CHAPTER 84

WIND-GENERATED LONGSHORE CURRENTS

by

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ABSTRACT

This paper evaluates, through the use of a stepwise multiple regression procedure, whether parameters descriptive of the surf-zone wave field adequately explain the variability in longshore current velocities, or if the inclusion of additional physical environmental parameters could significantly improve the ability to predict such currents. The data set consists of 250 LEO - observations, collected on a seasonal basis over one year, at Debidue Island beach, South Carolina.

A regression analysis was performed both on linear combinations of all measured wave parameters, and on non-linear parameter combinations proposed in various semi-empirical predictive equations. Invariably, in all the regression analyses, the longshore component of the wind velocity proved to be the independent variable explaining most of the observed variance in the current velocity. Therefore, the statistical data analysis presented in this paper strongly suggests that wind stress can be a most significant factor in surf-zone current generation.

INTRODUCTION

Longshore current velocities measured in the surf-zone at Debidue Island, South Carolina, are the vector resultant of velocity components due to the oblique approach of the breaking wave, the nearshore cell circulation system, currents generated directly in the nearshore zone by wind stress and, perhaps, components of a regional circulation system. It is generally assumed that the dominant factor in the generation of longshore currents is the oblique approach of the breaking wave. Accordingly, the two most important parameters determining the longshore current velocity are the wave height and the angle between the wave crest and the shoreline (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1973). A number of theories explain the generation of such currents and predict their magnitude. These theories are grouped according to their considerations of (a) conservation of mass, (b) conservation of energy flux, or (c) conservation of momentum flux (Galvin, 1967). Empirical equations, based on statistical analysis of parameters describing the breaking wave, have also been constructed (Harrison, 1968; Fox and Davis, 1972), though such equations are generally of limited value outside the specific area of formulation.

The objective of this study was to evaluate, through the use of a stepwise multiple-linear regression procedure, whether parameters descriptive of the surf-zone wave field adequately explain the observed variability in longshore currents, or if the inclusion of additional environmental parameters could significantly improve the ability to predict such current velocity. Linear combinations of breaker parameters and four proposed equations for prediction of longshore current velocity were used in the evaluation.

Galvin (1963), basing his model on the continuity of water mass, arrived at the following equation

$$V = k \cdot g \cdot m \cdot T_b \cdot \sin 2\alpha_b \qquad (1)$$

where V is longshore current velocity, g is the acceleration of gravity, m is beach slope, α_b is breaker angle, T_b is breaker period, and k is a parameter of the breaker form, here taken as 1.0 (Galvin and Eagleson, 1965).

Longuet-Higgins (1970) derived an equation by considerations of the conservation of momentum flux for breaking waves. The U.S. Army, Corps of Engineers, Coastal Engineering Research Center (1973) empirically determined the proportionality constant in Longuet-Higgins' equation by fitting it to laboratory data by Galvin and Eagleson (1965) and field data from Putnam et. al (1949). Thus, the "modified" Longuet-Higgins equation reads:

$$V = 20.7 \quad m \, (g \, H_b)^{\frac{1}{2}} \, \sin 2\alpha_b \, . \tag{2}$$

Fox and Davis' (1972) empirical equation for their Lake Michigan data set is:

$$V = 2.98 \frac{H_b}{T_b} \sin 4\alpha_b \tag{3}$$

Another empirical equation, derived by Harrison (1968) from analysis of surf-zone data at Virginia Beach, reads:

$$V = 0.17 + 0.037 \, \alpha_b + 0.032 \, T_b + 0.24 \, H_b \tag{4}$$

Equations 1 through 4 formed the basis for the statistical evaluation of the role of breaker parameters in explaining the observed variability in the longshore current.

MEASUREMENTS

Descriptive summary statistics for all longshore current velocity readings obtained between July 1974 and March 1976 are presented in Table 1. The mean longshore current is stronger to the south (35.8 centimeters per second versus 23.8 centimeters to the north). Extreme variability in current velocities is demonstrated by the fact that the standard deviation almost equals the mean. Inman and Quinn (1952) also found in their study of longshore current variability on the Pacific coast that the standard deviation often equalled or exceeded the mean. There is an indication in the data that fall current velocities are slightly higher than those at other seasons.

The data set includes only those velocity readings which were obtained at least 3 hours after sudden reversals in wind direction. It was determined that there was a lag of about 2 to 3 hours between reversals in the longshore wind component and corresponding reversals in the current.

Table 1. Longshore current velocities at Debidue Island (in centimeters per second)

	Direction[1]	N[2]	Mean	Std. Dev.	Median
Jul. 1974 - Mar. 1976	N	176	23.8	17.0	19.6
	S	271	35.8	27.9	28.4
Analysis by season					
Jul. 1974	N	0	----	---3	
	S	0	----	----	
Jun. 1975	N	120	22.6	15.0	
	S	98	37.3	28.7	
Sept. 1974	N	21	13.8	0.0	
	S	152	46.4	33.0	
1975	N	58	26.3	16.1	
	S	137	45.5	30.7	
Jan. 1975	N	61	22.7	14.0	
	S	107	33.8	21.4	
1976	N	57	17.2	13.2	
	S	136	34.9	25.6	
Mar. 1975	N	72	24.4	18.3	
	S	64	27.1	17.4	
1976	N	117	31.3	19.7	
	S	103	25.7	16.3	

[1]Current direction along shoreline. N is to the north, S to the south.
[2]Number of observations.
[3]No reading.

All measurements were made by observers on the beach in accordance with specifications set forth in the Littoral Environments Observation program by the Coastal Engineering Research Center. As demonstrated in figure 1, the southern end of Debidue Beach, where the measurements took place, is characterized by a straight, gently sloping beach. Bathymetric profiles (Humphries, 1977) demonstrate that the nearshore region has straight shore-parallel depth contours. Although the North Inlet tidal delta is only about 2 km south of the study site, no measureable influence of tidal currents was detected.

Fig. 1. Oblique aerial view to the south along the shore of Debidue Island

ANALYSIS

Three regression procedures were utilized in this data analysis:

(1) Simple correlation was used to test for linear relationships between any pair of variables. The Pearson correlation coefficient is a measure of the degree of proportionality between two variables.
(2) Stepwise regression enters one independent variable at a time until all are entered simultaneously. Their order of inclusion is determined by the computer - the independent variable which explains the largest amount of variance in the dependent variable is entered first. The others are then entered in order of decreasing variance explained. The proportion of the total variance in the dependent variable explained by an independent variable, or a combination of variables, is expressed by the multiple correlation coefficient, r^2.
(3) Multiple regression enters one independent variable at a time in any order specified by the investigator. Thus, the amount of variance explained by any independent variable of particular interest can be assessed.

The variable names used in the computations and the following analysis are defined in Table 2.

Table 2. Variable names used in multiple regression analysis of littoral processes.

Name	Definition
VEL	Observed longshore current velocity (in centimeters per second). (+) indicated current to the right (south); (-) indicates current to the left (north).
HGT	Breaker height (in centimeters).
PER	Breaker period (in seconds).
WINDL	Longshore component of wind velocity (m.p.h.)
WAVL	Sine of the breaker angle.
VGAL	Velocity calculated by Galvin's (1963) formula (eg. 1), (centimeters per second).
VELH	Velocity calculated by Longuet-Higgins (1970) formula (eq. 2)
VEFD	Velocity calculated by Fox and Davis' (1972) formula (eq. 3)
VHAR	Velocity calculated by Harrison's (1968) formula (eq. 4).

Table 3 is a matrix of the Pearson product-moment correlation coefficients for these 9 variables for the 1975-76 data set of 250 observations.

Table 3. Pearson correlation coefficients between littoral variables defined in Table 2.

	VEL	HGT	PER	WINDL	WAVL	VGAL	VELH	VEFD
VEL	--							
HGT	0.37	--						
PER	-0.11	-0.06	--					
WINDL	0.83	0.36	-0.07	--				
WAVL	0.68	0.27	-0.09	0.68	--			
VGAL	0.64	0.27	-0.01	0.66	0.97	--		
VELH	0.69	0.38	-0.07	0.70	0.97	0.95	--	
VEFD	0.70	0.46	-0.12	0.69	0.88	0.81	0.93	
VHAR	0.68	0.39	0.05	0.69	0.98	0.97	0.97	0.88

Bivariate data plots produced by computer give further information on the nature of these correlations. The plots of wave height and period versus current velocity show hardly any discernible trend. Clearly, these parameters do not excert any dominant control on the current velocity. The sine of the breaker angle shows a moderate correlation with the current velocity. The scatter is particularly large for small angles of breaker approach. Wind velocity shows a moderate correlation with the current velocity, again scatter is at a maximum for relatively moderate winds. By far the best correlation is that between the longshore component of the wind velocity and the observed current velocity. The correlation coefficient equals 0.83 and the scatter is small, and uniform, over the entire range of the independent variable. If the surf-zone wave parameters are combined as suggested in equations (1), (2), (3) and (4), the predicted and observed longshore velocities show correlations ranging from r equals 0.64 for Galvin's (1963) formula to r equals 0.70 for Fox and Davis' (1972) formula.

If the longshore component of the wind is considered to be the only independent variable, one can write a simple regression equation for the longshore current velocity as:

$$\mathrm{VEL} = 3.42 \cdot \mathrm{WINDL} + 6.3 \tag{5}$$

This is a wholly empirical equation, and all parameters affecting the longshore current velocity are lumped into WINDL. Equation (5) does not indicate how much is due to the oblique breaking of the wind-generated waves. However, the equation is of predictive value for longshore currents off Debidue Island (and probably elsewhere under similar environmental conditions).

The correlation coefficients between observed current velocity and that predicted by the tested equations are all reasonably high. This indicates proportionality. However, the magnitude of the predicted velocity generally differs substantially from that observed, as evidenced by the proportionality factors in the following regression equations (all velocities are in centimeters per second).

$$\mathrm{VEL} = 0.33\ \mathrm{VGAL} + 5.18,\ r = 0.64 \tag{6}$$

$$\mathrm{VEL} = 0.45\ \mathrm{VELH} + 4.6,\ r = 0.64 \tag{7}$$

$$\mathrm{VEL} = 2.0\ \mathrm{VEFD} + 4.1,\ r = 0.70 \tag{8}$$

$$VEL = 0.71\ VHAR - 14.4, \quad r = 0.68 \qquad (9)$$

Galvin's (1963) and Longuet-Higgins' (1970) equations are both semiempirical, both predict current velocities higher than those observed at Debidue Island. The empirical equation of Fox and Davis (1972) predicts current velocities which are generally too low by a factor of ½. Harrison's (1968) equation predict currents of essentially the correct magnitude.

To test for the relative importance of the independent variables in explaining the variance in the dependent one, a stepwise regression analysis was used. The test was performed both for the pooled annual data and for each seasonal data set. Results are summarized in Table 4.

Table 4. Percent of the variance in VEL explained by each of four independent variables entered successively in a stepwise regression analysis.

		1975		1976	
Variable	Annual	June	Sept.	Jan.	Mar.
WINDL	70	81	63	57	69
VGAL	1	0	0	2	2
VELH	2	0	1	2	4
VEFD	4	0	7	1	6

For all data sets, the longshore component of the wind velocity, WINDL, proved to be the independent variable explaining most of the observed variance in current velocity, VEL. The multiple correlation coefficient (r^2), for VEL versus WINDL ranged from 0.81 for the June 1975 data set to 0.57 for the January 1976 data. Expectedly, data noise was at a maximum in January and minimum in June because of the different weather conditions under which the field observers had to operate. It is quite significant to note that for the data set which was expected to be the most reliable, (June 1975), WINDL alone explained 81 percent of the variance. For this data set, the inclusion of breaker parameters combined into the predictive equations of Galvin (1963), Longuet-Higgins (1970), and Fox and Davis (1972), does not improve the multiple correlation coefficient. For the other data sets, these variables add a few percents of explained variance.

A series of regression equations can be developed depending on which variables or combinations of variables are included. Table 5 summarizes the two types of equations derived in this study; the first (equation 10) is the regression equation derived by treating each measured environmental parameter as an independent variable; the three subsequent equations (equations 11, 12, 13) are derived by combining the pertinent breaker parameters as suggested in Galvin's (1963), Longuet-Higgins' (1970), and Fox and Davis' (1972) predictive formulas. Breaker parameters not accounted for in the predictive formulas are included as independent variables. The amount of variance in VEL explained by each parameter combination is constant, about 72 percent. Typically, the longshore component of the wind speed, WINDL, alone explains 70 percent of the variance. All other parameters combined can improve the predictability by a mere two percent.

Based on a similar analysis, Harrison (1968) derived a regression equation for longshore current velocity at Virginia Beach, Virginia. However, simultaneous wind measurements were not obtained in his study, and the question of wind stress or breaking wave dominance in longshore current generation could not be assessed.

Table 5. Multiple regression equations for measured longshore current velocities. The equations are all based on the same data set, but utilize different combinations of independent parameters.

VEL = 2.78 WINDL + 44.2 WAVL + 0.12 HGT - 0.85 PER + 5.94	(10)
VEL = 2.73 WINDL + 0.69 VEFD + 4.72	(11)
VEL = 2.83 WINDL + 0.13 VELH - 0.94 PER + 13.28	(12)
VEL = 2.91 WINDL + 0.06 VGAL + 0.12 HGT - 1.15	(13)

CONCLUSION

Based on measurements of longshore currents at Debidue Island beach, South Carolina, it appears that the parameters descriptive of the surf-zone wave field do not explain a significant amount of observed current variance. In fact, the longshore component of the wind velocity explains more of the observed current variance than any single parameter, or combination of parameters, descriptive of the breakers.

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