CHAPTER 47

MODE AND PERIOD OF SAND TRANSPORT IN THE SURF ZONE

Benno M. Brenninkmeyer, S.J.

ABSTRACT

Three almometers-water opacity measuring devices-emplaced perpendicular to the beach,measure instantaneously and continuously the sediment concentration across the surf zone. Most of the variance of the sand movement is centered in frequencies of less than 0.25 Hz and between 1.15 and 1.25 Hz. Modes and frequency of sand transport differ within each of the dynamic zones of the surf. The motion of sediment in the inner and outer surf zones is small and virtually independent of the deep water wave periods. Outside the breaker zone, bed load movement is somewhat coincident with the prevailing swell period. Lighter concentrations move predominantly with a 0.8-0.9 second periodicity. In the breaker zone, sand moves along the bottom with frequencies equal to that of both the swell and sea, but most of the power is in lower frequencies. In the breaker zone sand is rarely thrown into suspension. In the transition zone, sediment motion is largely by suspension with a period a little longer than the swell.

INTRODUCTION

Measurement of water opacity and therefore particulate concentration have been made for quite some time. Shelford and Gail (1922) seem to have been the first to use various light emitting sources opposite a photo-cell in the field. Since then, many others, among them, Jakuschoff (1932), Petterson (1934), U.S. Interagency on Water Resources (1963), Homma and others (1965) and those mentioned by Das (1972) have used this principle. Longinov (1968) was the first to use photocells to measure suspended sediment concentration in the nearshore zone. Most of the instruments, used by these researchers, measure sediment concentration at a given point per unit time. The almometer (Brenninkmeyer, 1973, in press) can measure,at 1cm intervals, from 10 to 500 grams of sediment per liter of water in the bottom 1.2 meters of water simultaneously and continuously. This is achieved by placing a vertical series of 64 photo-electric cells opposite a high intensity flourescent lamp (Figure 1). The two parts are encased in separate water tight acrylic cylinders and attached to metal poles which are anchored in the substrate up to a meter apart. This separation allows an unimpeded sediment and water flow between the cylinders. The voltage change of each of the photo cells, as more or less sediment passes in front of them, is sampled up to every one fifth of a second, multiplexed and recorded on magnetic tape.

Three almometers were partially buried in a line perpendicular to shore on the beach at Point Mugu, California. This area, located 95 km northwest of Los Angeles, trends N 50°W and is

Department of Geology and Geophysics, Boston College, Chestnut Hill, Massachusetts 02167

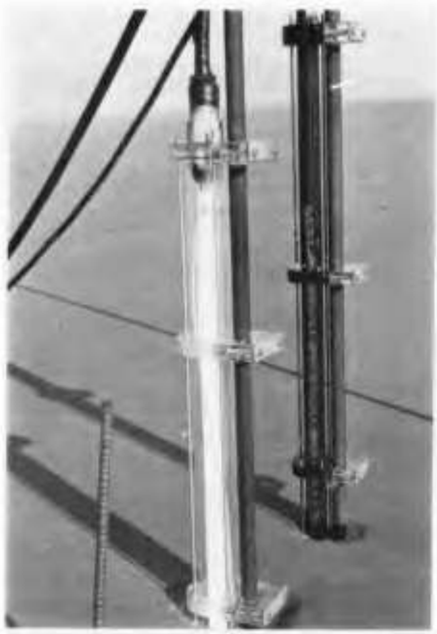


Figure 1. The almometer emplaced on the beach. The device consists of two acrylic cylinders; in one is a flourescent lamp in the other, 64 photo-electric cells.

influenced by a western swell which, during the two week test, was 75 to 90 cm in height with a 13-16 second period. Almost half the time the local wind waves were less than 30 cm high with a 4-8 second period. They also came from the west. The tides are mixed, with a predominant semidiurnal component. The tides have a mean range of 1 m and an extreme range of 2.8 m. The sand on the foreshore has a mean diameter of 0.16mm.

SAND MOVEMENT IN THE SURF ZONE

The three almometers were emplaced, one on the shoreface (15 cm below MLLW), the second in the lower beachface (30 cm above MLLW) and the third on the upper beachface (90 cm above MLLW) so that as the tide, rose and fell, each of the dynamic zones of the surf regime could be sampled. Only infrequently can the sediment movement caused by a single wave be detected with certainty across all three stations. Figure 2 is a typical example. Since the tide at the time depicted, was 1 m high, the shoreface (1) is under the breaker zone, the lower beachface (2) is in the middle surf zone and the upper beachface (3) is in the transition zone (Schiffman, 1965), the area where the leading edge of the surf plows into the backwash. Noteworthy

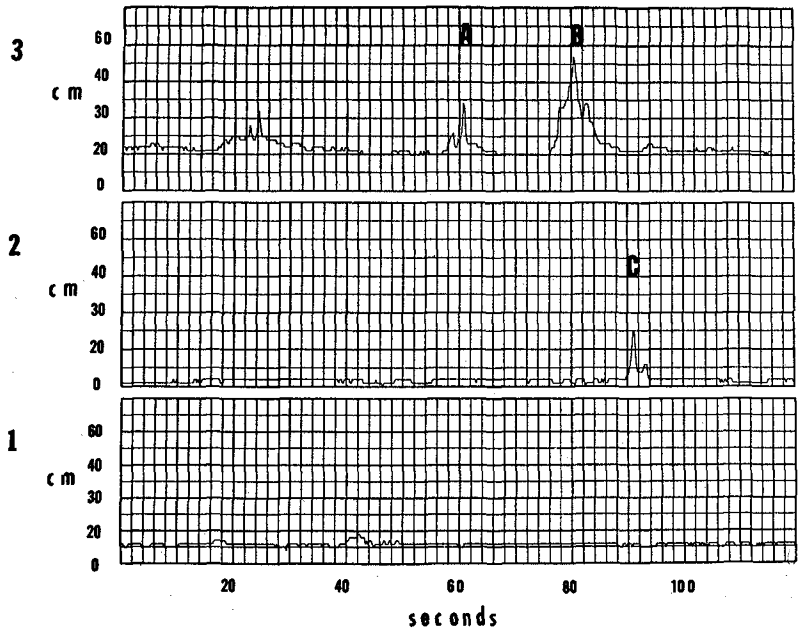


Figure 2 Time rate of change across the surf zone in the elevation of the sediment concentration of 135 grams per liter. 1) Breaker zone 2) Middle surf zone 3) Transition zone.

is the relatively little movement of sand in the breaker zone and the great agitation in the transition zone. A and B probably represent an incoming bore and its backwash. As Emery and Gale (1951) have pointed out, the swash period is considerably longer than the wave period, which at this time was 13 seconds. After the incoming swash passed, no deposition had taken place. Whereas, after the backwash 1 cm had been deposited. During or after more than half the backwashes deposition takes place.

The only real movement in the middle surf zone (2) was due to the backwash from B to C. The spacing of the two stations was 32 m so that the backwash velocity responsible for these sand uplifts was 2.3 m per second. Either this velocity was not sufficient to keep the sand in suspension or, more likely, another surge coming in overtopped the backwash and entrained the top of the backwash back towards the beach. In either case the suspension cloud diminished in elevation from 26 to 21 cm above the bottom.

TIME SERIES ANALYSIS

In order to determine the frequency of sediment movement a spectral analysis was performed on sets of 6000 data points covering a 20 minute period. The spectra manifest four diverse forms. In the most common, the great majority of the power is in the low frequencies,less than 0.1 Hz (Figure 3A). Sometimes, these peaks are coincident with the swell period but more usually they are longer than half a minute. Much less common are the spectra where the preponderance of the power is in the higher frequencies (Figure 3B) with periods of less than a second. Often the variance is split between these ranges Figure 3C). When this occurs there is a peak in the 0.15-0.25 Hz band. Here the peak is centered on 4.5 seconds. In between from 0.25 to 1.15 and especially beyond 1.25 Hz there is little power in any frequency. Only rarely does the spectra display a Dirac delta or impulse function (Figure 3D) if the station is under water. This form is to be expected only when a station is above the swash line. Yet a comparison of parts A and D in Figure 3, taken from the same station and the same time, but depicting different concentrations, shows that right inside the breaker zone there is little movement of the bottom while considerable quantities of sand, in a 70 gram per liter slurry, are moved with a periodicity greater than 13 seconds.

The frequencies in the 1.1-1.3 Hz band may or may not be present depending on the concentration under consideration. Figure 3C, 3E and 3F show three different concentrations for the same station located in the inner surf zone. The 0.81 and 0.86 second periods are absent from the 70 gram per liter concentration while they are present in the 40 and 375 gram per liter densities. The only time that these periods are of paramount

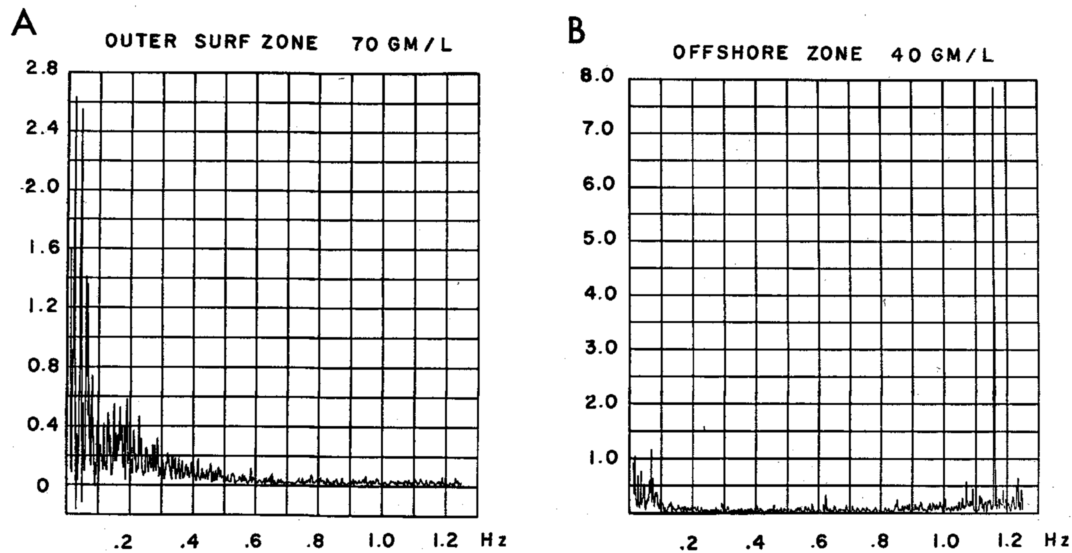


Figure 3 Diverse forms of the power spectra of sediment movement in the surf zone. Part A, all the power is in the lower frequencies. Part B most of the power is in the high frequencies.

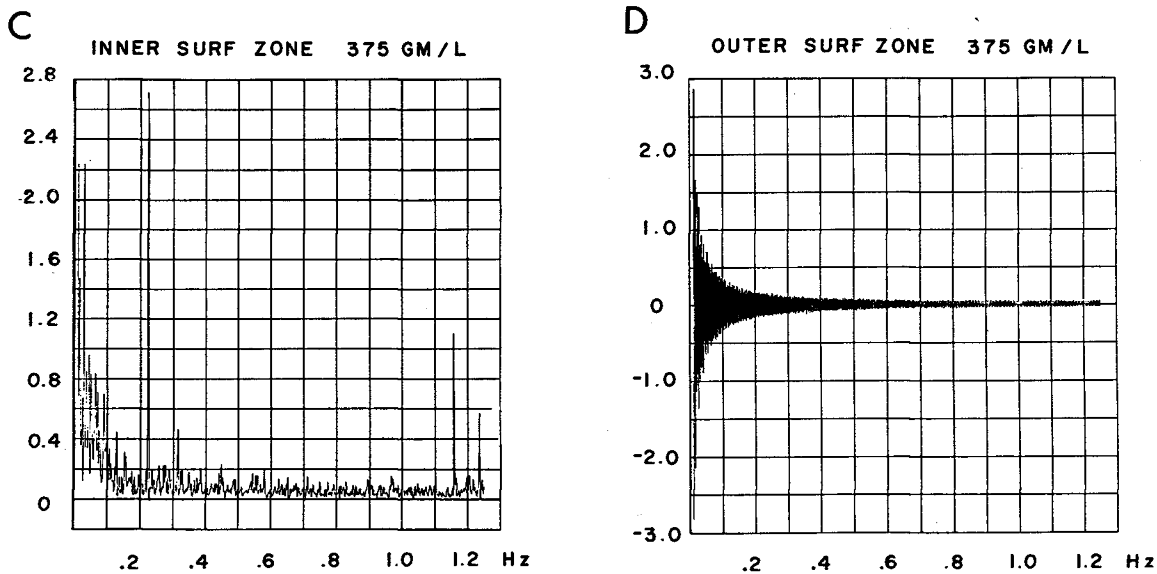


Figure 3 Part C most of the power of the spectrum is in .22 Hz band. Part D only infrequently does an impulse function or no movement of sand occur while the area is under water.

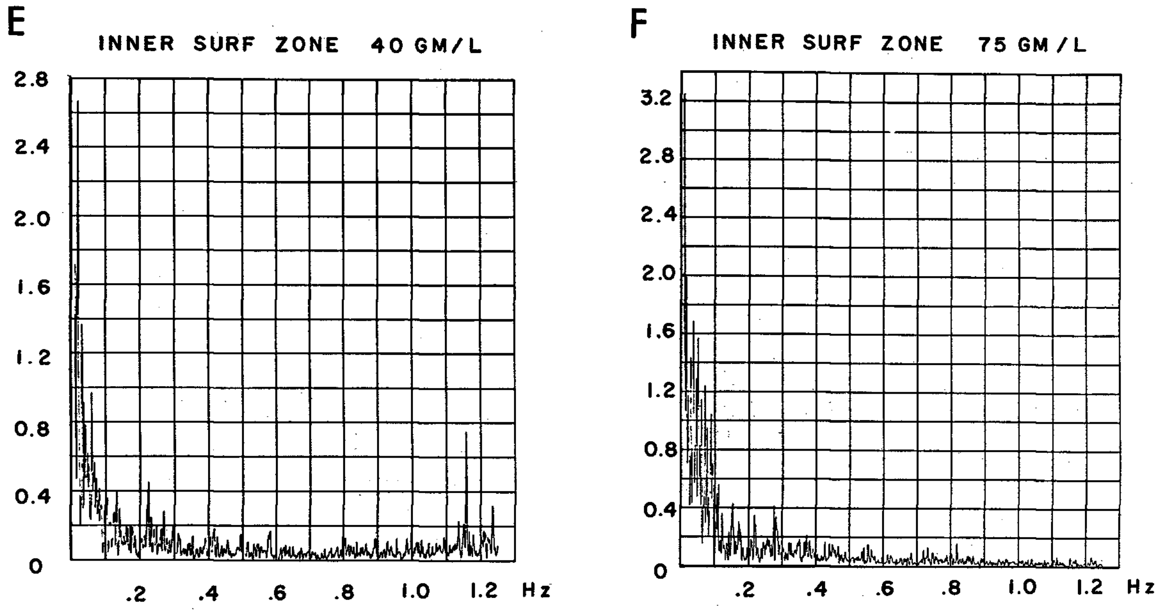


Figure 3 Part E. In the inner surf zone the 40 gm/l concentration changes elevation with a periodicity of greater than 16 seconds and 0.81 and 0.86 seconds. Part F. The latter periods are absent in the 70 gm/l concentration.

importance is in the lighter concentrations outside the breaker zone (as in Figure 3(B) where they may be the only frequencies present. Their significance is somewhat mystifying. They probably represent smaller movements superimposed on longer period steady drift. Yet everytime that a short periodicity occurs anywhere in the nearshore zone it is in this 0.8-0.9 second band. For short period movements one would expect a range of frequencies. But this is not the case. They may well be the fundamental mode of short term sand movement in response to the local turbulent component of the water which exist up to 1.5 Hz (Huntley and Bowen, 1974).

An enlargement of the lower frequencies, representative of the response of sediment to deep water waves in the different areas of the nearshore environment, is shown in Figure 4. Note that the power of sediment movement in cm^2 has been multiplied by 10. The power of the waves is in ft^2. Even with this tenfold increase in the power of the sediment movement, it seldom attains that of the deep water waves. In each set, the coherency between the waves and sediment is extremely low (0-0.2) in the middle and higher frequencies. It improves somewhat (0.2-0.4) for the lower frequencies, shown here, for the 375 gm/l concentration in the breaker zone and outside the breaker zone, and for all the concentrations in the transition and swash zones.

Outside the breaker zone only the heaviest concentrations, moving near the bottom, are somewhat influenced by the swell waves, whereas the lighter concentrations are caught up in the turbulence and have little response to the longer period sea or swell. Inside the breaker zone the sediment have a periodicity of movement that equals that of the swell and also the local sea. The lighter concentrations lag somewhat behind the predominant swell period and are less effected by the sea. Yet their main period of movement is much longer than either the sea or swell. So that in one area within the breaker zone, not every wave causes sand motion. This is perhaps, not valid for the entire breaker zone. The position of the plunge point is not constant, especially over a 20 minute time span and some of the breakers may have dissipated their energy before reaching the station or after passing it.

In the surf zone sediment movement is either non existant, spread out over many intermediate frequencies, each of which has relatively low amplitude, or moves only infrequently, less than once every 30 seconds. It appears, therefore, that sediment movement, in this zone, is virtually independent of the deep water wave periods. Dependency has to be sought in reflection, or other sources of energy such as edge waves, or the interaction between successive bores. Also the backwash may still be effective in this zone. There is a progressive increase seawards in the period of the bed load movement. This lengthening of the period seems to die out in the outer surf zone.

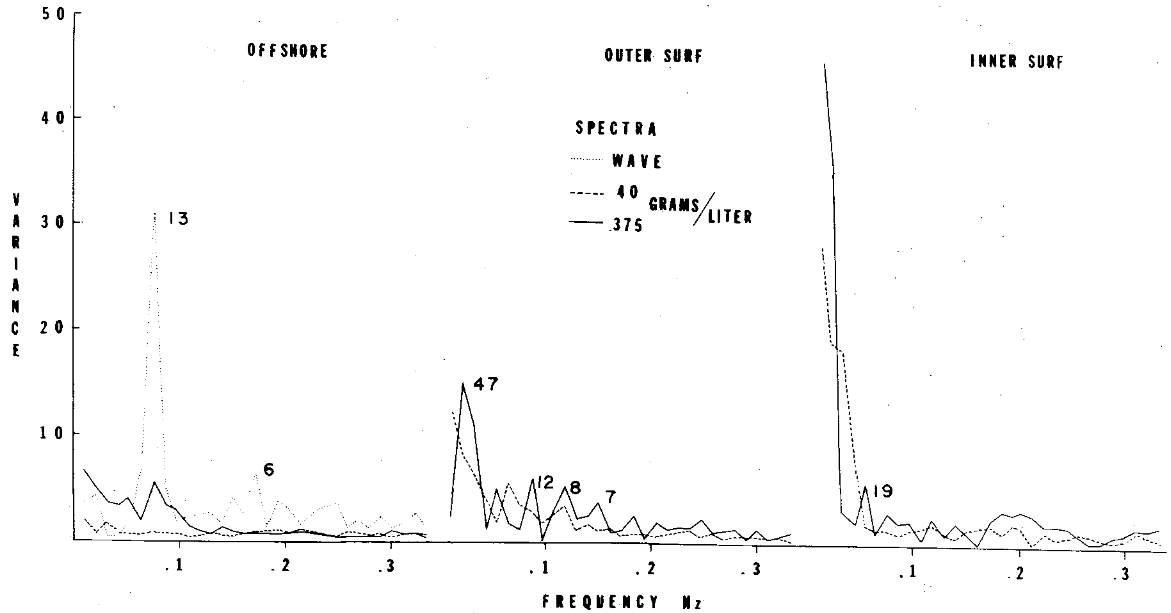


Figure 4 Wave and 40 and 375 gram per liter spectra power for the offshore and outer and inner surf zones. The sand spectra has been multiplied by a factor of ten. High tide. Wave height 90 cm approaching land at a 20° angle. Wave spectrum courtesy of the U.S. Army Corps of Engineers, Coastal Engineering Research Center.

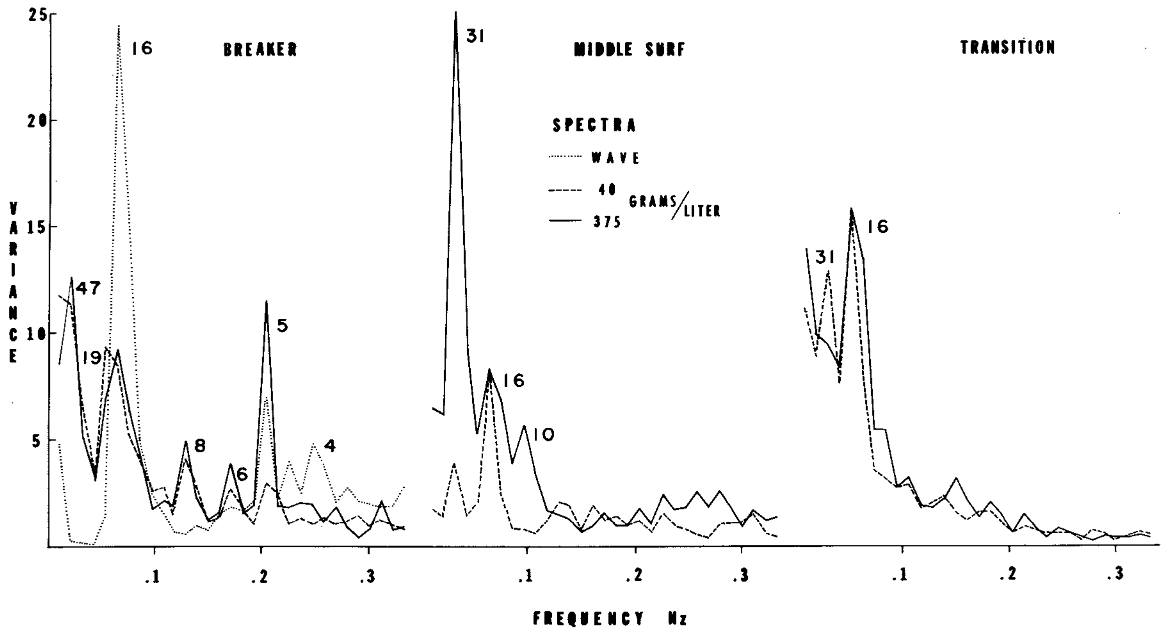


Figure 4B Wave and 40 and 375 gram per liter spectra for the breaker, middle surf and transition zones. The sand spectra power has been multiplied by a factor of ten. Flood tide. Wave height 75 cm, approaching land at a 20° angle. Wave spectrum courtesy of the U.S. Army Corps of Engineers, Coastal Engineering Research Center.

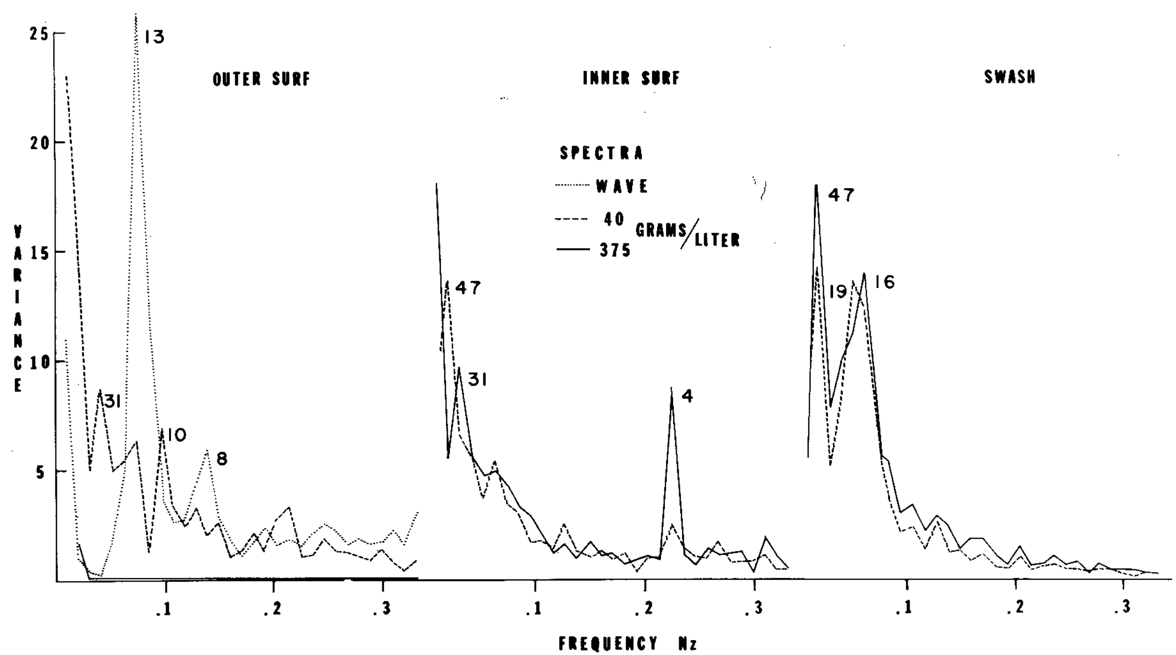


Figure 4C Wave and 40 and 375 gram per liter spectra for the outer and inner surf and swash zones. The sand spectra power has been multiplied by a factor of ten. Beginning of flood tide. Wave height 75 cm approaching land at 5° . Wave spectrum courtesy of U.S. Army of Engineers, Coastal Engineering Research Center.

In the transition and swash zones, the main swell period reappears in both concentrations with a lag of up to 3 seconds. This undoubtedly, represents the retardation of the incoming bore and coincident with that, the backwash period. The presence of the local waves is barely detectible since these have dissipated their relatively low energy prior to reaching the station in interference with the backwash from the swell.

SEDIMENT DENSITY DISTRIBUTIONS

The density distribution of the sediment in the water column of the surf zone also varies with the dynamic zone. Suspension of sediment occurs in clouds of short duration. Suspension of sediment is defined, herein, as any sediment concentration reaching an elevation greater than 15 cm above the bottom. This limit is the demarcation line between frequent and occasional occurences. In the 9 tidal cycles studies, 1213 times did the 150 gm/l concentration reach this elevation. Only once did sand of 500 gm/l density reach 1 m above the bottom. The lighter concentrations usually mimic each other in space and time rather closely. The heavier concentrations follow a much more subdued path and show reversals in elevation not experienced by the lighter concentrations,(Figure 5). Nor, in every instance, are the heavy concentrations effected when the lighter concentrations are raised above the bottom. Over 87% of these sand fountains (Zenkovich, 1967) occur when the still water level is within 30 cm above or below the bottom elevation at the station, ie. in the transition zone. More than twice as many of the fountains occur on the flood tide at the beachface station as compared to the ebb. Part of an explanation may be that the upper beachface is above the ground water level on the flood tide, whereas on the ebb tide it is below the ground water table (Emery and Foster, 1948, Fausak, 1970). Below the ground water table there is a surface tension combined with a probable decrease in the sand roughness coefficient making it more difficult for the sand to be suspended.

The sand uplifts range in duration from only half a second to 53 seconds, averaging 10.2 seconds. Their duration is dependent on water velocity. In the breaker zone, the sand fountains last an average of 5 seconds before they are carried out of the measurement field of the almometer. In the transition zone, when that is located on the lower beachface where it is relatively flat (1:50), the sand fountains remain for 15 seconds; on the upper beachface, where it is steeper (1:25), their duration is 11 seconds. On the ebb tide the fountains last somewhat longer than on the flood tide.

The water level is insignificant in effecting the heights attained by the suspension clouds. They average 24 cm in height even if the still water level is over a meter and a half above the bottom.

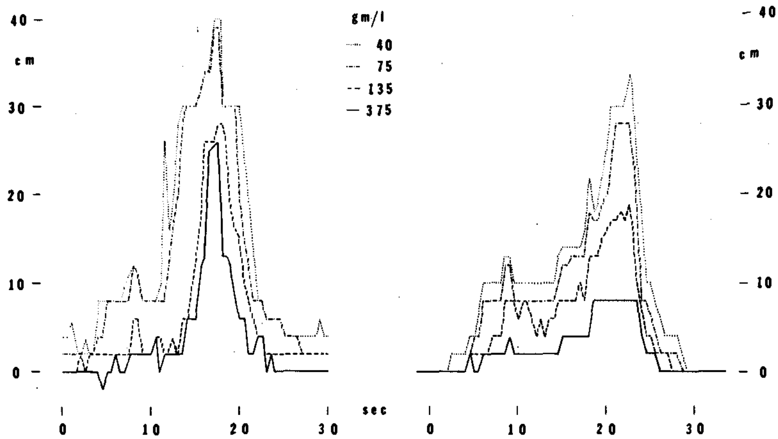
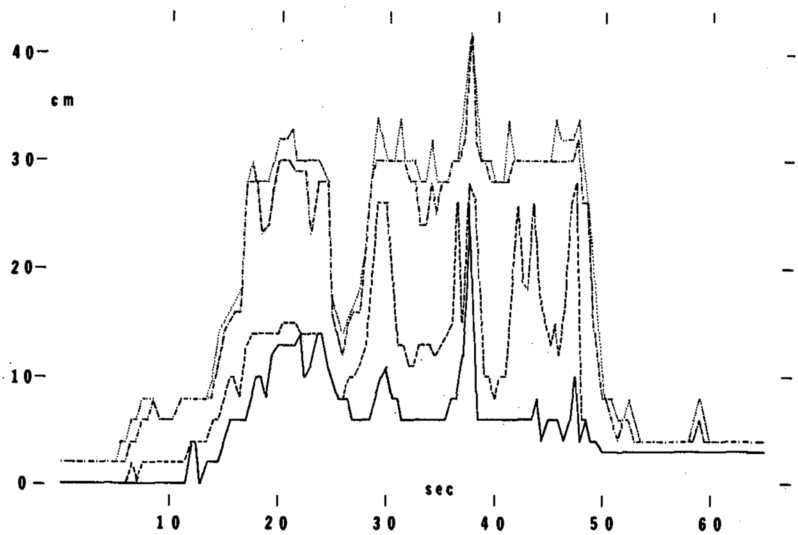


Figure 5 Fluctuations in elevation of various concentrations of sand within suspension clouds at the still water level



The average time between the sand fountains on the flood tide at the upper beachface is 1.7 minutes when the still water level is 0-30 cm below the station and 2.6 minutes when it is 0-30 cm above it. During the same tidal stages on the ebb tide, the average is 3.3 and 5.0 minutes respectively. Plotting the actual times between occurences (Figure 6) show that only two small peaks stand

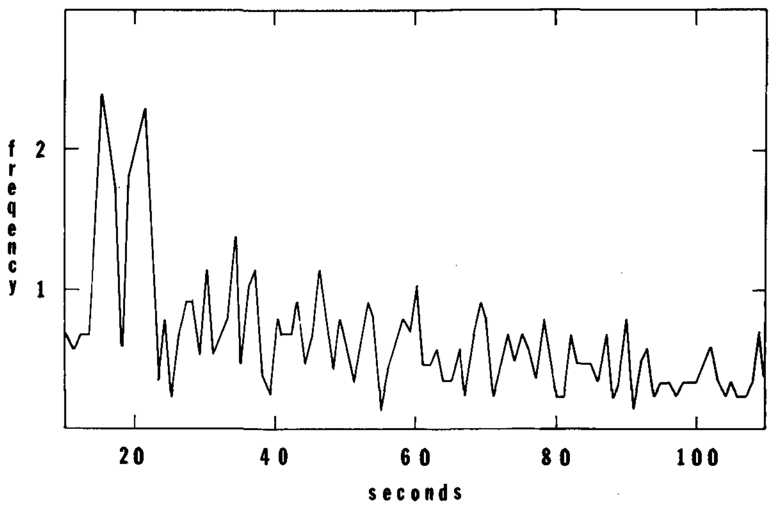


Figure 6 Frequency of occurence of sand fountains on the upper beachface.

out amidst all the scatter. The 15 second peak represent a 2 second retardation of the average swell period during the test, the second peak should be the corresponding backwash period.

There are various causes for the suspension of the sand in this zone. Measurements of the water velocities inside the surf zone (Longinov, 1961) show that the maximum vertical components occur right after the horizontal maximum or when the horizontal component is zero; when the water is changing from shoreward movement to seaward. Suspension in the latter case can occur when the backwash has a velocity greater than (gh)1/2 so that the incoming bore cannot progress against it, resulting in a hydraulic jump or roll wave. At an average backwash velocity of 180 cm/sec (Dolan, Ferm and McArthur, 1969) the water depth at which the Froude number becomes critical is just under 30 cm. In the breaking of this roll wave there is a brief suspension of much sediment.

Then the water movement eally stops and most of the suspendeds fall back to the bottom. The deposits of these suspendeds may well form the steep sided symmetrical ripples so common in the transition zone on steep beaches (Clifton and others, 1971). These ripples, on their own, may cause more suspension by creating a barrier to the backwash flow and again setting up a hydraulic jump.

Also, at the inner breaker line, the wave front is saturated with air bubbles which penetrate the bottom. The ascent of these bubbles have a suctional effect sufficient to draw up sand (Aibulatov, 1966).

Only four percent of the suspension clouds occur in the breaker zone. The sand surface changes often, with differences in elevation of the bottom of more than 6 cm per wave not uncommon. But great quantities of sand are rarely thrown into suspension. This dearth of sand fountains near the primary breaker suggests that the water and the air entrapped in the breaker does not reach the bottom but is absorbed in the water layers above it.

CONCLUSIONS

Measurements of changes in elevation of different sand concentrations within the surf zone have shown that diverse responses to the incoming waves are operative in each of the dynamic zones. Most of the sediment movement within each of these zones occurs with a periodicity two to three times longer than that of the incoming waves. Just outside the breaker zone, when sediment does move, the bed load is transported in pulses coincident with the prevailing swell period. A much shorter periodicity prevails in the lighter concentrations. Inside the breaker zone, sand moves with frequencies equal to both the swell and sea periods. The sand surface changes rapidly with differences in elevation of more than six centimeters per wave not uncommon. Here sand is rarely thrown into suspension. After the transformation of the wave into a bore in the outer surf zone, sediment movement is absent or small and therefore almost independent of the deep water wave periods. In the inner surf zone, suspended sediment transport increases in frequency, elevation and duration. In the transition zone sand movement by suspension becomes predominant. Upheavals of the sand are common and show a variety of different shapes in response to secondary breakers penetrating the bottom or hydraulic jumps. The frequency of movement reflects the predominant swell and backwash period with a lag of up to three seconds.

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