

## CHAPTER 55

### DISTRIBUTION OF SEDIMENT TRANSPORT ACROSS THE SURF ZONE

Edward B. Thornton  
Assistant Professor of Oceanography  
Naval Postgraduate School  
Monterey, California

#### ABSTRACT

The wave-induced sand transport alongshore is investigated by an energy principle approach. Although the energy approach has been used before, this is the first application to comparing theory and measurements of the distribution of littoral transport along a line perpendicular to the beach. Bed load transport equations are formulated for outside and inside the surf zone. Sand transport data were collected in the field using bed load traps. Wave, tide, wind, and current information was collected simultaneously in order to verify the derived predictive equations for longshore current and sediment transport. Quite reasonable predictions are obtained for the relative distribution of bed load transport, both inside and outside the surf zone.

#### INTRODUCTION

The wave induced sand transport alongshore is investigated using an energy principle approach. This method relates the work expended in transporting a quantity of sand to the energy available for transporting purposes. The development follows basically that of Bagnold [1] with some modifications to better suit the assumed conditions. The analysis is similar to Komar's [2] which was also based on Bagnold's approach. The inherent advantage of an energy approach is the simplicity and ease of physical interpretation. This type of approach also has had the most success for engineering applications in the oceans.

Bed load transport due to combined wave and current action is considered. The areas inside and outside the surf zone are discussed separately. Bagnold applied his analysis only to waves in deeper water, but the principle would be expected to be equally valid inside the surf zone.

The quantity of sand transported is a function of the energy available for transporting the sediments. This

energy is related to the energy utilized in bottom friction, viscous dissipation, and turbulence. For the case of waves and currents superposed, wave energy is utilized to put the sediment in motion, and, once in motion, the sediments can be acted upon by weak secondary currents. Hence, littoral drift can be considered as a stirring by the waves, which induces little net motion, and transport by the longshore current, which has net motion in the direction parallel to shore.

Energy dissipation outside the surf zone is primarily due to bottom friction, that is, most of the work is done on the bottom. Hence, the primary mode of transport outside the surf zone is by bed load. Energy is dissipated inside the surf zone both by the turbulence in the breaking waves and by friction acting on the bottom so that bed and suspended load transport are important.

#### BED LOAD TRANSPORT

It is assumed, in the problem being considered, that the bottom contours are straight and parallel so that the bed slope in the direction of net sand transport (parallel to the beach in the y-direction) is zero. It is further assumed that the slope of the beach is very small and that it is in dynamic equilibrium such that there is no net transversal (perpendicular to the beach in the x-direction) movement of sand. Hence, the slope of the beach will not affect the net sand transport and can be neglected. This is to say that the sand grains will maintain, on the average, the same relative position with respect to the bottom profile (distance offshore).

The average rate of work per unit bed area,  $P_h$ , required to overcome the resisting stress and maintain the bed load movement is proportional to the immersed weight of moving sand times the velocity of the sand grains moving along the bed,  $u_{sh}$

$$P_h \propto \left(1 - \frac{\rho}{\rho_s}\right) g m_h |\vec{u}_{sh}| \quad (1)$$

where  $\rho$  is the density of the fluid,  $\rho_s$  the density of the sediments and  $m_h$  the mass of the bed load transport. The absolute value sign is necessary since the sand grains can oscillate back and forth in response to the wave motion. The fluid motion responsible for the sediment transport is that of the waves and currents. The waves are assumed simple harmonic with zero mean motion, so that the net transport is due to the mean current in the longshore direction only. The net mass transport of the sediment per unit time per unit width perpendicular to the beach is defined

$$\bar{q}_h(x) = \bar{m}_h V_{sh} \quad (2)$$

where  $\bar{m}_h = \bar{m}_h(x)$  is the average mass of moving sediment per unit area of the bed with the mean velocity,  $V_{sh}(x)$  in the longshore direction.

Substituting Equation (2) into (1) leads to the expression for bed load transport.

$$\bar{q}_h \left(1 - \frac{\rho}{\rho_s}\right) g \frac{|\bar{u}_{sh}|}{V_{sh}} \propto P_h \quad (3)$$

The actual mean velocities of the sand grains are very difficult to measure. The mean sand grain velocities must be related to more measurable quantities in order to make Equation (3) workable. It is assumed, as a first approximation, that the mean velocity of the moving sand grains is proportional to the mean shear velocity in the direction of the sand particle motion. The mean shear velocity is defined

$$|\bar{u}_*| = \sqrt{\frac{|\bar{\tau}_h|}{\rho}} \quad (4)$$

where  $\bar{\tau}_h$  is the total mean bed shear stress. The ratio of the mean particle velocities is then given by

$$\frac{|\bar{u}_{sh}|}{V_{sh}} = b \left| \frac{\bar{\tau}_h}{\bar{\tau}_{hy}} \right|^{1/2} \quad (5)$$

where  $b$  is a constant of proportionality. It was shown by Thornton [3] that the ratio of the total mean bed shear stress  $\bar{\tau}_h$  to the mean bed shear stress due to the mean current in the  $y$  direction,  $\bar{\tau}_{hy}$ , is given by

$$\frac{\bar{\tau}_h}{\bar{\tau}_{hy}} = \frac{2}{\pi} \frac{u_{mh}}{V} \quad (6)$$

where  $V$  is the mean longshore current and  $u_{mh}$  is the maximum particle velocity of the waves at the bed. Hence, the ratio of the sand velocities is proportional to the square root of the water particle velocity ratio

$$\frac{|\bar{u}_{sh}|}{V_{sh}} \propto \left( \frac{u_{mh}}{V} \right)^{1/2} \quad (7)$$

The mean rate of bed load transport of sand per unit width in the longshore direction can then be expressed

$$\bar{q}_h \propto \frac{1}{g(1 - \frac{\rho}{\rho_s})} \sqrt{\frac{V}{u_{mh}}} P_h \quad (8)$$

The basic idea to underline is that the mass of sand transported is proportional to the available power.

#### A. Bed Load Transport Outside the Surf Zone

The mean work done in transporting the bed load and the available power are assumed proportional to each other. The fluid power available to transport the bed load is measurable as the product of the bottom shear stress due to the motion of the fluid times a representative flow velocity. This available power is equal to the work done on the bottom. The bed shear stress must be considered composed of both the wave and mean current components. The action of this combined, or total bed shear stress, can be thought of as the loosening of the sand grains off the bed which are then available for transport by the mean current. The mean current is the longshore current alone as the wave motion has little or no net motion. The total power expended is due to the combined wave and current action.

Outside the surf zone, there is normally little turbulent energy dissipated. Provided percolation can be neglected, the frictional energy dissipated on the bottom represents most of the energy dissipated. The reduction in wave energy, measurable as a decrease in wave height, is then indicative of the energy spent in sediment transport. In this case, the available power for sediment transport would be proportional to the total change in energy flux.

$$P_h = \frac{-\partial E c_g}{\partial x} = \left| \overline{u_{wh} \tau_h} \right| \quad (9)$$

where  $E$  is the wave energy density and  $c_g$  the group velocity of the waves.  $u_{wh}$  is the water<sup>g</sup> particle velocity at the bed due to the waves. The bottom shear stress assuming small wave angles of approach is given by

$$\tau_h = \frac{\rho f_w}{2} u_{wh} |u_{wh}| \quad (10)$$

where  $f_w$  is a friction factor.

Jonsson [4] showed that the friction factor for wave motion alone for rough turbulent boundary layers could tentatively be represented by

$$\frac{1}{4\sqrt{f_w}} + \log \frac{1}{4\sqrt{f_w}} = -0.08 + \log \frac{\xi_h}{r} \quad (11)$$

where  $r$  is a measure of roughness given by the ripple height and  $\xi_h$  is the maximum water particle excursion amplitude of the fluid motion at the bottom as predicted by linear wave theory. This representation is used in this formulation.

The longshore current formulation is based on the "radiation stress" concept where the changes in excess momentum flux due to the wave motion is balanced by the bottom shear stress due to the mean current (see Thornton [3]). The formulation includes changes in the mean water level. The longshore current outside the surf zone is given by

$$V = -\frac{\pi\sigma}{pgkf_wH} \cosh kh \frac{\partial}{\partial x} \left( E \frac{c}{c} \sin 2\alpha \right) \quad (12)$$

where  $k$  is the wave number,  $\sigma$  is the radial frequency,  $H$  is the wave height,  $\alpha$  is the angle between the wave crest and bottom contour,  $c$  is the wave speed, and  $h$  is the depth of water.

The mean bed load transport of sand per unit time per unit width in the longshore direction can then be expressed

$$\bar{q}_h = \frac{B}{g \left( 1 - \frac{\rho}{\rho_s} \right)} \sqrt{\frac{V}{u_{mh}}} \left| \tau_{wh} \tau_h \right| \quad (13)$$

where all the proportionality factors have been combined into  $B$  and must be determined experimentally.

#### B. Bed Load Transport Inside Surf Zone

Inside the surf zone, the dissipation of energy is greatly increased and is largely due to turbulent dissipation. The transport inside the surf zone is much greater than outside, and a large proportion of the transport is suspended load for which there is more energy available for transporting purposes. The actual bed load is still a function of the energy dissipated on the bottom which decreases with decreasing depth. There is also an additional amount of work done on the bed by turbulent energy being diffused and convected downward due to the breaking waves. It is assumed that inside the surf zone the bed load as well as the suspended load is a function of the total energy dissipated including both the energy dissipated on the bottom due to friction and turbulent energy dissipation due to the breaking waves.

$$P_h = \frac{-\partial E c}{\partial x} g \quad (14)$$

In the present analysis, it is assumed that the waves act as spilling breakers inside the surf zone and that they follow the breaking index,  $\kappa = 0.78$ , as predicted by the solitary wave theory. The wave height inside the surf zone is then given by

$$H = \kappa D \quad (15)$$

It is further assumed that the total wave energy can be described in terms of the wave height which is a function of the depth

$$E = \frac{1}{8} \rho g \kappa^2 D^2 \quad (16)$$

This is a non-conservative statement of the energy distribution within the surf zone. The wave speed is approximated using solitary wave theory and for shallow water

$$c_g = c = \sqrt{g(1 + \kappa)D} \quad (17)$$

The total mean transport inside the surf zone is then

$$\bar{q} = \frac{-1}{g(1 - \frac{\rho}{\rho_s})} \left[ B_s \sqrt{\frac{V}{u_{mh}}} \right] \frac{\partial E c}{\partial x} g \quad (18)$$

where  $B_s$  is the proportionality factor for inside the surf zone. For transport of sand in the surf zone, the proportionality factor will certainly be a function of the manner in which the waves break--just as are the wave-induced currents inside the surf zone.

The longshore current distribution inside the surf zone as given by Thornton [3] is used

$$V(x) = -\frac{5}{8} \frac{\pi \kappa}{F_w} \left( 1 - \frac{\kappa^2}{8(1+\kappa)} \right) c_b \sin \alpha_b \cos \alpha_b \frac{D}{D_b} \frac{\partial D}{\partial x} \quad (19)$$

where  $b$  subscript refers to conditions at the breaker line.

Equations (13) and (18) are rational equations for predicting the bed load sediment transport due to combined waves and longshore current outside and inside the surf zone. Unfortunately, unknown proportionality factors, or energy coefficients, have been introduced. Experiments have been conducted in laboratory flumes by Inman and Bowen [5] to experimentally determine the functional relationship of the coefficients. These experiments were

conducted by superposing waves on a current moving in the same direction. Unfortunately, no such relationships have evolved empirically to date.

#### FIELD EXPERIMENTS

A meaningful investigation of the sand transport processes in the surf zone requires the synoptic measurement of a number of hydrodynamic and sediment variables. Fairly complete and extensive data are required to evaluate the validity of the proposed sand transport relationships.

Field experiments were conducted in the surf zone at Fernandina Beach, located on the northeastern coast of Florida. The emphasis of the tests was to obtain information concerning the distribution of alongshore sand transport across the surf zone and the physical processes causing such movement. Sediment transport about the surf zone has been shown to be caused by a combination of shear stresses and turbulence due to wave and current action. Hence, an attempt to correlate sediment transport with physical parameters must include adequate wave and current measurements.

Experiments were initiated in 1962 and conducted intermittently at this location. Data from experiments conducted between 1964 and 1967 are used for testing the equations. In the course of this time, the method of measuring the various parameters changed, evolving to a relatively sophisticated level. Much of the test equipment was designed and developed especially for these experiments and is unique.

The experiments were conducted at various times of the year so that a variety of wave and weather conditions prevailed during the experiments. The measurements were taken from a pier traversing the surf zone seaward to the outer bar. A plan of the pier and location of the instrumentation are shown in Figure 1. A typical bottom profile taken adjacent to the pier is also shown in this figure. The beach and nearshore bottom profile is typically a one-or-two bar system with a gentle slope of 2 to 3 percent. The experiments were limited to the study of the sand transport in the area bounded by the outer and inner bar.

The sand characteristics have been studied thoroughly including size distribution, mineral composition, and differences of characteristics across the surf zone. The results generally showed the sand to be evenly sorted in the area of the sand transport measurements. The mean grain diameter at Fernandina Beach is approximately 0.2 millimeters.

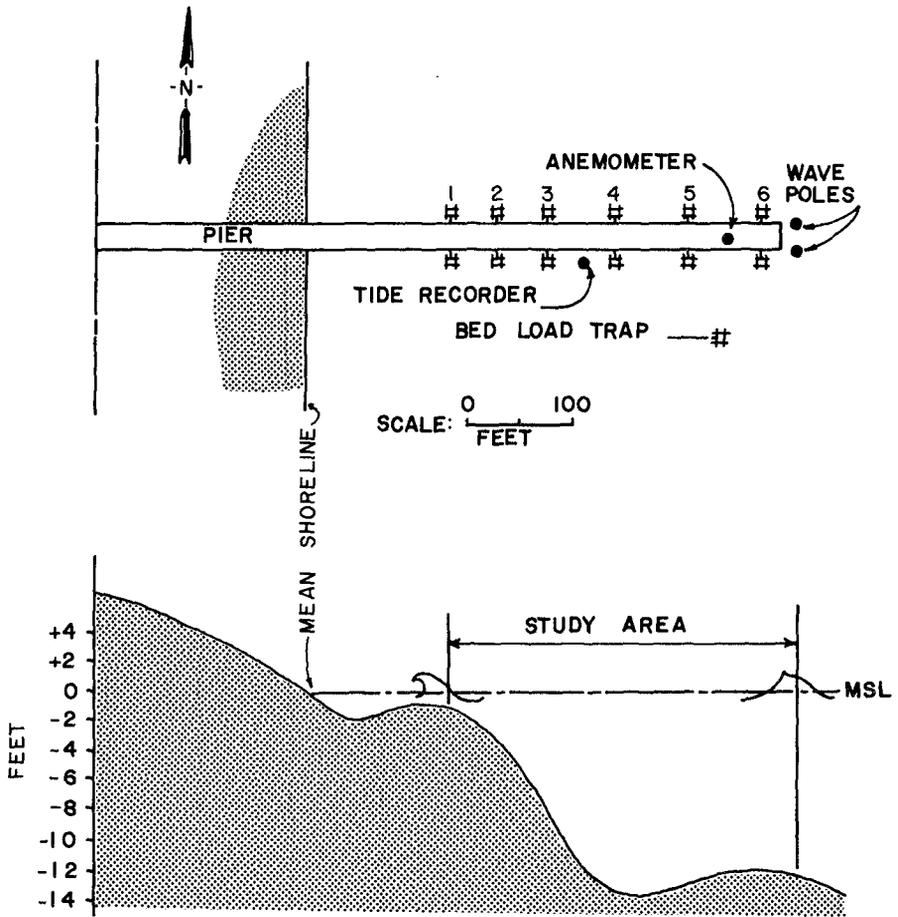


Figure 1.  
Plan of Pier Showing Instrument Locations and Typical Bottom Profile at Fernandina Beach, Florida

The physical parameters measured during the experiments were the wave height, wave direction, currents, tides, wind direction and speed, quantity of sediment transport, bottom contour profiles, and sediment characteristics. The experiments were conducted typically over approximately half a tidal cycle, usually four to six hours. The mean tidal range is 5.6 feet. The tide recorder, anemometer, and sand traps operated continuously during the experiment. Current measurements were taken by means of floats and current meters. The wave heights and direction were measured simultaneously. The instrumentation and details of measurements have been previously discussed by the author (Thornton [6]).

Taking measurements in the surf zone is usually a difficult problem due, in part, to the tremendous forces exerted by the waves. It is almost essential for synoptic measurements to have a stable platform from which to work. This platform, a fishing pier in this case, exerts some local influence on the environment being measured and care must be taken to minimize this effect. Thus, all measurements were made as far from the pier and its piling as possible, and the measurements were taken on the updrift side of the pier on which the incident waves impinge first.

#### A. Sand Transport Measurements

The quantity of sand transport was measured by means of bed load traps. The traps are aligned in the direction of the longshore current and are designed to intercept the bed load portion of the littoral drift. These traps rest on the bottom and sample an area 20 centimeters high by 40 centimeters wide. The bed load movement here is defined by the height of the traps and, as such, includes saltation. Up to six traps were operated simultaneously from the pier and are located as indicated in Figure 1. The unique design of these traps evolved over several years of use, and they have proven to be very rugged and dependable for the severe conditions to which they are subjected. An abbreviated description is given below. For a more complete description of the traps and attendant system, see Thornton [6] and Bruun and Purpura [7].

The body of the traps is elliptical in shape which serves two functions: to decrease current velocities due to the divergence from the entrance allowing sediment to fall from suspension during sampling, and to act as a circular tank in which a swirling motion is developed to put sediment in suspension for pumping out. The trap base is a sheet metal apron which is extended to reduce scour. Tag lines were attached to assure proper orientation. The traps were run typically on a sampling sequence of 15 minutes sampling with the doors open and 5 minutes pumping out with the doors closed. The doors operate pneumatically

from the pier. During the pumping-out cycle when the doors are closed, two jets of fresh water from inside the trap create a swirling action to put sediment in suspension. Simultaneously, the water-sand mixture is pumped out of the traps into filter baskets and drained of the water. The wet sand is put in sample bags and taken back to the laboratory where it is dried and weighed.

The accuracy of the sand traps is dependent on their efficiency in retaining the sand that passes into the trap. The trap efficiency is dependent on the wave conditions, being more efficient for light wave conditions where the turbulence and induced currents are less. The traps tend to become clogged for very heavy wave conditions, and all the sand cannot be pumped out in the sampling cycle; the traps also tend to bury themselves for extreme wave conditions. The traps were observed in the laboratory and field under light wave conditions and appeared to function very well. It was not possible to observe the traps under heavier wave conditions due to the increased turbidity of the water. A trap efficiency of between 40 and 100 percent is estimated as the representative range for most conditions.

#### B. Current Measurements

Simultaneous with the sand transport measurements was a complete measurement of the physical environment. The currents were measured using two means: floats in the earlier experiments and combined floats and a current meter in later tests. The float measurements consisted of filling large balloons (one foot in diameter when filled) with fresh water and releasing these from the pier and measuring their travel time over a prescribed distance. The fresh water makes the balloons slightly buoyant so that just the top of the balloon is visible. These proved to be a very effective means of measuring the longshore currents.

The direct measurement of water particle velocities in the presence of a wave field, such as the surf zone, has long been a problem. An electromagnetic flowmeter was used during these experiments and proved applicable for use in the surf zone.

#### C. Wave Measurements

The waves were measured by a variety of methods including mechanical, pressure, and resistance wire wave meters. The measurements were made at one or several locations along the pier.

Waves, as they occur in nature, are essentially aperiodic or random in appearance and, as such, have to be

treated as a statistical phenomenon. The studies were conducted over a relatively short duration of time, and the physical environment may be assumed quasi-stationary. Hence, spectral analysis or other statistical inference can be employed in treating this aperiodic phenomenon. Spectral analysis was used in the later experiments and provided valuable information concerning the energy distribution in and about the surf zone. The relations derived previously assume a single component wave system and are not formulated to accommodate a spectrum of waves. For this reason, and due to the variety of methods used in measuring waves, it is convenient to extract from the wave measurements a single parameter characterizing the energy content of the waves. This parameter was selected as the significant wave height which is defined statistically as the average of the highest one-third waves.

The wave direction was measured by sighting with a compass and noting the angle between the pier alignment and the wave crest. Aerial photography was also employed in a number of the experiments. The incident wave angle at particular points inside and outside of the surf zone were determined in this manner. These measurements refer to the angle of the "significant" wave. Wave measurements conducted in the later experiments, using two wave staffs stationed at the end of the pier and aligned parallel to the shore, allowed directional features of the waves to be determined. A directional spectrum is obtained by computing the Fourier transform of the cross-correlation function of the two wave records which associates one direction with each frequency component and is essentially a measure of the phase difference between the two sensor locations for each Fourier component. A more complete description of the spectral aspects of the experiments is given by Thornton [6].

The angle of wave incidence is the most importantly weighted variable in the predictive equations for the longshore current and sediment transport equations; it is also the most difficult parameter to measure accurately. Galvin and Savage [8] compared several methods for measuring waves from a pier using a compass and sighting along the wave crests. They concluded that the error in measuring wave angle may be easily  $\pm 2$  degrees, and this same variability will be assumed here. This amount of uncertainty in the measured angle can result in considerable error in the longshore current and sediment transport calculations--particularly, for small angles of approach.

The wave heights generally were determined from wave records greater than five minutes in length. Hence, the significant wave height was determined with a high degree of confidence. Visual measurements were used in the first experiments. Galvin and Savage (op. cit.) state an

accuracy of the breaking wave height of  $\pm 25$  percent for both wave meter and visual measurements. There is an uncertainty even for the wave meter measurements since there is a spatial variation due to variations in bottom topography. The wave meter measures only at one point that may not be representative of the general area.

#### RESULTS AND COMPARISON WITH THEORY

Thirty-one experiments were conducted in all, fourteen of which were judged appropriate for comparison with theory. The other experiments were deleted because of the presence of rip currents, lack of correlating data, equipment failure, or unfavorable weather.

The sand transport, like the waves and water particle motion causing the transport, is a stochastic process. The bed load transport was seen to vary considerably with time. All data used are mean values representing an assumed stationary system.

The data are used to test the bed load transport theory, Equation (13) for outside the surf zone and Equation (18) for inside the surf zone. It is necessary to make several assumptions in the application of the predictive equations. It is assumed that the ripple height was everywhere constant and equal to 0.05 feet. The same ripple height was used for predicting the mean longshore currents inside the surf zone and gave reasonable results. A constant ripple height is not necessarily a good assumption, but was made as a first approximation due to there not being enough information to assume otherwise.

Percolation losses have been found empirically to be very small for sand sizes less than 0.5 millimeters. Energy losses due to percolation have been neglected for application to the Fernandina Beach data because the mean grain size is much less than this value. A mean specific gravity of 2.65 was measured for Fernandina Beach sand, and this value was used in all calculations.

The theory requires wave and current information everywhere along the profile. The measured wave parameters, taken at one location, are used to obtain wave characteristics at each trap location by theoretically carrying the waves shoreward accounting for shoaling, refraction, and frictional dissipation. Predicted longshore currents were used in the littoral transport equations since there was a lack of measurements at each station. The objective is to obtain equations that can be easily utilized to predict the littoral transport from the measured physical environment, and the wave information at one point is all that is usually available.

The distribution of the measured and predicted bed load transport are compared for Test Numbers 19 and 22 in Figures 2 and 3. During Test number 19, all the traps were outside the breaker line which was the case in most of the experiments. The significant wave height was 3.8 feet, the mean wave period 6 seconds and the mean angle of wave approach 3.5 degrees.

Different values of the proportionality factor B were chosen for predicting the sediment transport distribution so that a best fit between theory and experiment for each test could be obtained. The rationale, in doing so, is that if one of the measured variables in the experiments, such as wave height or direction, was substantially in error, this error could change the absolute value of the prediction considerably, but have little effect on the relative distribution along the profile. The B values for inside the surf zone range from 0.42 to 1.0 for all tests except one. The exception was Test Number 25 for which a value of  $B = 0.13$  was used.

There appears to be a definite correlation of sediment transport with depth of water which is graphically illustrated in Figure 2 for Test Number 19. The energy density of the waves in the process of shoaling outside the surf zone generally increases with decreasing depth (provided frictional energy dissipation is not too great) to a maximum at near breaking. Since the energy density is generally a function of depth, the correlation of sediment transport with depth is explained. Indeed, the transport is shown to be a minimum in the trough of the profile, greater over the bar, and a maximum near the breaker line where the energy density is greater.

Measurements both inside and outside the surf zone were obtained in Test Number 22. In this experiment, the significant wave height was 3.8 feet, the mean wave period 8 seconds, and mean angle of wave approach 4 degrees. Again, there is a general correspondence of transport with depth outside the surf zone; a maximum occurs at the breaker line. The energy density gradually decreases for spilling breakers inside the surf zone, and a corresponding decrease in sediment transport is expected. This is clearly shown in Figure 3. It should be noted that a different proportionality factor has been used for inside and outside the surf zone which might be expected.

All the results for outside the surf zone are summarized in Figure 4. The same constant of proportionality,  $B = 1.0$ , has been used for all the predicted values so as to provide a comparison between the various tests. There are forty values in all to form the correlation. As can be seen, the data span a very large range of values, almost three decades on a log-log graph. The heavy line

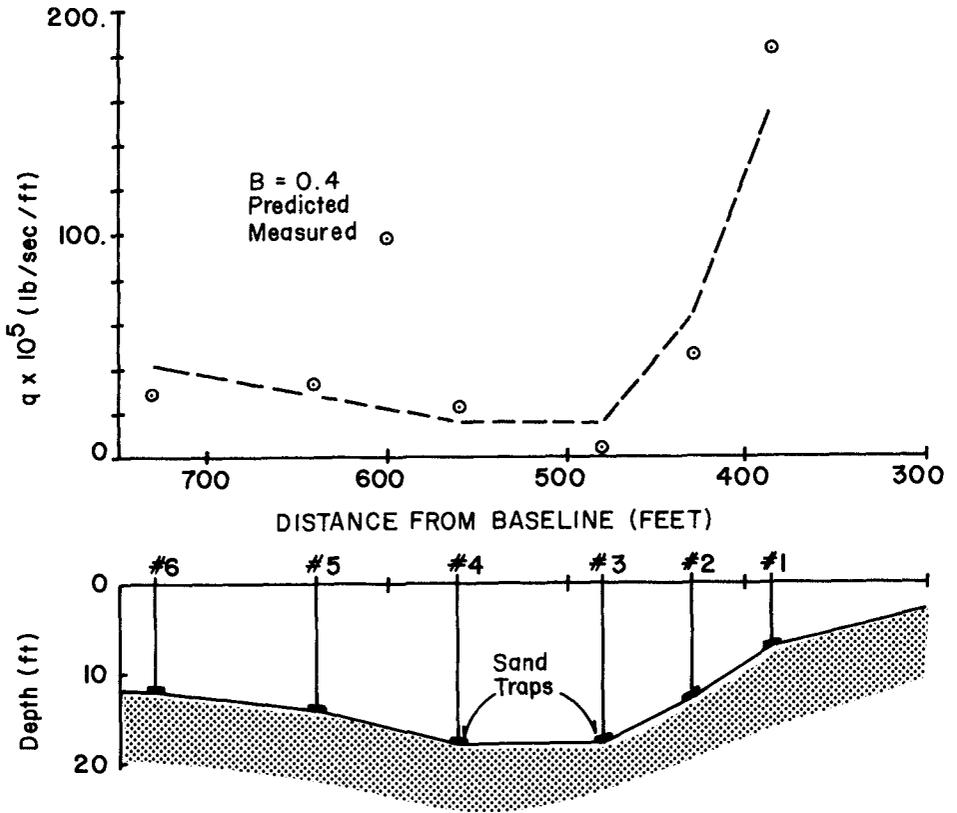


Figure 2.  
Distribution of Bed Load Transport outside the surf zone,  
Test Number 19

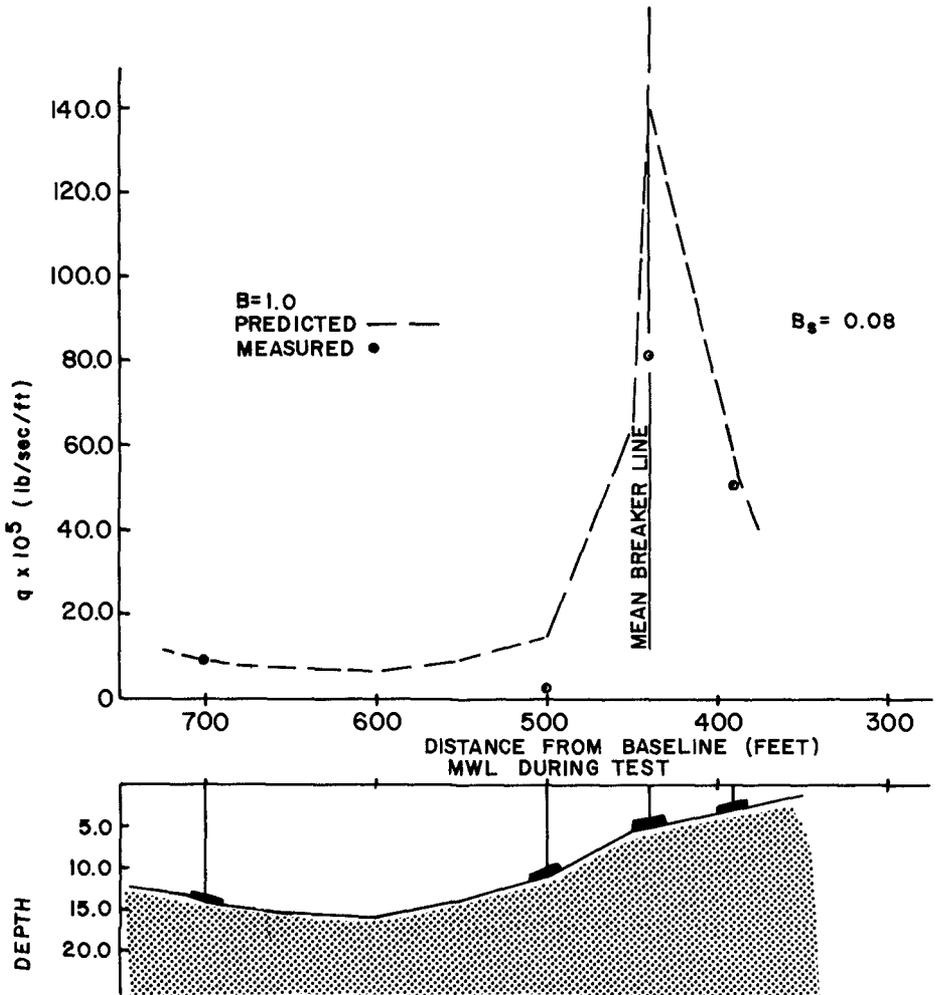


Figure 3.  
 Distribution of Bed Load Transport across the Surf Zone  
 Test Number 22

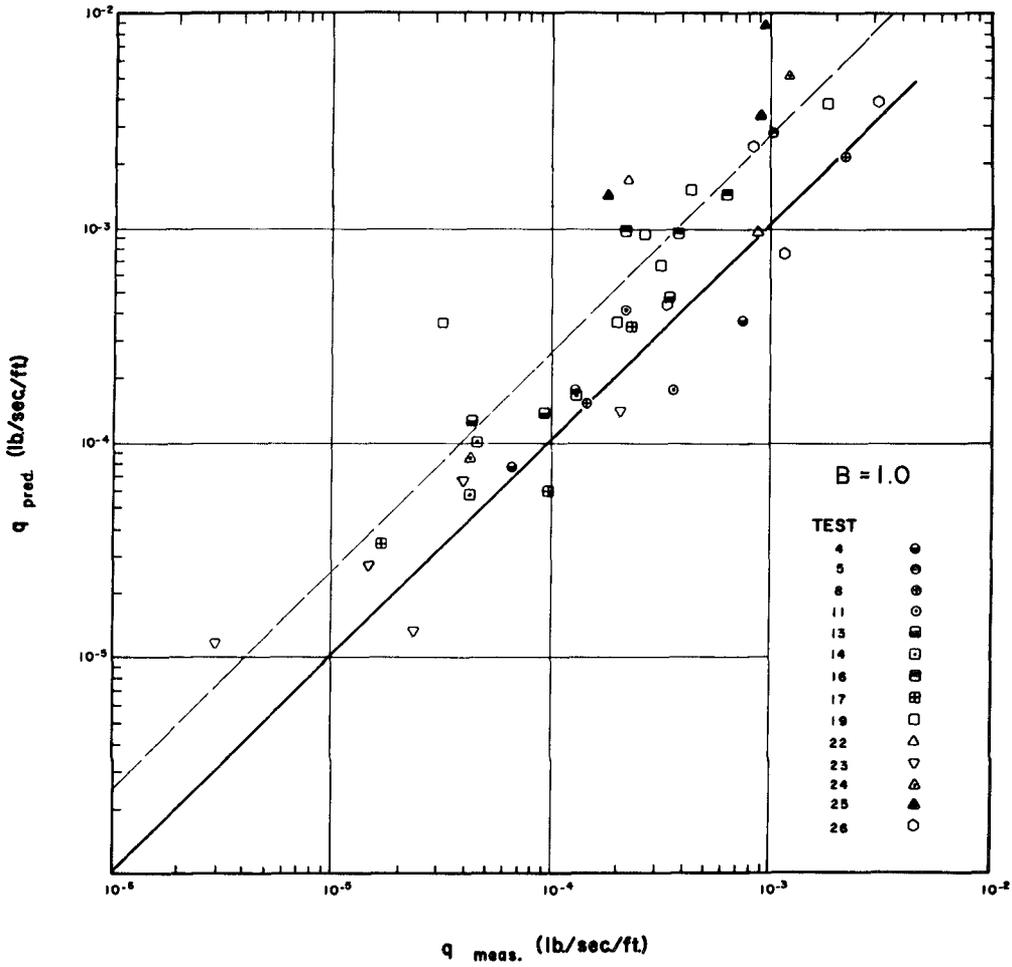


Figure 4.

Measured and Predicted Bed Load Transport outside the Surf Zone

denotes a one to one correspondence between predicted and measured values for the proportionality factor given by B. The dashed line indicates the expected range of variability of the measured values due to the efficiency of the traps in catching the bed load. The dashed line as drawn indicates that the traps are estimated to be at least 40 percent efficient in collecting the bed load. It is possible that, in some cases, the traps were more than 100 percent efficient, that is, they collected more than the actual net littoral transport. This might happen when there is no net flow in one direction alongshore, and the traps would collect sand moving in both directions, indicating a larger than actual net transport.

The predicted and measured values for inside the surf zone are shown in Figure 5. Unfortunately, there is a paucity of data for sediment transport inside the surf zone. This is primarily due to the design of the traps in that they function poorly for very high transport rates as generally occurs inside the surf zone and have a tendency to become buried. A proportionality factor of  $B = 0.08$  was used for all experiments inside the surf zone. The estimated limits of variability extend the same range as before. All the values except one fall within the estimated variability of traps. This, in itself, is considered to be very good correlation for predicting conditions so complicated and varied as occurring inside the surf zone.

The values of B are necessarily limited to the particular sediment characteristic found at Fernandina Beach. The most important characteristics are the mean grain size,  $d = 0.2$  millimeter and the specific gravity equal to 2.65. Although the distributions were indicative of only one grain size, the relative distributions are expected to vary little. This is due to the fact that the influence of grain size (provided percolation is not important) would be primarily to change the factor B and the friction factor  $f_w$ . Since B is assumed to be constant, and  $f_w$  varies only slowly, the relative distribution would not be expected to differ substantially for different grain sizes.

As mentioned previously, the measured currents were not used in comparing the results. The measured longshore currents outside the surf zone are generally several times greater than the predicted values. The bathymetry at Fernandina Beach is not ideal for the application of the derived theory in that there is typically a bar-trough formation. The bar may tend to trap the shoreward mass transport of the waves between the bar and the shoreline. This fluid contribution over the bar could constitute a considerable influence on the longshore velocity outside the breaker line. The discrepancies between theoretical and measured longshore currents could also be a result of neglecting the influence of internal shear stresses. The

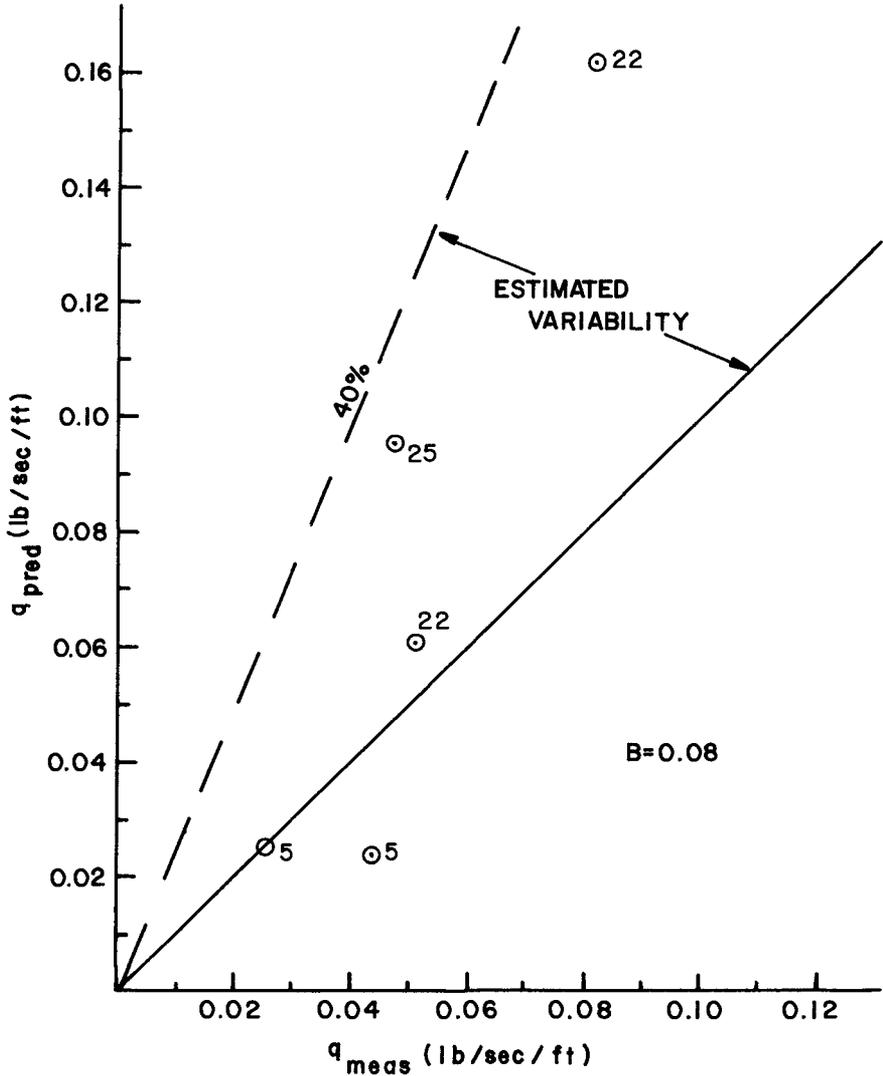


Figure 5.  
Comparison of Measured and Predicted Bed Load Transport inside the Surf Zone.

coupling across the breaker line, due to lateral transport of momentum offshore, would increase the predicted longshore current values outside the surf zone.

If the actual values of the longshore current were used, instead of the predicted values, the proportionality factor  $B$  would be decreased for outside the surf zone. This would result in the proportionality factors, applicable to inside and outside the surf zone, being more nearly equal. The predicted and measured longshore current velocities inside the surf zone correspond well so that the substitution of the measured values would not substantially change the  $B_s$  value inside the surf zone.

#### CONCLUSIONS

The wave-induced sand transport alongshore was investigated by an energy principle approach. The aim of the investigation was to present usable predictive formulas. Bed load transport equations were formulated for outside and inside the surf zone. Although the energy approach has been used before, this is the first application to comparing theory and measurements of the distribution of littoral transport along a line perpendicular to the beach.

Sand transport data were collected in the field using bed load traps. Wave, tide, wind, and current information was collected simultaneously in order to verify the derived predictive equations for longshore current and sediment transport. The longshore current formulation including only bottom shear stress was used in the sediment transport predictive equations.

The field data were correlated with the predictive equations to determine separate proportionality factors for inside and outside the surf zone. The proportionality factors are limited to the particular parameters found at the experimental site. In particular, the sediment transport rates would certainly be dependent on the sand characteristics such as grain size and sediment density. However, the comparison of theory and experiment show that the relative distributions, which would be expected to have little dependence on sand characteristics, were fairly well predicted. Quite reasonable predictions were obtained for the relative distribution of bed load transport, both inside and outside the surf zone; although, the absolute values were not as well predicted. Hence, the equations could be used as a qualitative predictive relationship for engineering application.

## BIBLIOGRAPHY

1. Bagnold, R. A. Mechanics of Marine Sedimentation, The Sea, Interscience Publishers, New York, 3:507-528, 1963.
2. Komar, P. D. The Mechanics of Sand Transport on Beaches, J. of Geophysical Research, Vol. 76, No. 3, Jan. 20, 1971.
3. Thornton, E. B. Variations of Longshore Current Across the Surf Zone, Proc. Twelfth Coastal Engineering Conf., ASCE, 1970.
4. Jonsson, I. G. Wave Boundary Layers and Friction Factors, Proc. Tenth Conf. Coastal Eng., ASCE, 127-148, 1966.
5. Inman, D. L. and Bowen, A. J. Flume Experiments on Sand Transport by Waves and Currents, Proc. Eighth Conf. Coastal Eng., Council on Wave Research, 137-150, 1963.
6. Thornton, E. B. A Field Investigation of Sand Transport in the Surf Zone, Proc. Eleventh Coastal Engr. Conf., ASCE, 1968.
7. Bruun, P. and Purpura, J. Quantitative Research on Littoral Drift in Field and Laboratory, Proc. Ninth Conf. Coastal Eng., ASCE, 267-288, 1964.
8. Galvin, C. J. and Savage, R. P. Longshore Currents at Nags Head, North Carolina, Coastal Eng. Res. Center Bull. 2, U.S. Army Corps of Engrs., Washington, D.C., 1966.