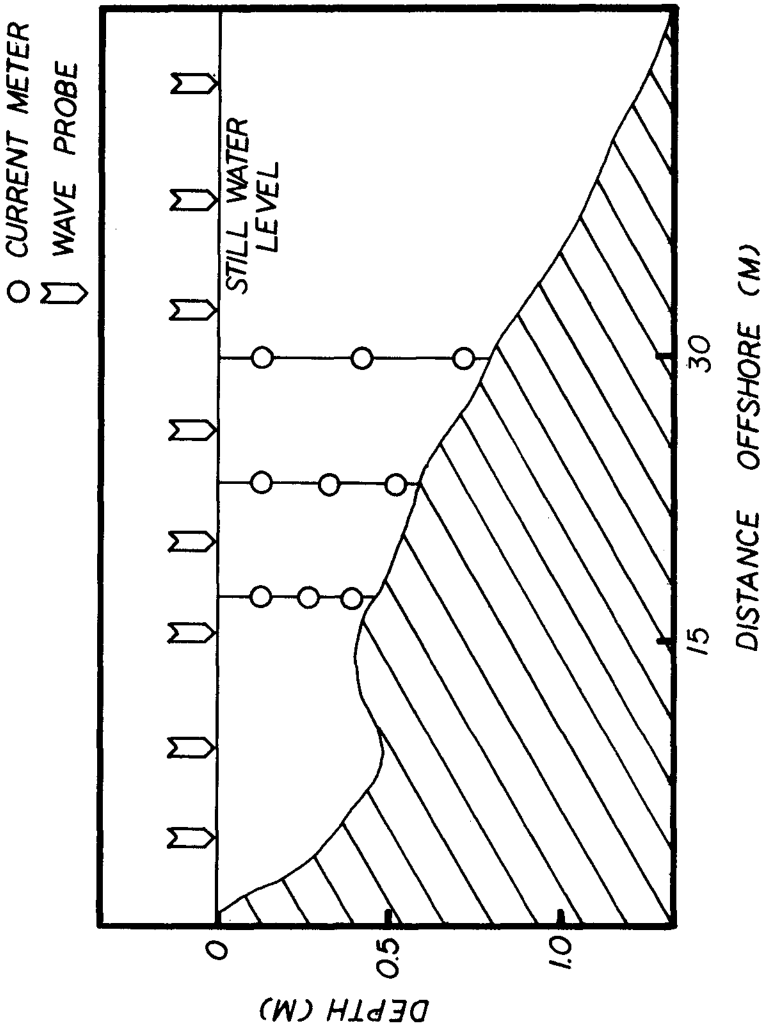

FIGURE 2. BATHYMETRIC PROFILE SHOWING CURRENT METER LOCATIONS AND WAVE MONITORING STATIONS.

Application of this approach to nearshore circulation has been the subject of recent work (Dette, 1974; Earl, 1974; Collins, 1972; and others). Consideration of probability distributions of wave characteristics across the surf zone anticipate a variation in wave height, incidence angle and celerity. Under a monochromatic assumption, all waves are expected to break at the same location in the surf zone. However, with a random distribution of the sea surface, the breaker line becomes a breaker zone and the region over which energy dissipation is active also becomes a broad zone.

Data obtained from the ducted impeller flow meter array were analyzed for their periodic and steady state components. The time intervals between discrete on-off signals of the meter were converted to instantaneous velocities. These velocities were then interpolated on equal time intervals between adjacent points. This data was then subjected to spectral analysis to determine its periodic components. Inherent to the monitoring system are aliasing problems. Data from the flow meter was only available at discrete instants of time, therefore, frequency information was lost from the signal. Frequencies greater than twice the interval between meter signals (averaged approximately 1.0 seconds) can not be resolved. Filtering of the input signal and smoothing of the power spectrum was therefore employed.

The analytical treatment of the longshore current flow field should be developed within the framework of an incompressible, inviscid fluid. The problem also must be formulated in a time dependent context with shallow water wave parameters as inputs. It is therefore necessary to evaluate the initial state of the wave field incident at the outer surf zone (Figure 3).

To evaluate wave induced unsteadiness of the longshore current flow field it is advantageous to remove from the experiment all secondary variations in the velocity field not directly related to the incident breaking waves. For this reason, only wave and current data collected during constant sea state conditions was acceptable for this investigation. The wave field was, therefore, required to be statistically steady in its mean, $\partial\bar{\eta}/\partial t = 0$. This restriction eliminates the existance of significant long period fluctuations in the longshore current velocity field induced by either growth or decay in the wave field incident at the outer surf zone. This restriction, however, does not preclude wave transformations within the surf zone, hence, $\partial\eta/\partial x \neq 0$.

It is not necessary for the incident wave field to be non-uniform in the alongshore direction for periodic unsteadiness in longshore current velocity to exist. Significant unsteadiness in the velocity field should be expected both from direct velocity contributions from breaking waves and from interactive phenomena associated with the entire wave group (Meadows and Wood, 1975).

Incident Wave Field Conditions

Wave Field Steady in Mean Wave Field Uniform in Y-Direction (Alongshore)	Wave Field Steady in Mean Wave Field Non-Uniform in Y-Direction (Alongshore)
$\overline{\frac{\partial \eta}{\partial t}} = 0$	$\overline{\frac{\partial \eta}{\partial t}} = 0$
$\frac{\partial \eta}{\partial x} \neq 0$	$\frac{\partial \eta}{\partial x} \neq 0$
$\frac{\partial \eta}{\partial y} = 0$	$\frac{\partial \eta}{\partial y} \neq 0$

Longshore Current Uniform in Y-Direction (Alongshore)		Longshore Current Non-Uniform in Y-Direction (Alongshore)	
Steady	Unsteady	Steady	Unsteady
$\frac{\partial u_i}{\partial t} = 0$	$\frac{\partial u_i}{\partial t} \neq 0$	$\frac{\partial u_i}{\partial t} = 0$	$\frac{\partial u_i}{\partial t} \neq 0$
$\frac{\partial u_i}{\partial x} \neq 0$	$\frac{\partial u_i}{\partial x} \neq 0$	$\frac{\partial u_i}{\partial x} \neq 0$	$\frac{\partial u_i}{\partial x} \neq 0$
$\frac{\partial u_i}{\partial y} = 0$	$\frac{\partial u_i}{\partial y} = 0$	$\frac{\partial u_i}{\partial y} \neq 0$	$\frac{\partial u_i}{\partial y} \neq 0$

FIGURE 3. INITIAL CONDITIONS DEFINING POSSIBLE ANALYTICAL CONSIDERATIONS FOR THE DEVELOPMENT OF LONGSHORE CURRENT THEORIES BASED ON THE INCIDENT WAVE FIELD.

The approximation $\partial\eta/\partial y = 0$, requires the incident waves remain long crested and two dimensional as they move through the surf zone. Hence, the initial conditions for a steady, uniform incident wave field have been established.

Another representation of the near shore wave field is that of a non-uniform sea surface in the alongshore direction, $\partial\eta/\partial y \neq 0$. Under this condition, additional driving forces for periodic variations in the longshore current velocity field may be expected. This condition may be a manifestation of either a short-crested sea surface or longer period edge waves. Both of these types of alongshore wave motion result in additional release of energy to the longshore current. However, at a fixed point in the surf zone, the direct cause of these secondary velocity fluctuations can not be established. Their magnitude will at best appear as a residual when all other primary fluctuations are accounted for.

Once the initial conditions describing the incident wave field have been established, the nature of the longshore current flow may be defined. As with the case of the incident wave field, the resulting longshore current flow field may be either uniform or non-uniform in its longshore extent. Classical treatments of longshore current have generally been restricted to a two dimensional long crested incident sea surface encroaching on a bottom with straight and parallel contours. Therefore, with the exception of rip cell formation, the longshore current is treated as uniform in the y-direction.

Figure 3 shows the various analytic assumptions which can be applied to the incident wave field and related longshore current. Existing longshore current theory is formulated on the assumption that only one of the eight possible combinations shown is observed in the surf zone (wave field steady and uniform, longshore current uniform and steady). The major restriction of these classical longshore current theories is that the motion has been confined to steady state, $\partial \overline{ui}/\partial t = 0$. The field investigation of Wood and Meadows (1975) has shown that at a fixed point in the surf zone variations in excess of 150 percent of the mean longshore current velocity occur over time periods from three to eighty seconds. These unsteady motions persist horizontally across the surf zone and vertically from the surface to the bottom. The persistance and magnitude of the observed velocity fluctuations imply that time dependent analytical treatments of conservation equations are necessary in order to properly predict longshore current velocity.

It is reasonable to assume that the total longshore current velocity field is composed of a steady and a fluctuating component which result from the incident wave field.

$$V = \bar{V} + V' \tag{13}$$

Recent field measurements (Wood and Meadows, 1975) suggest that the steady flow component and the fluctuating flow component are of comparable magnitude. Similarly, there exists in the surf zone driving components that can be expected to contribute only to the steady portion of the flow field and others that contribute only to the unsteady portions. Therefore, the governing differential equations for longshore current flow (Collins, 1972) should have been retained in their original time dependent form.

Consider the momentum and continuity equations for a two dimensional, incompressible, constant density fluid in the x and y direction (perpendicular and parallel to the beach respectively

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = - g \frac{\partial \eta}{\partial x} + T_x - B_x \qquad (14)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = - g \frac{\partial \eta}{\partial y} + T_y - B_y \qquad (15)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \qquad (16)$$

where T_x and T_y are the radiation stress components in the x and y direction respectively and B_x and B_y represent corresponding components of bottom friction.

Now let the velocity components u and v be composed of both a steady and a time dependent component of comparable magnitude, in the following form

$$u = \bar{u} + u' \qquad v = \bar{v} + v'$$

and the free surface elevation, η, be similarly decomposed into a steady and a fluctuating surface component

$$\eta = \bar{\eta} + \eta'.$$

The governing equations now become:

$$\frac{\partial u'}{\partial t} + \bar{u} \frac{\partial \bar{u}}{\partial x} + u' \frac{\partial \bar{u}}{\partial x} + \bar{u} \frac{\partial u'}{\partial x} + u' \frac{\partial u'}{\partial x} + \bar{v} \frac{\partial \bar{u}}{\partial y} + \bar{v} \frac{\partial u'}{\partial y} +$$

$$v' \frac{\partial \bar{u}}{\partial y} + v' \frac{\partial u'}{\partial y} = - g \frac{\partial \bar{\eta}}{\partial x} - g \frac{\partial \eta'}{\partial x} + T_x - B_x \qquad (17)$$

$$\frac{\partial v'}{\partial t} + \bar{u}\frac{\partial \bar{v}}{\partial x} + u'\frac{\partial \bar{v}}{\partial x} + \bar{u}\frac{\partial v'}{\partial x} + u'\frac{\partial v'}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + \bar{v}\frac{\partial v'}{\partial y} +$$

$$v'\frac{\partial \bar{v}}{\partial y} + v'\frac{\partial v'}{\partial y} = - g\frac{\partial \bar{\eta}}{\partial y} - g\frac{\partial \eta'}{\partial y} + T_y - B_y \tag{18}$$

$$\frac{\partial \eta'}{\partial t} + \frac{\partial[(\bar{u} + u')h]}{\partial x} + \frac{\partial[(\bar{v} + v')h]}{\partial y} = 0 \tag{19}$$

(Note: previous field observations have shown that $\partial\bar{u}/\partial t$ and $\partial\bar{v}/\partial t$ are non-zero terms due to slight variations in the main flow, however their magnitude is negligibly small).

Spectral analysis of the longshore current velocity series (Figure 4) indicated that significant energy was associated with the incident breaking wave period, 4.2 seconds. However, other dominant signatures occur at longer periods, with the maximum being 78.8 seconds. The observed longshore current velocity fluctuations seem to fall into three period ranges of interest. These periods are: 3 to 10 seconds, order of the incident breaking wave period, 25 to 200 seconds, range of the anticipated long period edge wave modes; and greater than 200 seconds, for the quasi steady state component.

The most obvious contribution to unsteadiness of longshore current velocity arises from the longshore component of the breaking wave horizontal particle velocity. Theory suggests that the longshore current velocity is most directly related to the magnitude of the longshore component of the breaking wave horizontal particle velocity at the surface, $c_b \sin \theta_b$. When time averaged, this oscillatory component was assumed to generate a mean longshore current, $\bar{v} = f(c_b \sin \theta_b)$. In order to evaluate the magnitude and the distribution of this component of the velocity field, only the periodic component of the velocity series is of interest. Hence, the steady state component was removed from the series. The magnitude of the horizontal particle velocity was evaluated throughout the water column. Experimentally derived profiles of maximum horizontal particle velocities and their variation with depth from the tank studies of Morison and Crooke (1953), and Divoky, Le'Mahaute' and Lin (1970), and the field studies of Miller and Zeigler (1964) and Wood (1970) were used for this evaluation. The calculated longshore component of these breaking wave maximum horizontal particle velocity profiles, $U_h' \sin \theta_b$, is plotted for each of the above studies on Figure 5. The velocity range for the three current meter depth locations through the water column of the observed periodic component of the longshore current from this investigation is also plotted on Figure 5.

The observed magnitudes of the fluctuating longshore current velocity compare favorably with the expected magnitudes of the longshore component of the breaking wave horizontal particle velocity. However,

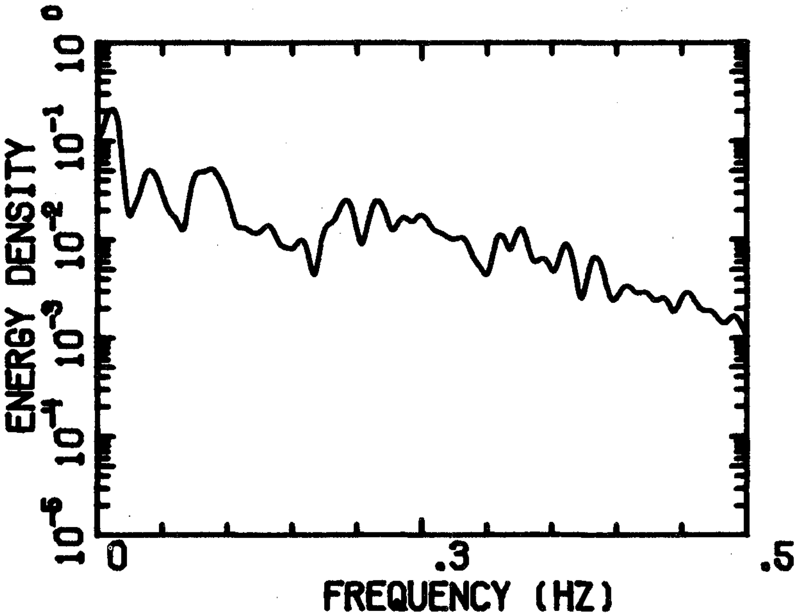

FIGURE 4. POWER SPECTRA FOR UPPER CURRENT METER COMPUTED FROM FIFTEEN MINUTE LONGSHORE CURRENT VELOCITY SERIES.

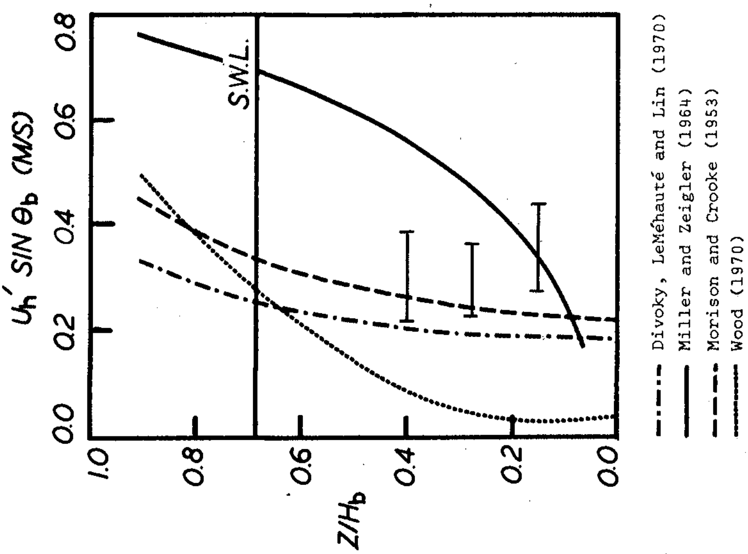

FIGURE 5. COMPUTED LONGSHORE COMPONENT OF BREAKING WAVE MAXIMUM HORIZONTAL PARTICLE VELOCITY COMPARED WITH OBSERVED DEMEANED LONGSHORE CURRENT VELOCITY FLUCTUATIONS FROM THIS INVESTIGATION.

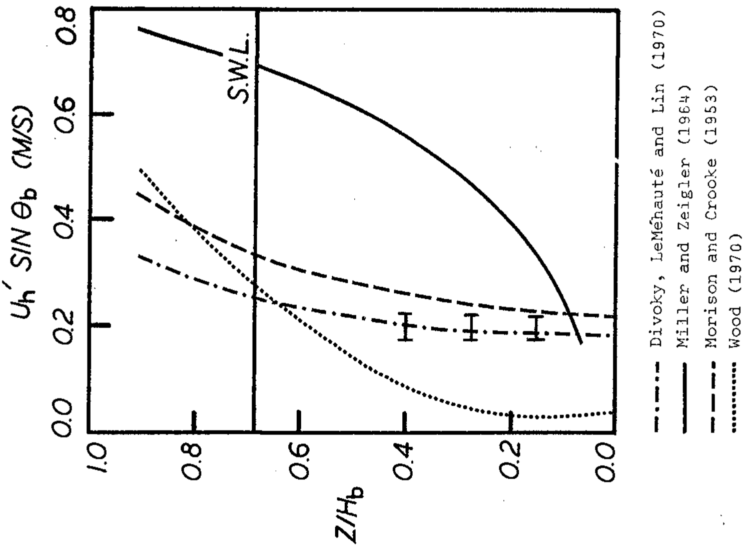

FIGURE 6. COMPUTED LONGSHORE COMPONENT OF BREAKING WAVE MAXIMUM HORIZONTAL PARTICLE VELOCITY COMPARED WITH OBSERVED DEMEANED AND FILTERED WAVE PERIOD (3-10 SECONDS) LONGSHORE CURRENT VELOCITY FLUCTUATIONS FROM THIS INVESTIGATION.

the magnitude of the velocity fluctuations from this investigation are generally, with the exception of Miller and Zeigler (1964), 50 to 100 percent larger than would be predicted from these studies. Re-examination of the longshore current velocity series provides an explanation for this decrepancy.

The demeaned longshore current velocity records with which the horizontal particle velocity profiles were compared, contain additional frequencies of longshore current velocity fluctuations. To isolate only that component of unsteadiness associated with the longshore component of the wave horizontal particle velocity, all frequencies other than the breaker zone wave frequencies were removed from the record. Band pass filtering was performed on the fifteen minute longshore velocity records to remove the effect of any long period waves from the observed fluctuations. The filtered series only contained fluctuations whose periods were between 3 and 10 seconds, Figure 6. This filtered series is then the observed longshore current velocity component resulting from the breaking wave horizontal particle velocity, $U_h' \sin \theta_b$. This filtered series of longshore current velocity fluctuations exhibit several characteristics that would be anticipated to be associated with breaking wave induced motions. First, the velocity fluctuations are nearly symmetrical about the abscissas, thus, suggesting that these motions are truly the result of the oscillatory wave particle velocity. Second, the magnitudes of the observed fluctuations are nearly uniform with depth. Near uniformity with depth is suggested by shallow water wave theory as well as by the observed maximum horizontal particle velocity profiles of Morison and Crooke (1953) and DiVoky, LéMehaute' and Lin (1970). The observed magnitudes of this filtered series of longshore current velocity fluctuations are in excellent agreement with the results of both previously mentioned tank experiments and are bracketed by the profiles obtained from the field investigations of Wood (1970), on the low side and by Miller and Zeigler (1964), at the upper end. This agreement suggests that the contribution of the breaking wave horizontal particle velocity to fluctuations in longshore current velocity has been isolated from the observed time series.

Results of spectral analysis of the fifteen minute longshore current velocity series has shown significant energy at a period of approximately 80 seconds. Examination of the band pass filtered (3-10 seconds), demeaned longshore current velocity series also shows repeated occurrences of groups of high velocity pulses in the long-shore current. The regular occurrence of these pulses at approximately 80 second intervals suggest a correlation with the spectral signature at that same period.

The distinction must be made that the individual high velocity pulses still retain their identity of approximately 5 second period and that groups of these large pulses arrive as a beat phenomenon at approximately 80 second intervals. However, for the spectral signature at an 80 second period to exist a wave phenomenon at that frequency must be present. Since, periodic amplitude modulation alone of the wave period fluctuating velocity series would not produce a spectral response at that period. It appears that this long period longshore current velocity fluctuation may be driven by the surf beat. Thus the fluctuating portion of the longshore current flow is composed of at least two distinct components. A component of period coincident with the breaking wave period and a long period component of approximately 80 seconds, Figure 7.

The original longshore current velocity series was then low band passed filtered to only allow periods between 200 seconds and 25 seconds to remain. This filtered, demeaned series (Figure 7) shows the existence of the anticipated long period wave phenomena of approximately 80 second period. The maximum magnitude of this velocity component was approximately $\pm$ .3 m/sec. The phase of this long period fluctuating component corresponds to the arrival of groups of high velocity pulses of the wave period fluctuation series. If we return to the conservation of mass theory of Bruun (1963) the suggestion was made that the longshore current flow is a response of the surf zone to an influx of mass associated with translatory breaking waves. Since the arrival of the group of high velocity pulses in the longshore current velocity field, is in phase with the long period velocity fluctuation, then perhaps this oscillation is a response of the surf zone to an increased mass flux. As was suggested by Bowen (1967), a corresponding set-up, set-down phenomenon could be expected in the longshore direction. However, since this correlation does appear to exist between the long period and wave period portions of the fluctuating flow, the generation of a low mode edge wave may be a reasonable expectation. The calculated maximum period for a zero mode edge wave for the conditions of this field investigation was 77.8 seconds (Guza and Inman, 1975). The nearshore beach face slope of 5.7° approaches the 6° beach slope for which these calculations were made. This is in agreement with the observed 78.8 second period fluctuation in the longshore current velocity. However, the effect of the well developed barred beach configuration, present during this study, on maximum edge wave periods is not clear, the choice of an "effective" beach slope over this region greatly alters the anticipated edge wave periods. Edge wave period calculations for the area immediately adjacent to the steep beach face suggests a period of 27.7 seconds. Examination of the power spectra for the current meter array at this location in the surf zone does show a weak signal at this frequency.

The major portion of the observed time dependent fluctuations in the longshore current velocity can be accounted for by the two components previously discussed. However, the linear addition of the breaking wave period fluctuating component, V_W', and the long period component, V_L' does not produce the original longshore current velocity series. The steady state component contributing to the longshore current velocity is absent from the series. The magnitude of the

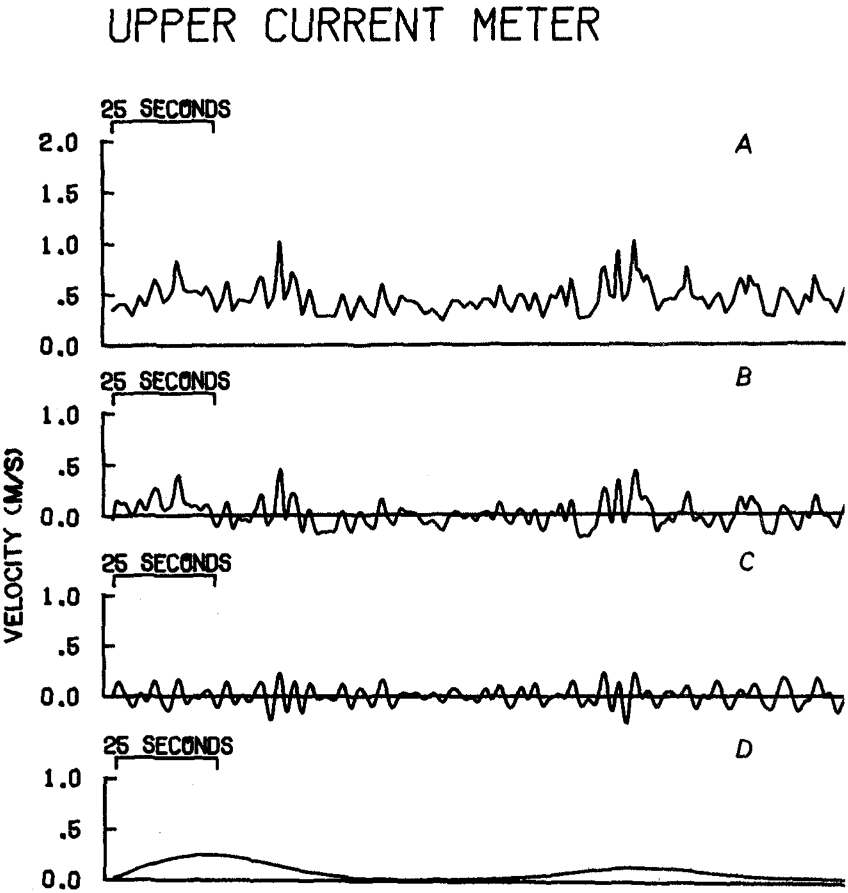

FIGURE 7. REPRESENTATIVE FLUCTUATING LONGSHORE CURRENT VELOCITY SERIES FROM UPPER CURRENT METER: A) TOTAL OBSERVED LONGSHORE CURRENT VELOCITY SERIES; B) DEMEANED LONG-SHORE CURRENT VELOCITY SEREIS; C) DEMEANED, BAND PASS FILTERED (3-10 SECONDS) LONGSHORE CURRENT VELOCITY SERIES; AND D) DEMEANED, BAND PASS FILTERED (25-200 SECONDS) LONGSHORE CURRENT VELOCITY SERIES.

steady longshore current velocity component $\bar{V}$, for this set of observations, was approximately 0.65 m/sec. For the purpose of this analysis, the steady state component is defined as the velocity component whose period of variation in magnitude is greater than 200 seconds. Therefore, there must exist a net stress on the fluid within the surf zone of sufficient magnitude to produce the observed steady component of the flow.

The radiation stress concept as applied to the generation of longshore currents by Longuet-Higgins (1970, 1 & 2) states that the presence of waves exerts a net stress on the water of the surf zone. This excess flow of momentum is a result of the flux, toward the shoreline of momentum parallel to the coast

$$Sxy = \overline{\int_{-h}^{\delta\eta} \rho uVdz.} \qquad (20)$$

This formulation, employing the radiation stress concept, for the prediction of steady longshore currents has been critized (S.P.M., 1973) for predicting the magnitude of longshore currents too low. However, for the results of this investigation, the formulation of Longuet-Higgins predicts the magnitude of the steady component, that which it was intended to predict, very well. The calculated value for the steady longshore current component using this formulation was 0.61 m/sec. While the observed steady component ranged from 0.60 to 0.66 m/sec (Wood and Meadows, 1975).

CONCLUSION

Three distinct longshore current velocity components have been isolated which contribute to the total observed longshore current velocity

$$V = \bar{V} + V_W' + V_L' \qquad (21)$$

where $\bar{V}$ is the steady longshore current velocity component and V_W' and V_L' are respectively the wave period and long period fluctuating longshore current velocity components. The mean longshore current velocity component, $\bar{V}$, was found to be dominated by the combination of the fluctuating components V_W', the incident breaking wave period fluctuations, and W_L', the long period fluctuations. Variations in the longshore current velocity of 90 to 150 percent of the mean current velocity have been shown to occur over periods from 3 to 80 seconds and these fluctuations have also been shown to persist horizontally across the surf zone as well as vertically from the surface to the bottom. In addition an interactive mechanism appears to be in operation within the surf zone by which short period velocity fluctuations, order of the incident wave period, appear to interact with long period fluctuations in the longshore current velocity. This interaction seems to be excited by 80 seconds periodic variations in the magnitude of the short period longshore current velocity fluctuations. Decomposition of the longshore current velocity record has shown that a steady state component also contributes to the observed velocity field. The formulation of longshore current theories based on temporally or spatially averaged quantities is a physically inappropriate procedure. In view of the results of the field investigation of Wood and Meadows (1975) it is unrealistic to expect a steady or slowly varying longshore current velocity field in the presence of an irregular oscillatory wave field. Consequently, a reevaluation of the reasonability of the steady state approach to the prediction of longshore current velocity is clearly needed. The success of solutions to problems associated with the coastal environment depends on an appropriate and complete understanding of physical processes active in the environment. The steady state approach to the longshore current velocity field cannot provide this understanding.

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