CHAPTER 18

LONGSHORE TRANSPORT OF SAND

by

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ABSTRACT

Simultaneous field measurements of the energy flux of breaking waves and the resulting longshore transport of sand in the surf zone have been made along three beaches and for a variety of wave conditions. The measurements indicate that the longshore transport rate of sand is directly proportional to the longshore component of wave power.

INTRODUCTION

The importance of waves in transporting sand along the shore has been recognized for many years, but quantitative measurements of transport rate as a function of wave energy flux have only been possible during the last two decades and then only in model wave basins. The study of the longshore transport phenomena in the real surf zone requires synoptic measurements of the flux of wave energy and the transport rate of sand.

This is a preliminary report of a continuing study that is being conducted along three natural beaches. El Moreno Beach, Mexico, on the northern Gulf of California; Silver Strand Beach, Coronado, California, and, Scripps Beach, La Jolla, California. The sands on these beaches range in median diameter from 180 to 600 microns, and the waves incident to the beaches varied from one-third to one meter high wind waves from the Gulf of California, to one to two meter high swell from the Pacific Ocean.

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PROCEDURE

The direction and flux of wave energy is measured from an array of digital wave sensors placed in and near the surf zone. The wave staffs and their installation is described in Koontz and Inman (1967) and a schematic diagram of the array is shown in Figure 1. The array has both on-offshore and longshore components with spacings between staffs of about one-quarter of the wave length of the prevailing waves.

The output from the array is entered on magnetic tape, and later programmed on a computer to obtain the wave spectra and cross-spectral analysis for the various members of the array. The wave spectrum is obtained by Fourier analysis of the time series of water level fluctuations at each sensor, using a rapid procedure (Fast Four) modified from Cooley and Tukey (1965). The spectrum consists of the squares of the absolute values of the complex Fourier coefficients, which serve as estimates (having dimensions of length squared) of the energy density in each elemental frequency band (Figure 2). The sum of the energy densities under the spectral peak of the incident waves is the mean-square elevation $\langle \eta^2 \rangle$ of the water surface described by the time series. The mean wave energy per unit area of the water surface is given by the product of $\langle \eta^2 \rangle$ and the weight per unit volume ρg of the water

$$E = \rho g \langle \eta^2 \rangle = \frac{1}{8} \rho g H_{rms}^2 \qquad (1)$$

where H_{rms} is the root-mean-square wave height. The flux of energy, or power transmitted per unit of wave crest length is given by the product of E and the group velocity G of the waves, $P = EG$. The direction of energy flux is interpreted from the phase difference between the various sensors. Sensors at or near the breakpoint of the waves are used to obtain the angle α that the breaking wave makes with the beach. The longshore component of wave power per unit length of beach is then given by

$$P_{\ell} = P \sin\alpha \cos\alpha \qquad (2)$$

Quantitative measurements of the longshore transport rate of sand are obtained from the time history of the position of the center of gravity of tracer injected onto the beach. The sand tracer is native sand colored with a thin coating of fluorescent dye. The tracer is introduced onto the beach face in single injections of between 45 and 90 kilograms. The movement of the sand is indicated by the subsequent distribution of the tracer as determined from approximately 200 volume samples taken from the beach face at various times after injection. Figure 3 shows an example of a tracer distribution obtained from such a sampling. The mean distance of transport is taken as the distance between the injection point and the new center of gravity of the tracer

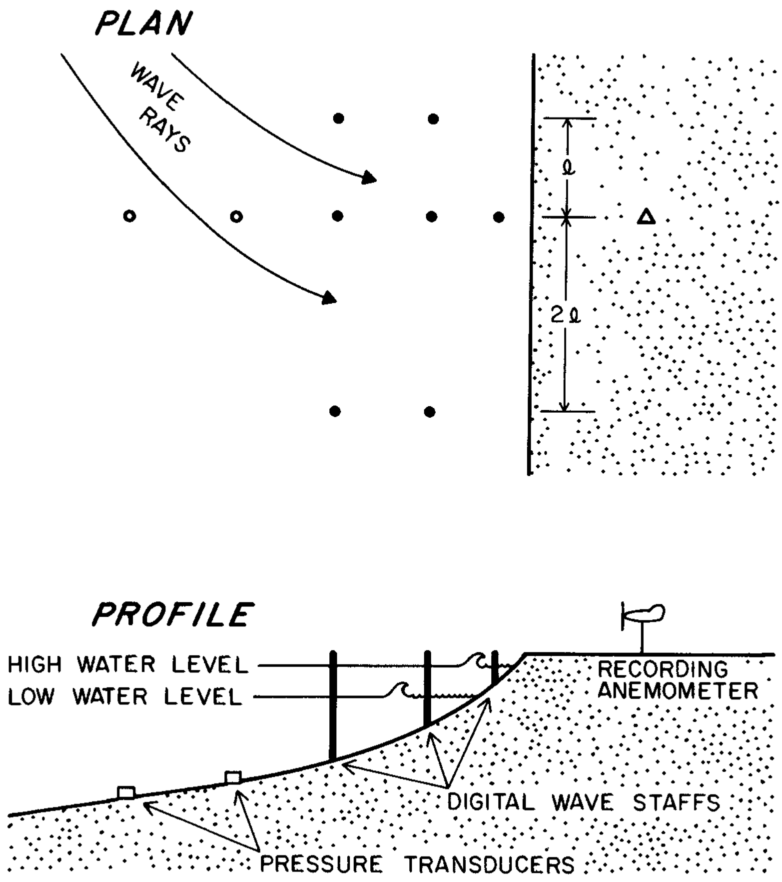

Figure 1. Schematic diagram of sensor array used for measuring direction and flux of wave energy (after Koontz and Inman, 1967, Fig. 16) Cross-spectral analysis shown in Figure 2 is from a longshore pair of such an array.

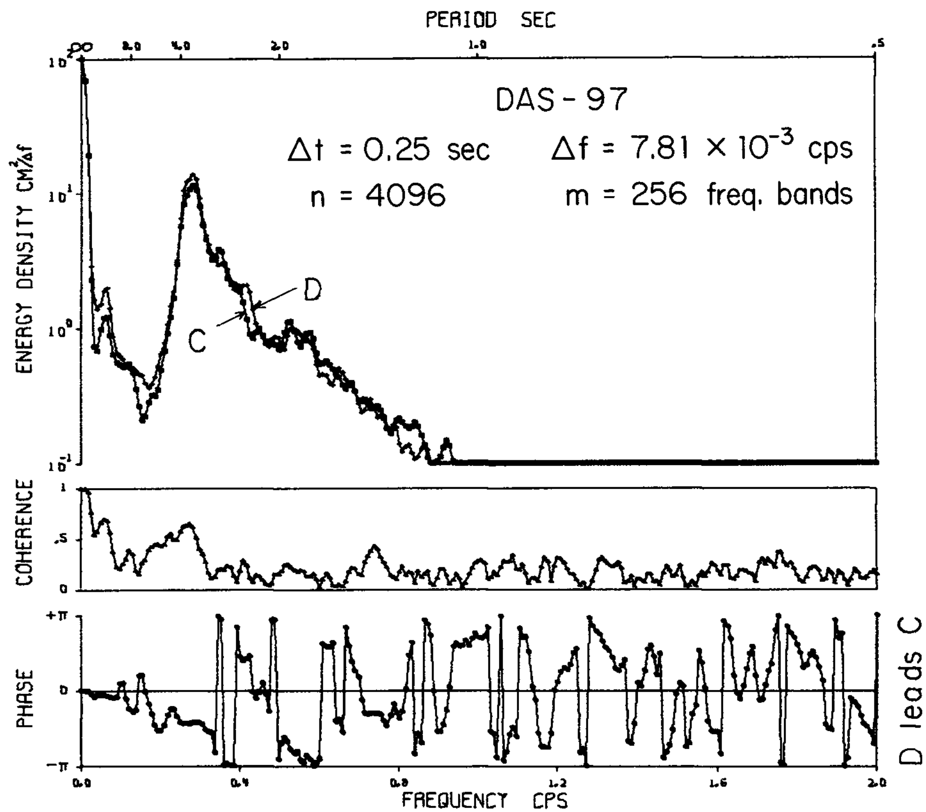

Figure 2. Wave spectra and cross-spectral analysis for two members of an array of digital wave staffs. Staffs were parallel to and just outside of the break point of the waves. The analysis shows that the spectral peak for the incident waves occurs at a frequency of 0.28 cps (period of 3.6 sec), and that the rms wave height was about 34 cm.

distribution, while the thickness of the sand layer involved in the transport is determined from the depth of burial of tracer in cores taken from the beach. The bulk volume of sand transported per unit time, S, is the product of the mean longshore distance of transport, the width of the beach, and the thickness of the layer of motion, all divided by the time between injection and sampling.

The accuracy of the measured transport rate is dependent upon the portion of the original tracer that can be accounted for by the sampling program. Most of the tracer should be accounted for by an initial sampling soon after injection of the tracer. The rate of decrease in the accountable tracer budget with successive sampling intervals should be commensurate with the estimated loss by lateral diffusion to concentration levels below the threshold of sampling sensitivity. If more than one-quarter of the injected tracer cannot be accounted for in the sampling program, the data are considered unsatisfactory and not used.

DISCUSSION

Simultaneous measurements of the longshore transport rate of sand and the flux of wave energy have been made on three beaches and under six different wave conditions with breaker heights up to two meters. The new data is plotted together with previous field and laboratory data in Figure 4. The longshore transport rate, I_ℓ, is expressed as immersed weight transport per unit time so that the transport is defined in terms of the difference in densities of the sand, ρ_S, and of the fluid, ρ. The relation between the immersed weight transport and the volume transport per unit time, S, is given by

$$I_\ell = (\rho_S - \rho)\, g\, a_1\, S \qquad (3)$$

where g is the acceleration of gravity and a_1 is the correction for pore-space. a_1 was assumed equal to 0.6 in transforming the data of other workers into immersed weight.

The best fit curve for the new data agrees generally with the relation

$$I_\ell = K\, P_\ell \qquad (4)$$

suggested by Inman and Bagnold (1963), with a value of K equal to about 0.7. Figure 4 shows that the longshore power of the new measurements is about one-half that for previous field data, for a given transport rate. This discrepancy appears to result from the erroneous use of the significant wave height in computing wave power for the earlier field observations (Inman and Frautschy, 1966). The expressions for wave power are based on the root-mean-square wave height, H_{rms}, which is also the wave parameter measured in the laboratory for simple waves of steady amplitude. For real waves having a single narrow band of frequencies, the use of the significant wave height gives a wave power that is erroneously high by a factor of two (Longuet-Higgins, 1952).

The results of this study indicate that the rate of longshore transport of sand is: (1) directly proportional to the longshore component of wave power for fully developed transport conditions; and, (2) independent of sand size within the range of about 180 to 600 microns studied here.

The new field data indicate that the longshore transport of sand is directly proportional to the longshore component of wave power. However, it appears that the transport conditions are not fully developed for all laboratory experiments and that the transport mechanism is therefore less efficient than for conditions that prevail in the field. This difference in efficiency must be considered in any attempts to extrapolate laboratory measurements to field conditions.

The size of the sand on the beach appears to have little effect on the transport rate. In suspended load transport, the size of the sediment, because of the dependence of settling velocity on size, is an important variable. This suggests that suspended load transport of sand in the surf zone is less important than bed load transport.

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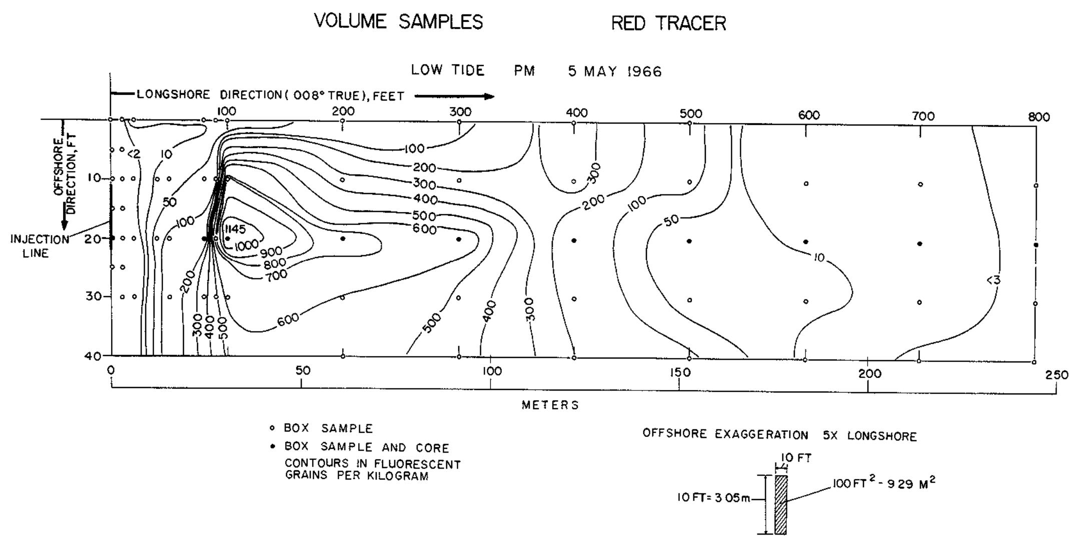

Figure 3. Distribution of tracer along El Moreno beach after approximately 200 minutes of wave action. Injection was 45.9 kilograms of El Moreno beach sand treated with fluorescent dye. The center of gravity of the new distribution is 75 meters from the injection line and the depth of motion was found to be 10.5 cm. The transport rate for this run was 6.2×10^6 dynes/sec and the longshore component of wave power was 1.0×10^7 ergs/cm sec.

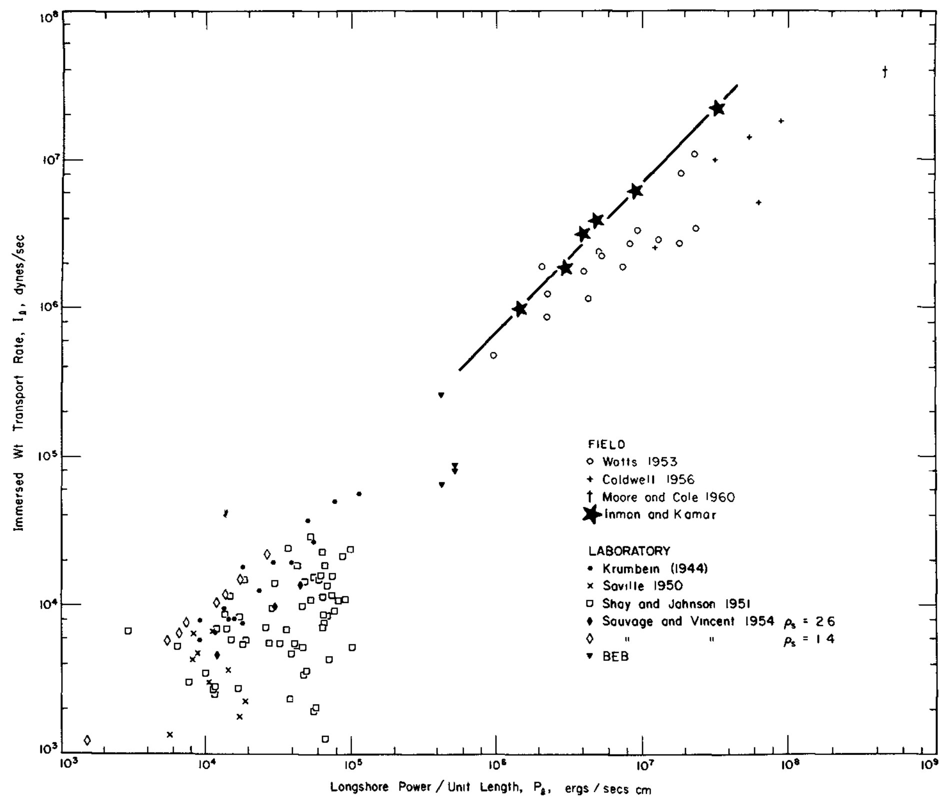

Figure 4. Relation between the immersed weight longshore transport rate and the longshore component of wave power per unit length of beach. The various sources of plotted data are listed in the references, the "BEB" data is given in Savage (1962).

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