CHAPTER 147

FINE-SCALE MEASUREMENT OF SEDIMENT SUSPENSION BY BREAKING WAVES AT SUPERTANK

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ABSTRACT

During the SUPERTANK data collection project, a mobile, vertical array of five Optical Backscatterance Sensors was used to measure sand suspension in the outer surf zone. Test conditions included both regular and random waves, and two different wave energy levels. Examination of the data reveals significant cross-shore variation in both the structure of the time-dependent concentration, as well as mean suspended load.

INTRODUCTION

A primary element of sediment transport in the nearshore is the process of sand entrainment by breaking waves and the resulting suspended load that is available to be carried by currents. Field measurements of Hanes (1988) outside the surf zone and Beach (1989) inside the surf zone indicate that sand suspension often occurs on a wave-by-wave basis; i.e., important phase information may be lost when transport is calculated based upon the long-term mean concentration. Most field measurement efforts have been limited to documenting the mean suspended load and its distribution with depth; however, temporal and spatial detail of the initiation, movement, and settling of sand clouds has not been examined.

The SUPERTANK Data Collection Project (Kraus, Smith, and Sollitt, 1992) provided the opportunity to make high-resolution measurements of sediment suspension by breaking waves in a controlled laboratory setting at large scale. Hydrodynamic data, consisting of fluid velocity and free surface displacement, were also collected. The experiments were designed to study the behavior of sand suspension under breaking waves, measured at high spatial and temporal resolution, with the aim of developing and verifying quantitative models for sand

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transport. The two data sets selected are an initial investigation of the substantial amount of concentration measurements obtained near the break point during the SUPERTANK project.

EQUIPMENT

Tests were conducted at the large wave channel operated at the O.H. Hinsdale Wave Research Laboratory, Oregon State University. A 76-m long beach of well sorted quartz sand was placed in the channel at the beginning of the SUPERTANK project. Figure 1 is a plot of the fall speed distribution for the sand used during the SUPERTANK project. Data obtained in the settling tube analysis also provided grain size distributions from the fall speed of the sand grains.

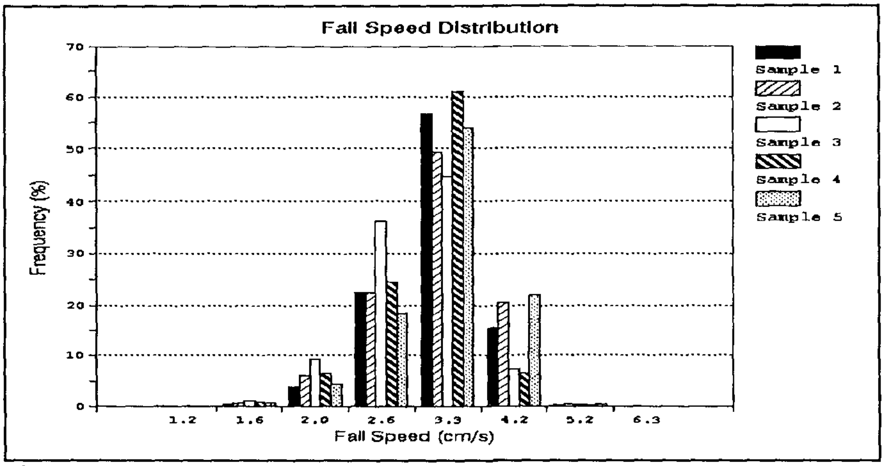

Figure 1 Fall speed distribution of the sand used during the SUPERTANK project.

The median grain diameter determined from the fall speed distribution was 0.25 mm. Result of these analyses are similar to those obtained by other SUPERTANK participants using mechanical sieve analysis.

Suspended sediment concentration was determined using five Optical Backscatterance Sensors (OBS), whereas free-surface displacement was obtained with a capacitance wave gage. The vertical and cross-shore components of the fluid motion were measured with four electromagnetic current meters (EMCM). A 8mm-format video camera was used to visually record the waves as they passed by the instruments. From this, qualitative, macro-characteristics of each passing wave could be determined.

The OBS were mounted to an aluminum sailboat mast, with the sensor beam axis oriented parallel to the wave crests. The array could be adjusted vertically using a pulley and winch system, to accommodate changes in bed elevation. The wave gage was mounted to a second sailboat mast and could also be moved vertically, to compensate for changes in the water level under different test conditions.

The EMCMs were mounted on an aluminum strut, with the instruments evenly spaced in the vertical, and oriented so that the vertical and cross shore components of the fluid velocity would be detected.

The three arrays were mounted on the shoreward side of a self-propelled carriage, which spanned the walls of the wave channel. The cross-shore position of the sensors could be changed with relative ease by moving the carriage.

PROCEDURE

SUPERTANK was a collection of tests dedicated to cross-shore processes in a large wave channel. Each of the major tests were broken into runs which were short periods of continuous wave activity. The mobile OBS array was utilized in a total of 179 runs during the SUPERTANK project. The data presented in this paper are from four runs out of the test series labeled ST_20, second out of a total of twenty tests. Two of the runs were with regular waves, and two were with random waves. In all runs, the breakers were of the plunging type.

Data collection began approximately 45 sec before the start of a run so that still-water offsets for the OBS array could be determined. The video camera was manually started at the beginning of the run and did not require further adjustment. While a run was underway, the sensors could be monitored by viewing graphical displays.

In the two regular wave runs, the carriage was moved across the region of incipient breaking, pausing at five locations which ranged from 6 m seaward of the break point to just shoreward of the plunge point. Data were collected for approximately five minutes at each position. The entire procedure was repeated for a second 40-minute run with different wave conditions.

OBS must be calibrated for the sand at the project site due to variations in optical properties. Calibration was accomplished by immersing each sensor into a tank containing a sand/water mixture. The mixture was stirred continually to ensure a constant mean concentration in the region of the sensor.

Fig. 2 presents the calibration curves for the five OBS. It can be seen that the OBS were linear, therefore the sensor output can be converted to engineering units by applying the appropriate gain and offset.

The measurements records were found to contain occasional spikes which are attributed to electronic noise and not actual fluctuations in sediment concentration. All of the SUPERTANK OBS data were filtered

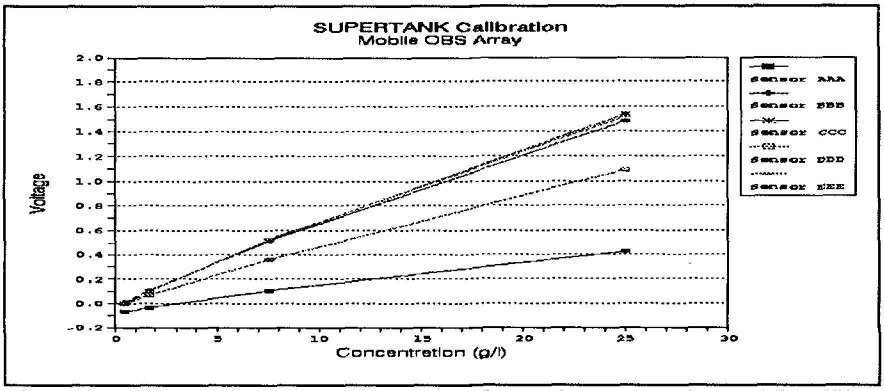

Figure 2 Calibration curves for OBS used during SUPERTANK.

by a program which removes outlying points, replacing the value with one interpolated between the preceding and succeeding points.

REGULAR WAVES: TIME SERIES

The following time series plots pertain to the sensor closest to the bed under regular waves. In most cases the sensor at the bottom of the array detected the greatest concentrations and most clearly displayed the event-based structure that is of interest.

Regular Wave Run #1

Fig. 3 presents the OBS time series for a sensor approximately 8 cm from the bed, with a cross-shore position 6 m seaward of breaking. Offshore conditions for this run were a wave height of 0.6 m and period of 3 s. At this location the waves were just beginning to strongly shoal, and the OBS record showed only a small amount of suspension near the bed.

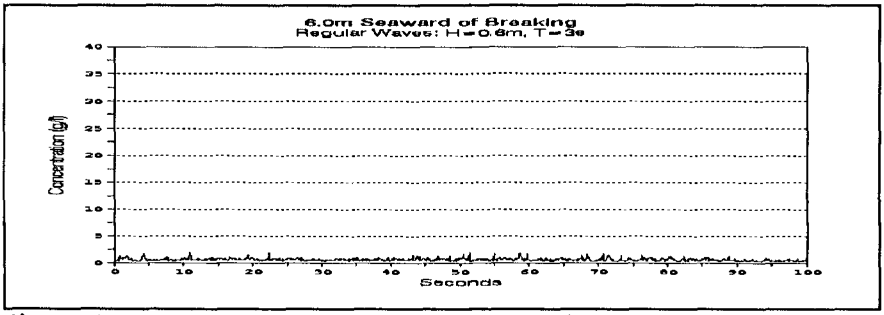

Figure 3 OBS time series 7.8 cm from the bed

Fig. 4 presents data from a position 4 m seaward from the break point, and is an example of concentration fluctuation that is directly correlated to the 3 sec oscillatory motion. The sensors indicate regular changes from a low background concentration to relatively high concentration within one wave period.

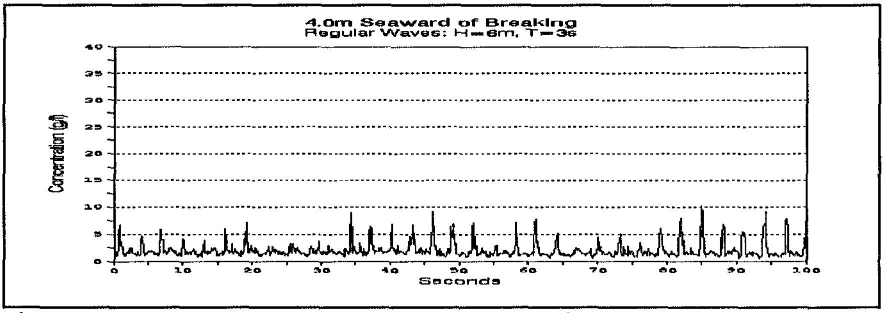

Figure 4 OBS time series 7.5 cm from the bed

Moving to a position 2 m from the breakpoint, the background concentration increased from 1 g/l to 2-3 g/l as seen in Fig. 5. The events at this position are regular, but are not as sharply peaked as those found 4 m from the breakpoint. The complete time series for this run contains a noticeable long period oscillation, part of which can be seen in this 100-sec segment, and may be caused by seiching in the channel.

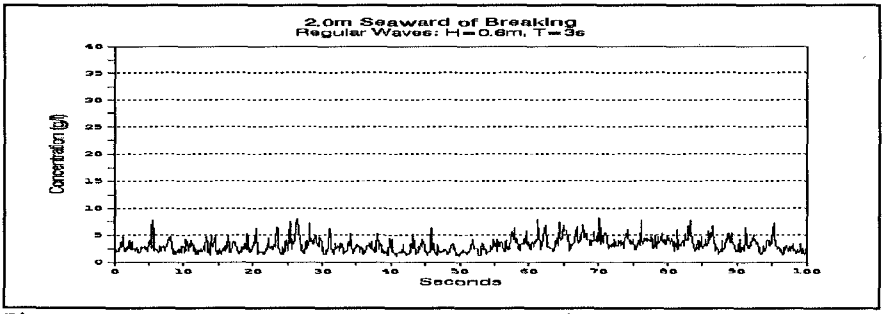

Figure 5 OBS time series 6.8 cm from the bed

At the break point (Fig. 6), the background concentration increased to nearly 5 g/l, and some peak concentrations lie above 10 g/l. The oscillatory structure is absent and peak concentrations are no longer strongly linked to the wave period.

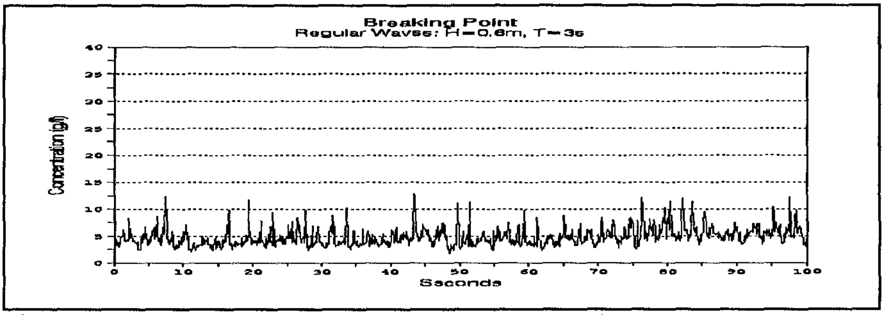

Figure 6 OBS time series 6.8 cm from the bed

In Fig. 7, which corresponds to a location 2 m shoreward of the break point and just shoreward of the plunge point, the most noticeable feature in the OBS record is that the background concentration has dropped to about 2 g/l. However, the peak concentrations remain relatively high. This time series shows no indication of wave-correlated structure, with the peaks in sediment concentration not following a distinguishable pattern.

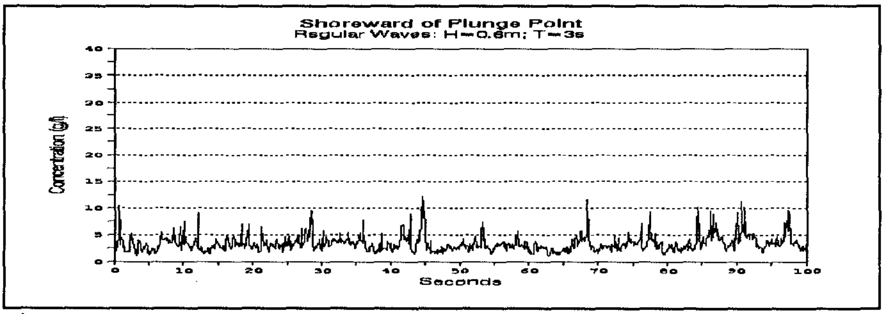

Figure 7 OBS time series 6.8 cm from the bed

These records indicate the temporal and spatial structure of the boundary between the relatively clear water outside the surf zone, and the cloud of sediment entrained and maintained by the intense turbulence levels induced by breaking. As the boundary advected back-and-forth in the oscillatory flow, it was visually observed to drift offshore several meters from its origin near the breaking point. A sharp gradient in suspended sediment concentration defined the boundary between the cloud and the surrounding water.

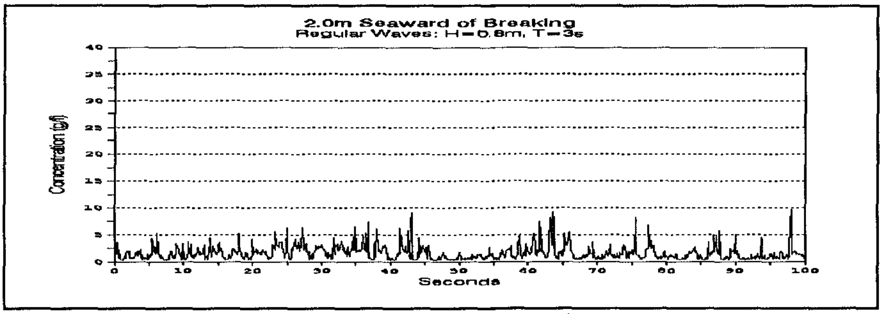

Figure 8 OBS time series 7.5 cm from the bed

Regular Wave Run #2

In this second run, the offshore wave height was increased to 0.8 m, whereas the wave period remained at 3 sec. The position of the break point shifted approximately 4 m offshore from the previous run. Fig. 8, corresponding to a position 2 m seaward of this break point, shows that the magnitude of the sediment concentration in this time series oscillated regularly, much like in the previous run (Fig. 5); however, the background concentration was notably less with the larger wave conditions.

As seen in Fig. 9, by moving only half a meter closer to the breakpoint the peak concentrations increased, indicating deeper penetration into the sediment cloud as the boundary advected past the sensor. Suspension peaks were regular but not all of the same magnitude.

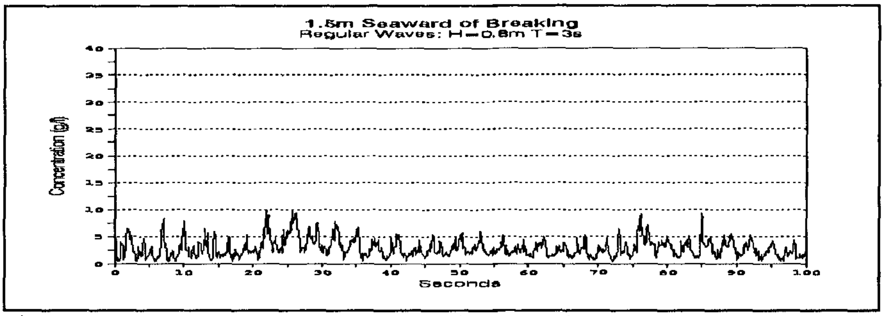

Figure 9 OBS time series 8.4 cm from the bed

At the break point (Fig. 10), there was a notable increase in the amount of sediment in suspension. Peak concentrations ranged from 15 to 20 g/l, and the background concentration was about 5 g/l, which are significantly greater than was observed at the break point in the first run.

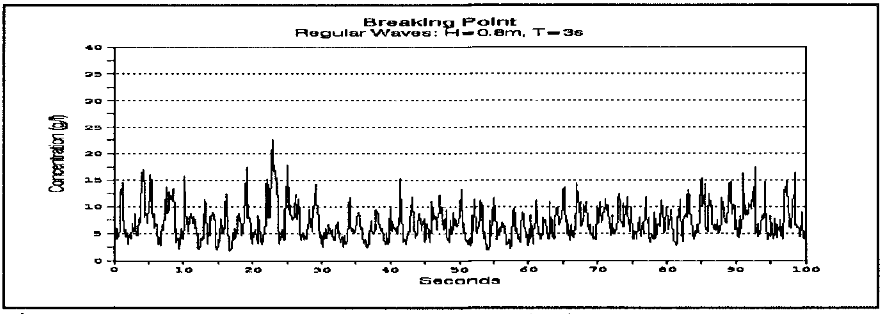

Figure 10 OBS time series 8.4 cm from the bed

Fig. 11 displays data that were collected 0.8 m inside the point of incipient breaking, which was still seaward of the plunge point. In this region, the highest peak concentrations of suspended sediment and greatest suspended load were found. No regular structure is apparent in the time series, and only in a few instances can 3-sec period events be observed.

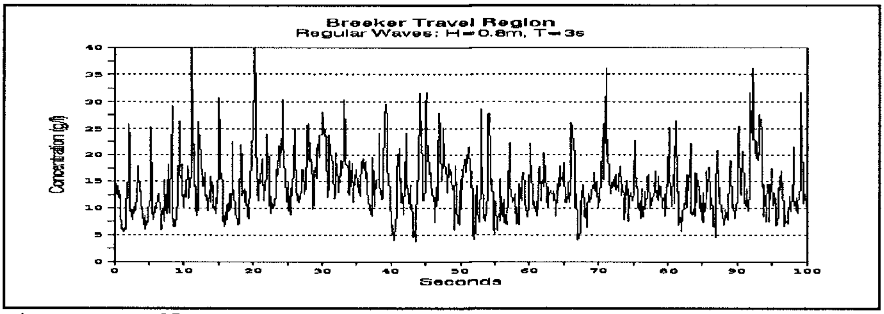

Figure 11 OBS time series 8.4 cm from the bed

4.3 m shoreward of the break point (Fig. 12), the background concentration drops to approximately 3 g/l and the peaks are reduced to the 5 to 10 g/l range. Fluctuations in sediment concentration appear to be considerably more random after the plunge point. The shoreward boundary of the sediment cloud is not as well defined as the seaward boundary, indicating more efficient cross-shore mixing in the broken wave region as would be expected.

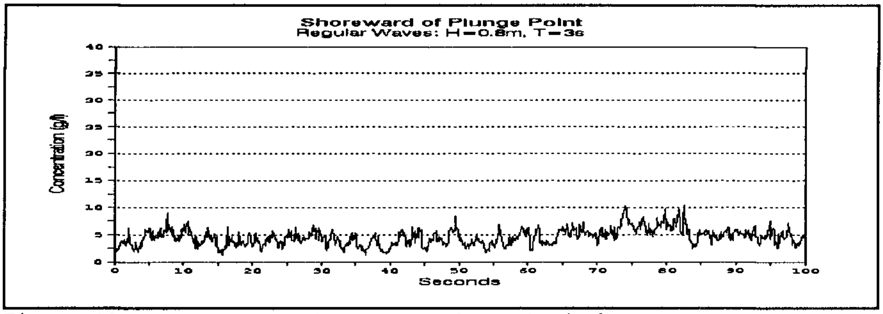

Figure 12 OBS time series 7.5 cm from the bed

REGULAR WAVES: MEAN CONCENTRATION PROFILES

Fig. 13 and Fig. 14 present mean concentration for all five OBS in the vertical array, for the two regular wave conditions discussed above. Mean concentration was calculated from the entire record that was collected at each station. Sensor elevations ranged from 7 to 34 cm above the bed.

<u>Regular Wave Run 1</u>

Fig. 13 displays the mean concentration profiles at the five cross-shore positions identified in Fig. 3 through Fig. 7. The profiles are labeled 1 through 5, with Profile 1 being the most seaward and Profile 5 being the most shoreward.

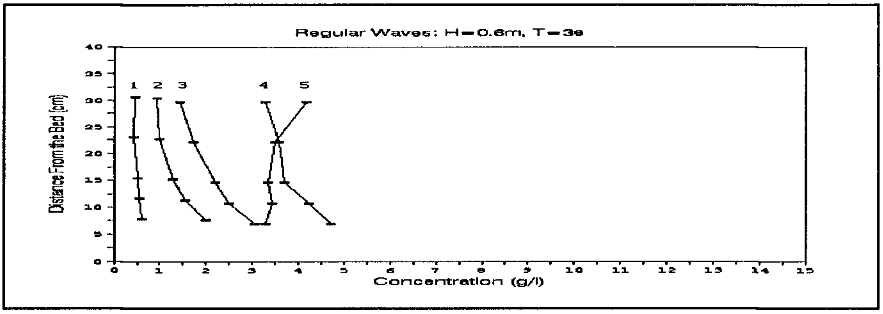

Figure 13

The first curve is for the cross-shore position 6-m seaward of the break point, where there was little suspended material as indicated by the low mean concentrations and the absence of vertical structure. The second curve, which is 2-m closer to the break point, shows an exponential decrease in concentration with distance from the bed. Profile 3 is 2 m seaward of the break point, where the curve is similar in shape to the previous, but with an increase in the amount of suspended material.

Profile 4, which was taken at the position where the wave crest began to curl over the front face, the concentration nearly doubled from the previous location. Here the profile is no longer smooth, but has a noticeable kink. After breaking (Profile 5) there is a distinct inversion in the mean sediment concentration profile.

<u>Regular Wave Run 2</u>

Fig. 14 displays the mean concentration profiles at the five cross-shore positions identified in Figs. 8-12. The mean concentration profiles are numbered 1 through 5 as in Fig. 13.

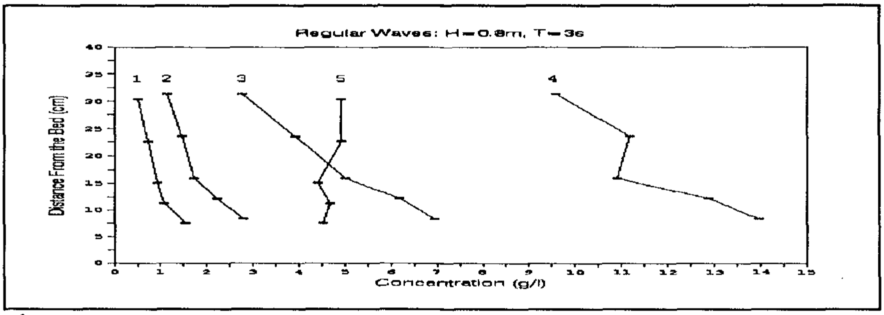

Figure 14

Seaward of the break point, the mean concentration profiles again show an exponential shape similar to those in Fig. 13. Profile 2 shows that the amount of suspended material was nearly twice of that in Profile 1, even though these locations were only 0.5 m apart. At the break point (Profile 3), the vertical structure loses its exponential character, as in Profile 4 of the previous run.

The highest mean concentrations measured at any cross-shore position are found in Profile 4, which was located between incipient breaking and the plunge point. Here the profile has an irregular shape, but concentration still decreases with distance from the bed. Even though this profile was taken less than 1 m landward of the previous position, mean concentrations doubled. Profile 5, which is shoreward of the plunge point, the concentration profile was inverted, but not to the degree observed in the first regular wave case.

RANDOM WAVES: TIME SERIES

Most of the tests during the SUPERTANK project dealt with random waves. Unfortunately, there were no runs with random wave conditions during which the OBS array was shifted to different positions in the surf zone. However, for comparison of random and regular waves, two random wave runs were identified that had similar energy levels and breaking conditions as the two regular wave runs. All four runs were conducted in immediate succession, so that the bottom profile underwent only slight change.

Random Wave Run 1

The design wave conditions were 0.6-m significant height and 3-sec peak period. For the entire 40 min run, the OBS array was positioned about 5.4 m seaward of breaking, 0.6 m shoreward of the first position for the regular wave case.

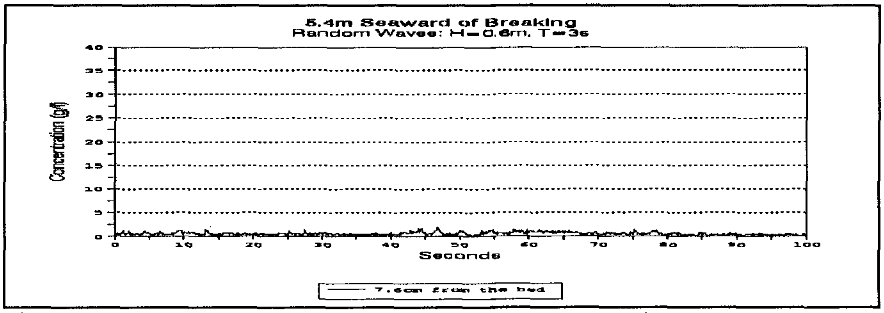

Figure 15 OBS time series 7.6 cm from the bed

Fig. 15 presents a 100-sec segment of the 40 min run. Concentrations measured at this position under random waves were comparable to those measured in the first regular wave case (Fig. 3). Background concentration was low and the suspension events were sparse during both runs.

Random Wave Run 2

The offshore conditions for the second random wave case were 0.8-m significant wave height and 3-sec peak period. The OBS array was positioned about 2.1 m seaward of breaking, nearly the same as the first position for the 0.8-m regular wave case.

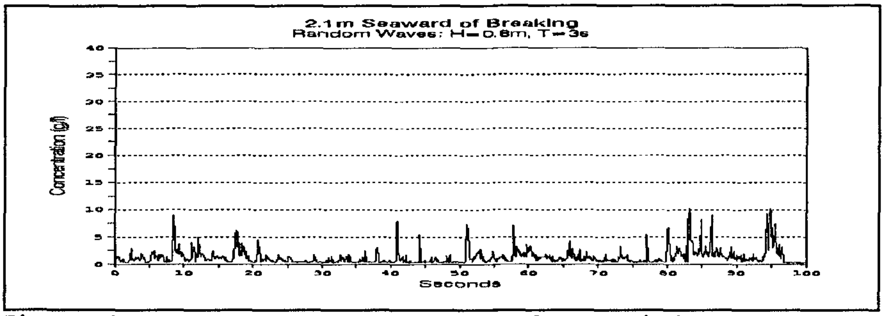

Figure 16 OBS time series 7.5 cm from the bed

In Fig. 16 it can be seen that with random waves the sediment suspension events are intermittently spaced and the peak concentrations are less uniform than those in the regular wave run (Fig. 8). There are also sections where little suspension occurs; however, no new structure (i.e. structure that was not encountered at some location in the regular wave run) is evident. Visual observations confirmed that smaller waves produced a sediment cloud of smaller dimensions and lower concentration.

RANDOM WAVES: MEAN CONCENTRATION PROFILES

Average concentrations for each of the sensors in the OBS array were calculated and the mean concentration profiles were generated for the random wave cases. Since data were available at only one cross-shore position for the two random wave tests, the random wave profiles are plotted together with a concentration profile from a comparable position during the regular wave runs.

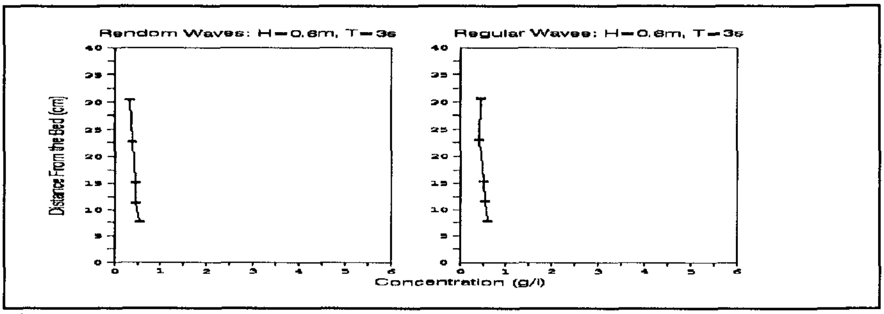

Figure 17 Mean Concentration Profiles

Fig. 17 shows the mean concentration profiles for the two types of waves at positions nominally 6 m seaward of breaking. The position of the array in the regular wave case was 0.6 m seaward of the random wave case. The shape of the curves and magnitude of the concentration are nearly identical.

Fig. 18 shows sediment concentration profiles under comparable regular and random wave conditions, but from a location nominally 2 m seaward of breaking. They display very similar exponential decay in concentration with distance from the bed. The mean suspended load for the random wave case is slightly lower than in the regular wave case. The consistent amount of energy available on a wave-by-wave basis for regular wave conditions may generate this higher background concentration.

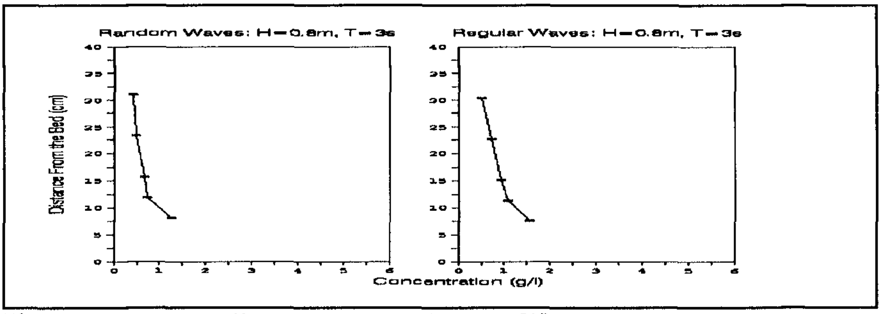

Figure 18 Mean concentration profiles

CONCLUSIONS

The temporal behavior of suspended sand concentration, as well as the mean suspended load, changes dramatically as one moves through the outer edge of the surf zone. Suspension just outside the breaking region is characterized by a relatively well-defined boundary between clear water and sediment in suspension. The position of this boundary oscillates with the motion of the waves and drifts offshore with the mean cross-shore current, resulting in a concentration that varies regularly with the wave period. Mean concentration profiles in this region display the classical exponential shape.

The highest concentrations of suspended sediment are found in the region of initial breaking, where the sand cloud originates. Here much of the oscillatory structure in the time series is lost, with peaks in concentration occurring randomly, even for regular waves. Mean concentration adopts a profile that decays roughly linearly with distance from the bed. Just shoreward of the region of initial breaking the profile of mean concentration inverts.

For random waves, suspension is more irregular and intermittent, as should be expected. However, the mean concentration profiles are similar in both magnitude and shape as for regular waves.

ACKNOWLEDGEMENTS

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