CHAPTER 56

LONGSHORE TRANSPORT OF SUSPENDED SEDIMENT

by

John C. Fairchild*

ABSTRACT

In excess of 800 suspended sediment samples were collected from stations along the City Pier, Ventnor, New Jersey and Jennettes Pier, Nags Head, North Carolina using a tractor-mounted pump sampler. Most samples were collected within the surf zone at the Ventnor site. At the Nags Head site, sample collections included the surf zone, but generally extended over a wider range of the nearshore zone. Average sampling time was 3 minutes. Nozzle elevation varied from 3 inches above the bottom up to a maximum about mid-depth, generally not greater than 2.5 feet above bottom. Maximum concentrations at Ventnor ranged up to 2.6 ppt by weight and at Nags Head were about 4.0 ppt. Median size at Ventnor ranged from 0.12 to 0.15 mm and averaged about 0.20 mm in depths of 4 feet and less at Nags Head. Results are summarized in a series of scatter plots which relate suspended sediment concentration to nozzle height, wave height, water depth and sampling distance from an observed wave-breaker-line. Results are compared to CERC laboratory data, to two excerpted concentrations from unidirectional flow tests and to the CERC TR-4 design curve of longshore wave energy versus longshore transport.

Introduction

Design criteria for problems involving sediment transport by wave action could be greatly improved by development of empirical relationships from field measurements covering a wide range of wave conditions. In the absence of adequate data or predictive techniques, the coastal engineer has relied on historical compilations of dredging and survey records to obtain longshore transport estimates. Better techniques are needed and therefore, field and laboratory studies of sediment transport are needed to gain added knowledge of natural beach processes, leading to better predictions of longshore transport rates. This paper reports on some data on suspended loads gathered in both ocean and laboratory waves.

Longshore transport of suspended sediment is one of the two basic modes of wave induced sediment transport, the other mode being bedload transport whereby the bed sediment is pushed or rolled along the nearshore bottom by wave action, and the resulting shear stress in the bottom boundary layer. The total amount of suspended material moving along a given shore over a given time depends on the complex interactions of several factors, including wave conditions, water depth, beach slope, characteristics of the beach materials and total range of the tide. Important among the several inter-

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* Research Hydraulic Engineer, Coastal Engineering Research Center, Washington, D. C.

actiona is the generation of the longshore current during the wave breaking proceas. This current transporta large amounts of bottom materials forced into suspension by wave-generated currents and turbulence.

An early estimate of the longshore transport of suspended sediment was made by Watts (1), using pump samplings of suspended sediment from a pier at Pacific Beach, California. Updated estimates of the longshore transport of suspended aediment may be made from field and laboratory data, including suspended aediment concentrations and related wave parameters, now on hand at CERC (2). Thia data was obtained at two Atlantic coast sites, and in the CERC laboratory wave facilities using pump sampling techniques.

The paragraphs which follow briefly describe the field sampling, compare the field results to CERC-laboratory data and to two excerpts of data from unidirectional flow tests, and finally, compare computed longshore tranaport rates to the Coastal Engineering Research Center TR-4 design curve of longshore transport versus longshore wave energy flux.

Field Sampling

In excess of 800 suspended sediment samples were collected from stations along the City Pier, Ventnor, New Jersey and Jennettes Pier, Nags Head, North Carolina, using a tractor-mounted pump sampler (3). Figure 1 is a achematic illustration of the sampler on a fishing pier. Most samples were obtained

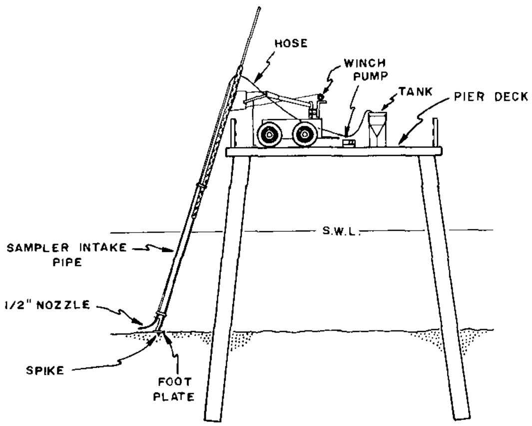


FIGURE 1: SCHEMATIC VIEW OF A TRACTOR-MOUNTED SUSPENDED SAND SAMPLER ON A PIER

within the surf zone at Ventnor, N. J. under varying intensities (types and proximities) of wave breaking. Nags Head samples were collected in the surf zone, but generally extended over a wider and deeper range of the nearshore zone. Figure 2 is a schematic illustration of the areas of interest in the sample collections which shows a surf zone, a swash zone and an offshore zone. Average samplings of 3 minutes time were made from a height of 3 inches above the bottom up to a maximum height at about the mid-depth level. Each sample, as initially pumped through a 1/2-inch intake nozzle, was a 40 gallon volume of water-sediment mixture which was decanted in the field to a sample-size quantity of wet sand. Laboratory analysis and data reduction at CERC yielded a suspended sediment concentration and a size distribution for each sample. In the Ventnor data, maximum concentrations were about 2.6 ppt by weight (equivalent to 380 grams (.84 lb) of sand in 40 gallons of seawater) and minimum concentrations were of the order of .025 ppt (less than 4 grams in 40 gallons). In the Nags Head data concentrations above 1.0 ppt by weight occurred more frequently with two measured values which were above 4 ppt. However, there was also a greater percent occurrence of concentrations below .01 ppt in the Nags Head data. Median diameter of the suspended sediment ranged from .12 to .15 mm for the Ventnor data and averaged 0.20 mm in depths of 4 feet or less at Nags Head. In depths of 8 to 12 feet at Nags Head, median diameter of suspended sediment samples averaged about 0.17 mm.

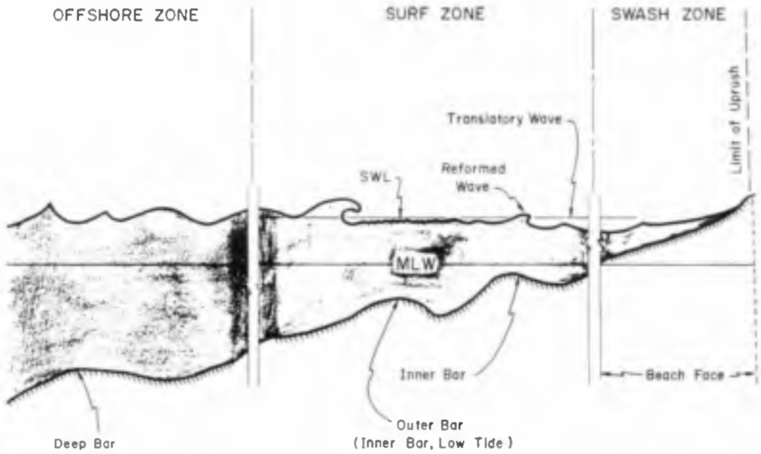


FIGURE 2: SCHEMATIC PROFILE OF A SURF ZONE

Discussion of Results from Sample Collections

Table 1 lists the principal variables considered in this study. The concentration, C_w, is considered to be a dependent variable determined by an unknown function of elevation, depth, wave height, and distance from the wave-breaker-line

$$C_w = f\ (E_B,\ d,\ H,\ S_B).$$

The variables Q and θ_b are used in the final section of this paper.

Table 1. DEFINITION OF VARIABLES

C_w - suspended sediment concentration (ppt by wgt)

E_B - elevation of suction nozzle (ft above bottom)

d - water depth at sampling station (ft)

H - significant wave height (ft)

S_B - distance from the wave-breaker-line (ft, + is landward)

Q - longshore transport rate (100,000 yd^3/yr

θ_b - angle between a wave breaking crest and the shoreline (designated α_b in Fig. 13, CERC TR-4)

The results from the sample collections at Ventnor, N. J. and Nags Head, N. C. are summarized in a series of scatter plots which relate suspended sediment concentrations, C_w, in parts per thousand (ppt) by weight to the 4 independent variables. Sediment concentration is presented in the several figures which follow by sampling stations, and by all stations plotted together on general scatter plots. The sampling station scatter plots show data collected at a specific station on the pier usually within a period of 3 hours or less. The general scatter plots are representative of all the data collected and so may have more significance than data collected at a specific station and over periods of - say 2 to 3 hours.

Figures 3 and 4 are single station scatter plots which show the vertical distribution of suspended sediment concentration for two pier stations at Ventnor, and two pier stations at Nags Head, respectively. Note that the ordinate in each figure represents concentrations of suspended sediment, C_w in ppt by weight and that the abscissa represents sampling nozzle heights, E_B, in feet above the ocean bottom. Two sets of points are plotted in the right-side graph in Figure 3, with the open circles representing samplings before 1200 hours and the filled circles representing samplings after 1300 hours. It was observed during the samplings that there was an abrupt increase in the wave activity at about 1300 hours and this graph shows how quickly the concentration level responds to the increased wave height, and how much flatter the trend is for the higher waves ($\overline{H}$ = 1.82 ft).

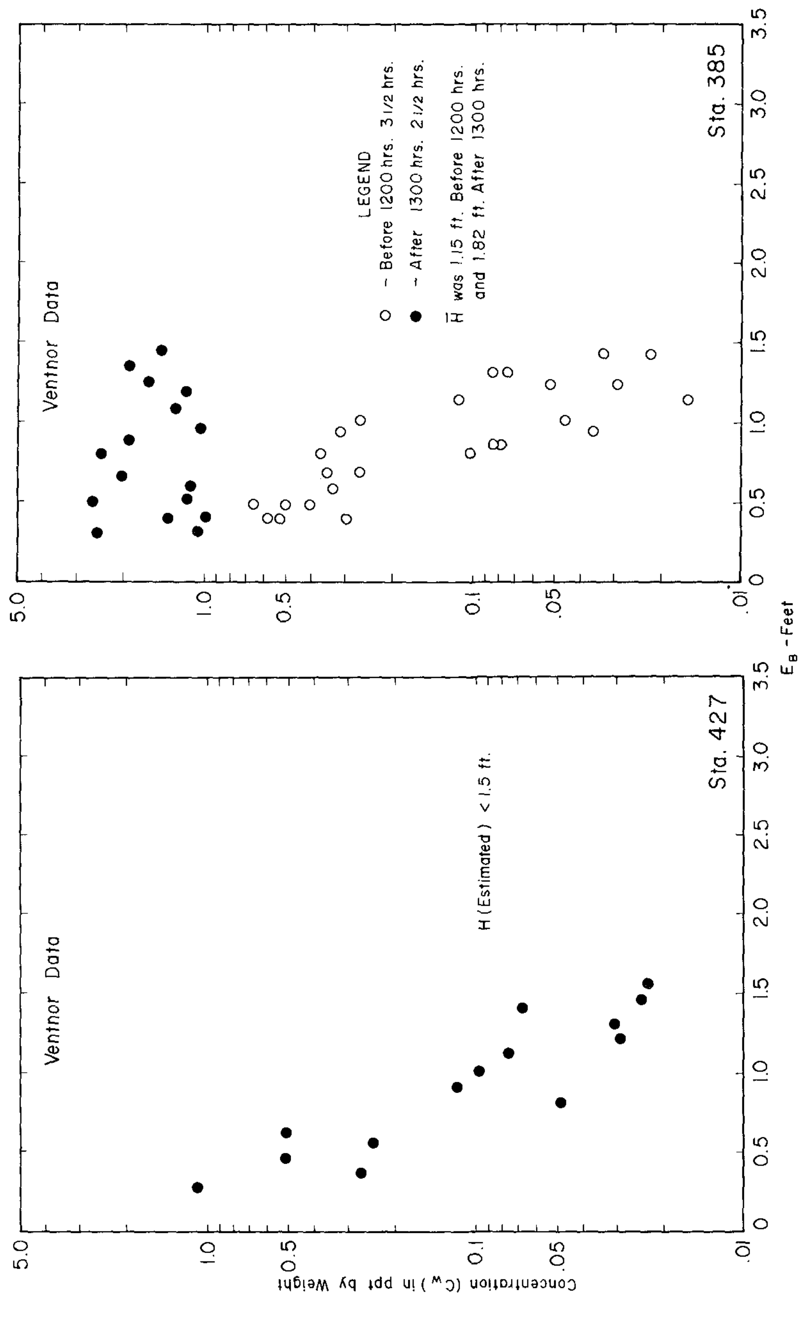


FIGURE 3: VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT CONCENTRATION

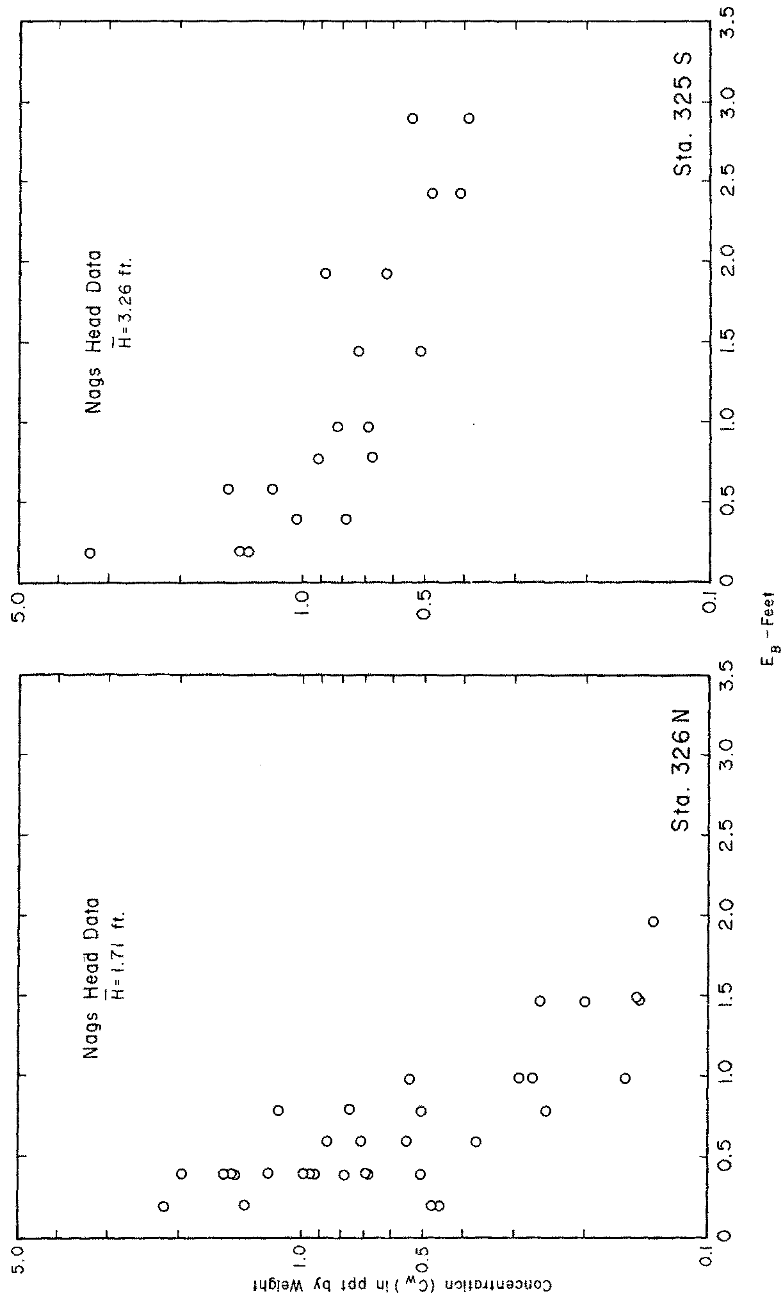


FIGURE 4: VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT CONCENTRATION

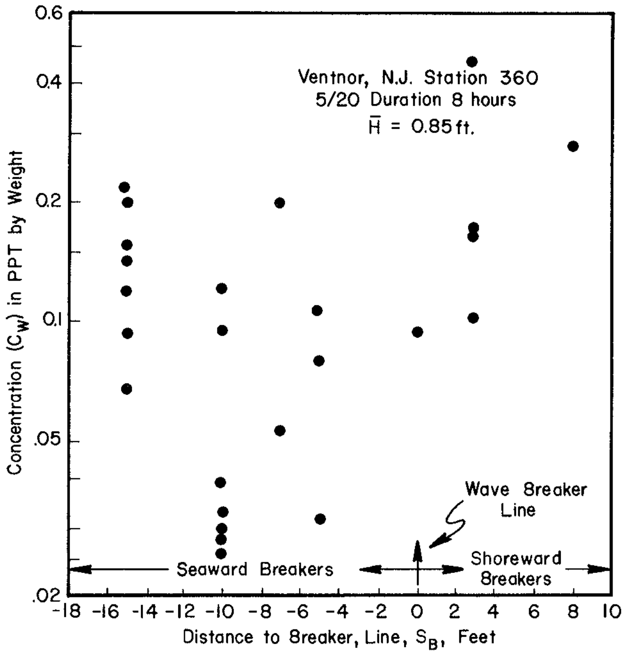
Also, note the considerable difference in the steepness of the scatter trends in Figure 4 for the Nags Head data. Based on a study of numerous plots, it was found that a higher wave or more intense wave activity was usually aasociated with the flatter distribution trends.

Figure 5 relates concentration of suspended sediment to the distance of the sampling station from an observed wave-breaker-line for the Ventnor data. The top graph relates suspended sediment concentration to distance from a moving wave-breaker-line for a single station during an eight hour period. The bottom graph shows the same type of relationship but for shorter periods of time on three separate dates. Based on the author's examination of the effect of other factors such as wave height, water depth, nozzle height, it is his judgement that the type of wave breaking (surging, plunging or spilling) is what caused the particular distribution of the three data groups shown in this scatter plot.

The next three figures, 6, 7 and 8 are more representative of all the data collected than the last three figures which gave results for data collected at a single station and generally over times of two or three hours. The first of these, Figure 6, relates suspended sediment concentration, C_w, in ppt by weight, to distance from the wave-breaker-line, S_B, for two nozzle height ranges above the ocean bottom at Ventnor, N. J. The next scatter plot, Figure 7, shows the relationship of suspended sediment concentration, C_w to the parameter, H/d, wave height over water depth. Note that the left graph in Figure 7 shows the results for the Ventnor data and the right-side graph shows results for the Nags Head data. Figure 8 concludes this phase of the results with an additional graph relating suspended sediment concentration, C_w, to the parameter, H/d, wave height over water depth, for samples collected above 0.5 feet and less than 1.0 feet above the ocean bottom. The legend of the left side graph for the Ventnor data divides the data into two classes, one class for samples collected seaward of the wave-breaker-line, another class for samples collected shoreward of the wave-breaker-line. Note that the right-side graph for the Nags Head data in Figure 8 appears to have a gap in the data scatter appearing just about where the peak occurs in the data scatter for the Ventnor data, left graph in the figure.

The results presented in Figures 5-8 may be explained as follows: As the shallow water waves approach breaking, the concentration of suspended sediment increases sharply from barely non-breaking waves to fully breaking waves with shoreward advance and with increase in H/d (wave height over water depth). Scatter configurations (Note Figures 7 and 8) indicate that the suspended sediment concentration peaks near the wave breaker index (H/d = 0.78)(4) and that concentrations decrease gradually with the shoreward advance of spilling translatory waves and with further increase in H/d.

The next two figures present all data collected in these field studies. The first of these, Figure 9, relates suspended sediment concentration to H^2 (wave height squared). These data show very much scatter. In noting the scatter in this figure, it must be recognized that the plotted concentrations were collected at a range of elevations above the ocean bottom - E_B from 0.25 to 2.50 feet. Scatter plots presented earlier have indicated that this elevation variable significantly affects the total scatter in the graphs. The scatter trend in the top graph in Figure 9 appears to change noticeably near an H^2 of 1.5 and trend toward the upper right.



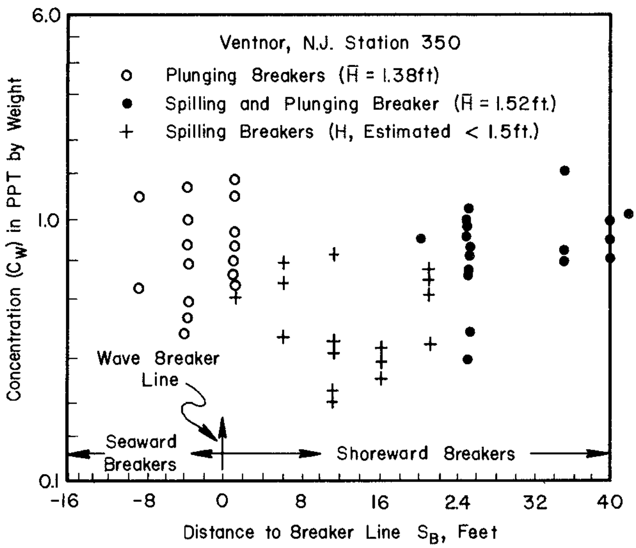


FIGURE 5: VARIATION IN SUSPENDED SEDIMENT CONCENTRATION ACROSS A MOVING BREAKER LINE

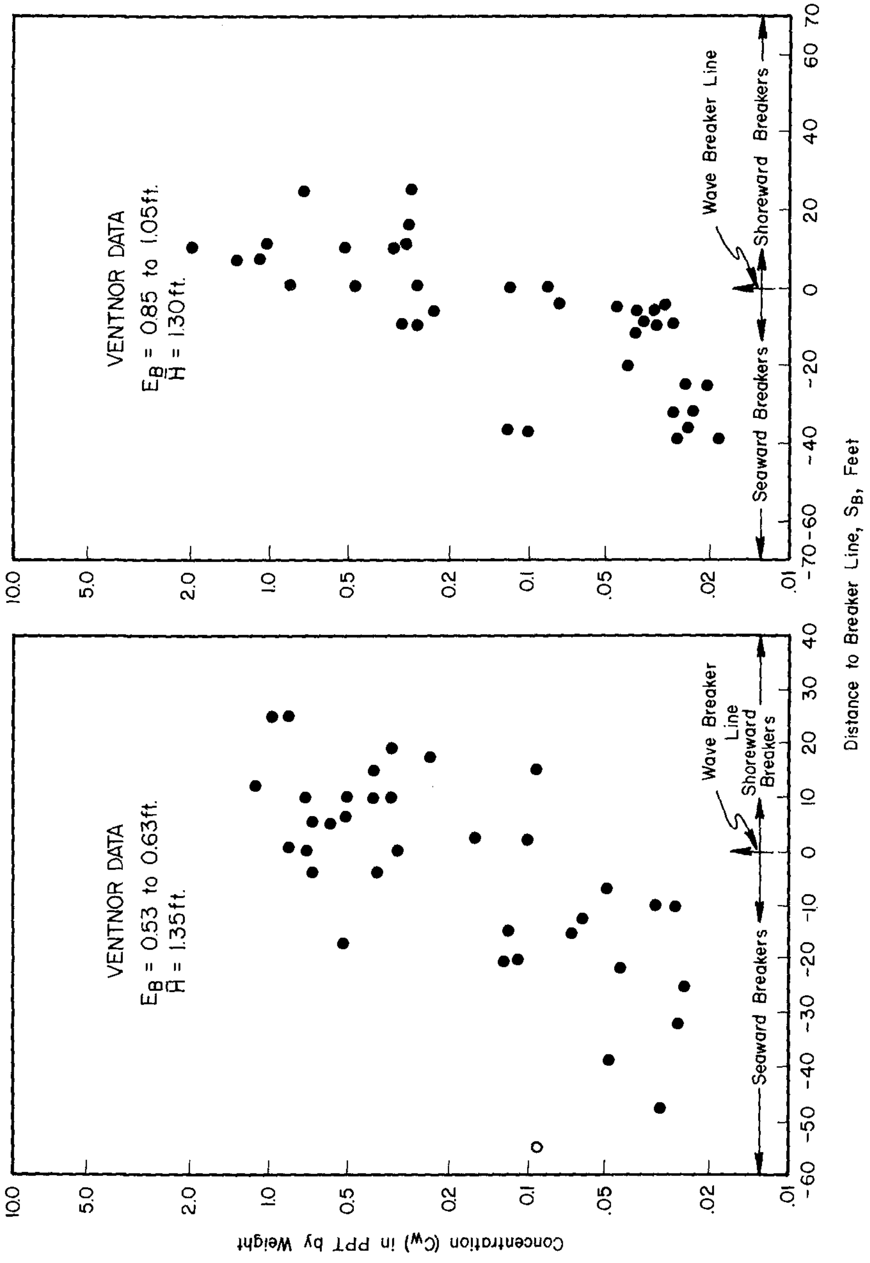


FIGURE 6: VARIATION IN SUSPENDED SEDIMENT CONCENTRATION ACROSS A MOVING BREAKER LINE

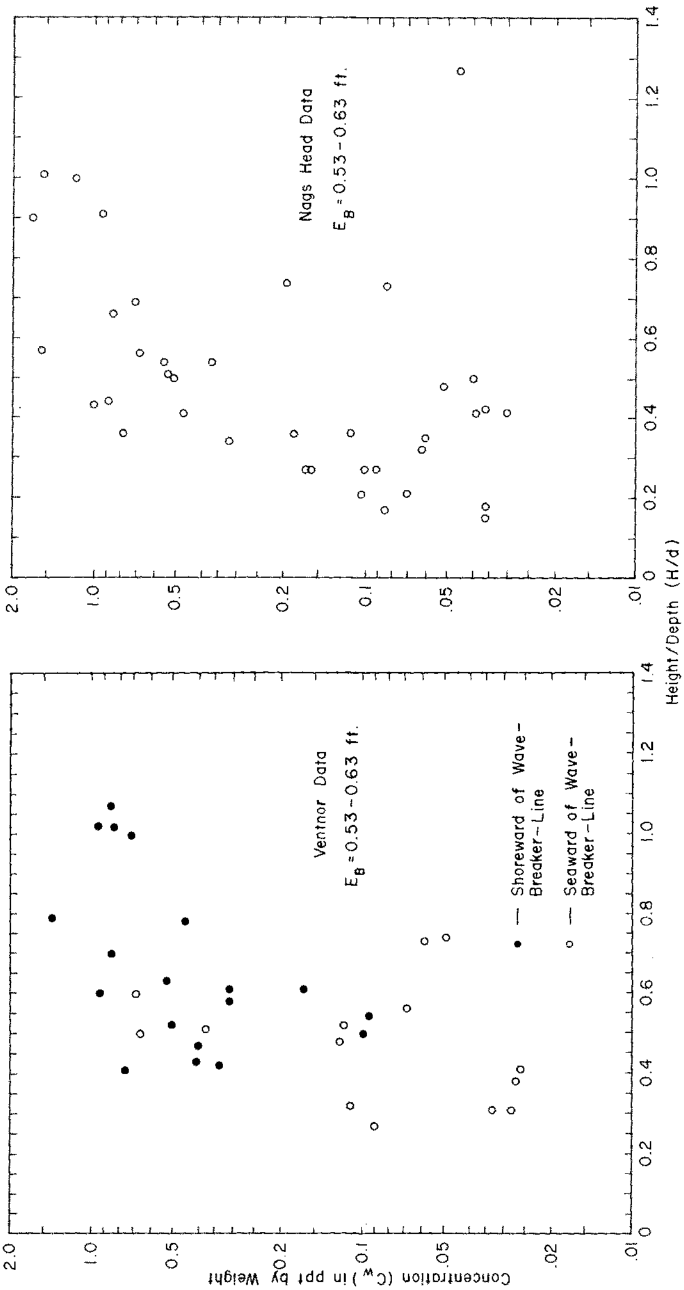


FIGURE 7: RELATIONSHIP OF SUSPENDED SEDIMENT CONCENTRATION TO (H/d) WAVE HEIGHT/WATER DEPTH

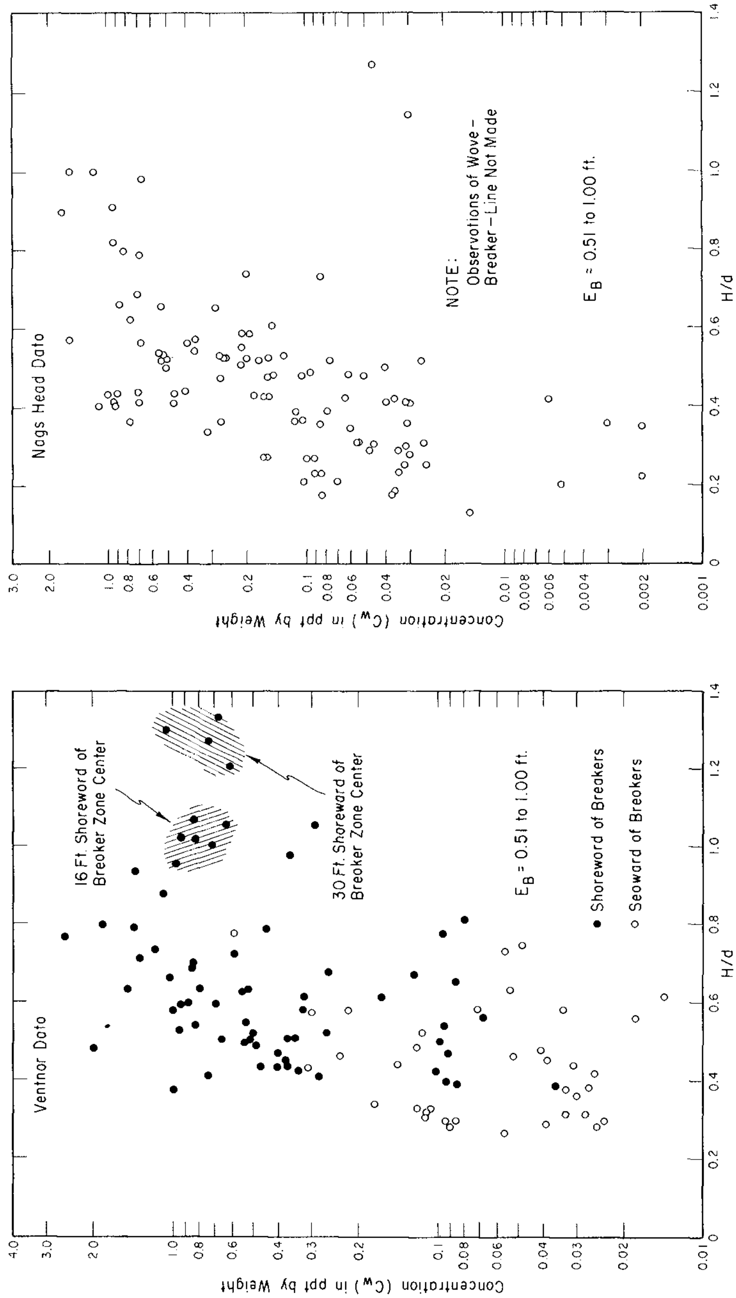
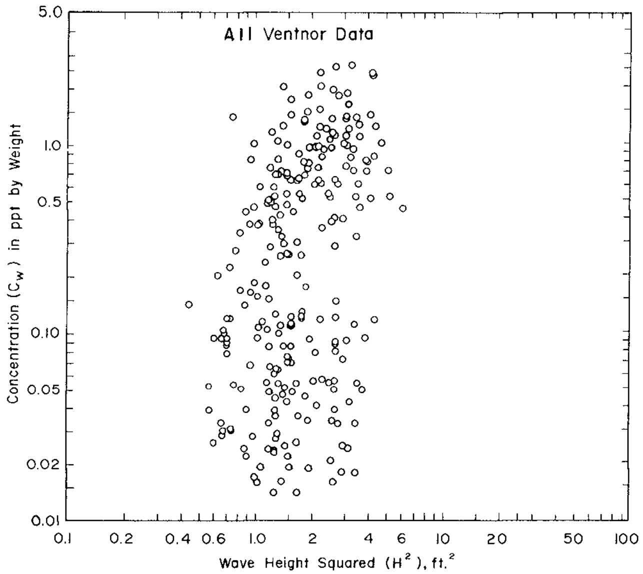


FIGURE 8. CONFIGURATION OF THE SCATTER IN A PLOT OF SUSPENDED SEDIMENT CONCENTRATION VERSUS WAVE HEIGHT OVER WATER DEPTH



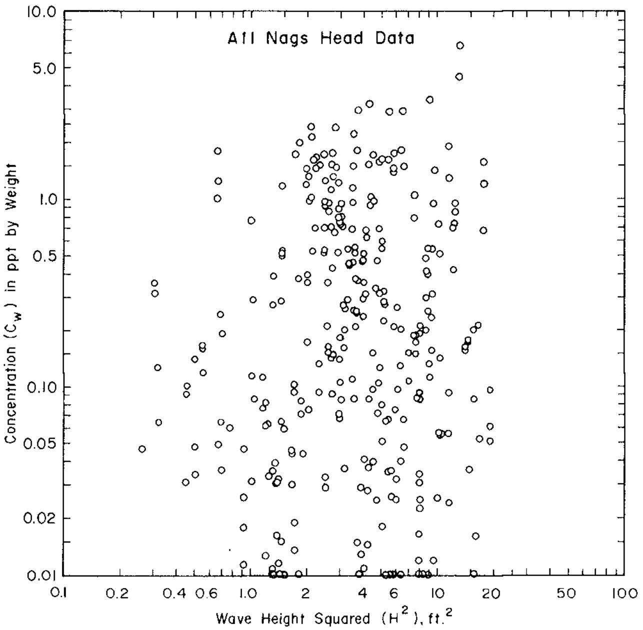


FIGURE 9: VARIATION OF SUSPENDED SEDIMENT CONCENTRATION IN RELATION TO WAVE HEIGHT SQUARED

In the next all-data scatter plot, Figure 10, C_w is plotted against the parameter, H/E_B wave height over sampling nozzle elevation above the ocean bottom. The total scatter in these plots, especially that for the Ventnor data on the left, is significantly less than in the last Figure of C_w versus H^2; the reduced acatter in Figure 10 results largely from the inclusion of E_B in the denominator of the abscissa, which accounts for the effect of variable nozzle elevation above the bottom. By overlaying the two sections of this figure, it was observed that the Ventnor data has a somewhat steeper slope than the Nags Head data. This may be explained by the fact that the median diameter of the Ventnor sand (0.12 - 0.15 mm) is significantly less than that of the Nags Head sand (about 0.20 mm), so that the Ventnor sand is more uniformly mixed, and being significantly smaller may be sustained in suspension at relatively higher elevations by a given energy or turbulence input.

Particle size effects in relation to wave-induced suspended sediment are summarized in Figure 11. The two scatter plots in this figure relate the median particle size and the coarser 5th percentile of the samples to water depth and nozzle height above bottom for the Nags Head data. These scatter trends show a very gradual decrease in median particle size with increase in water depth, and also with increase in E_B, nozzle height above bottom. Scatter trends for the Ventnor data were very similar but an actual points plot for the Ventnor data was not included due to space limitations. Instead, as the legend in Figure 11 shows, a visual best fit curve from the actual Ventnor data is displayed near the bottom of each graph.

Figure 12 is a composite plot of suspended sediment concentration versus wave height squared, as indicated for sampling elevation, $E_B \leq 1.00$ foot above the bottom, enabling comparison of the Ventnor, N. J. and Nags Head, N. C. results, with other field and laboratory results. The upper graph shows plotted points from two sets of laboratory tests (SPTB and 72 ft wave tank) and three sets of CERC large wave tank tests grouped about the plots from the two field tests at Ventnor, N. J. and Nags Head, N. C. This graph gives an overview of variations in the concentrations of wave-induced suspended sediment in laboratory and in average condition ocean waves - from small tank waves with 3 to 6 inch heights up to CERC large-wave tank waves with 7.0 feet breaker heights. The lower graph in Figure 12 is an averaged version of the upper one, where each scatter grouping has been averaged as a single point. The SPTB data actually comprised three data sets as the lower-graph legend shows. In addition, the lower graph includes three added points as follows: one point from data collected at Mission Bay, California and reported by Watts (1); and, two points from measurements of suspended sediment in the Missouri River and in a laboratory flume.(5) In plotting the unidirectional flow data, the flow depth is assumed analogous to the wave breaker height, since breaker depth equals breaker height to a first approximation.

In summary, the various data plotted in Figure 12 show an expectable relationship (C_w increasing with H^2). These results suggest the possibility of further application of suspended sediment results from unidirectional flow in studies of wave-induced suspended sediment. The unidirectional flow

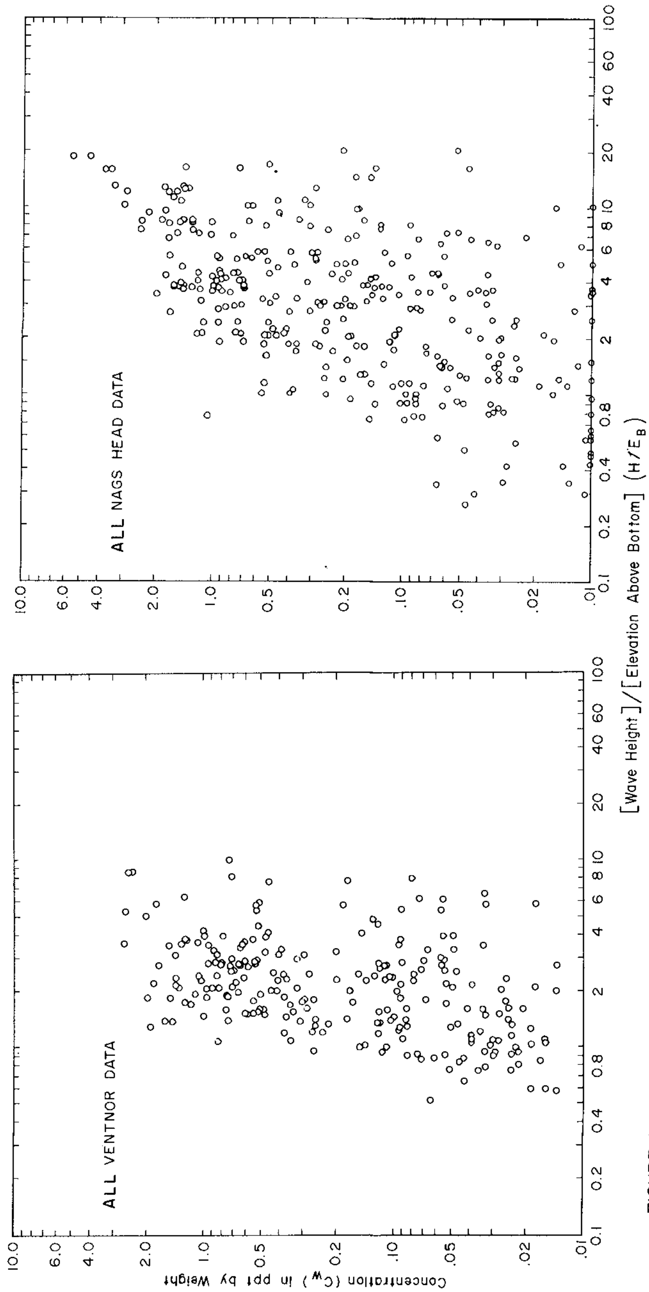


FIGURE 10: VARIATION OF SUSPENDED SEDIMENT CONCENTRATION IN RELATION TO WAVE HEIGHT OVER NOZZLE HEIGHT

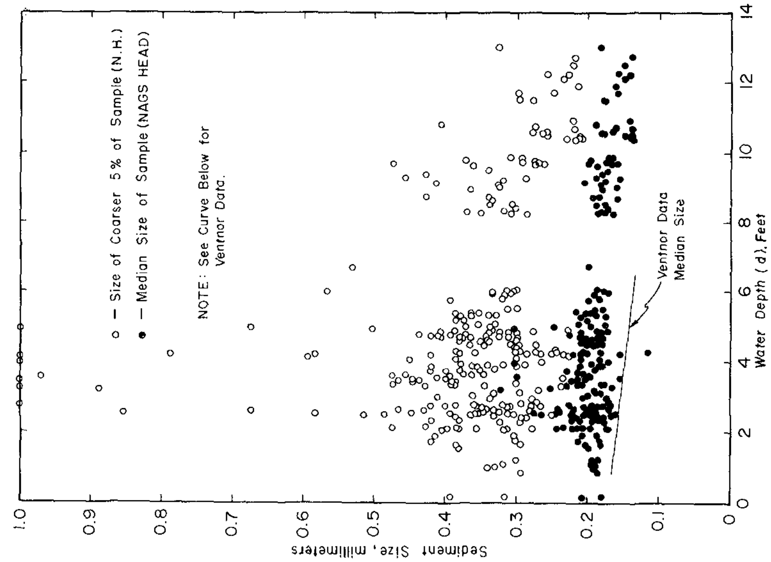


FIGURE 11A: RELATION OF SUSPENDED SEDIMENT SIZE TO WATER DEPTH

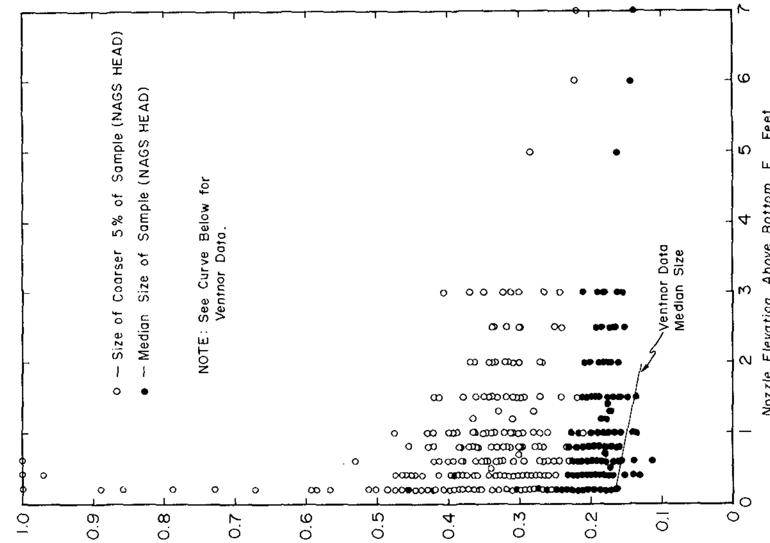


FIGURE 11 B: RELATION OF SUSPENDED SEDIMENT SIZE TO NOZZLE ELEVATION

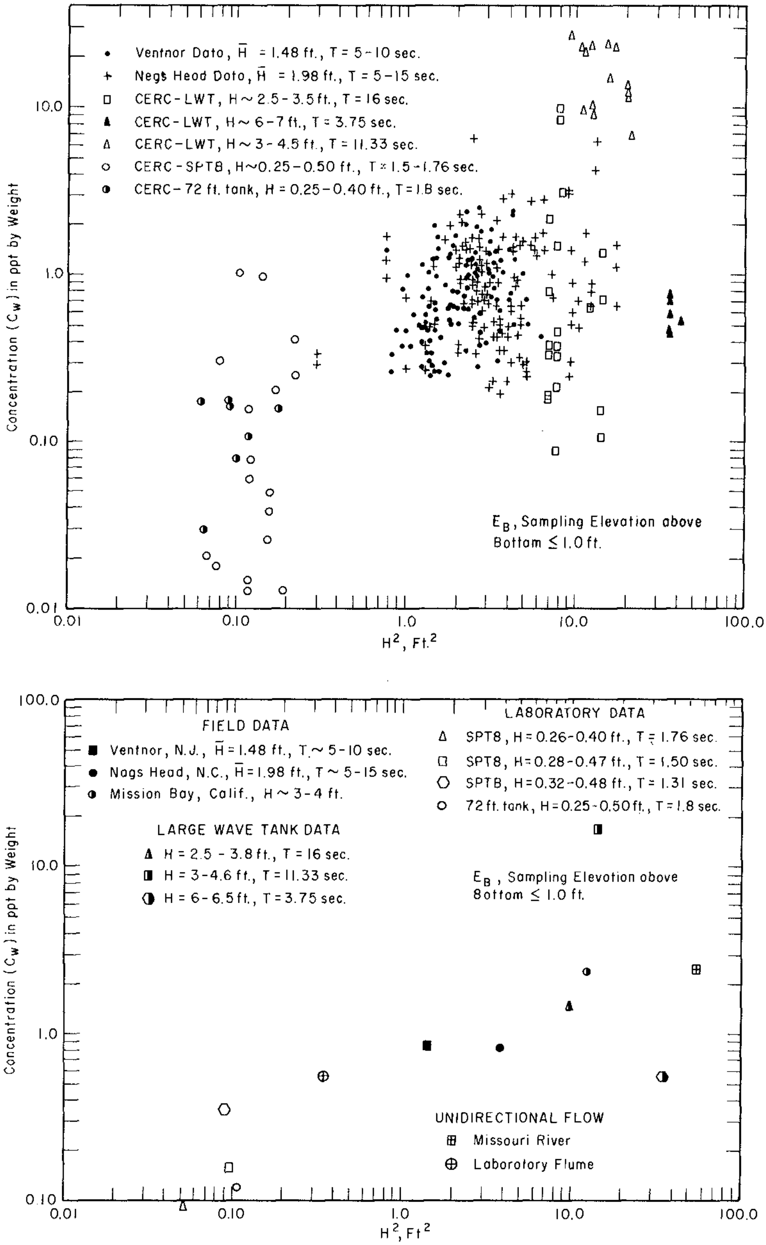


FIGURE 12. SUSPENDED SEDIMENT CONCENTRATIONS IN OCEAN AND LABORATORY WAVES

conditions are very different from those in the surf zone. However, much data, and empirical and theoretical development are available from unidirectional flow studies which will provide useful concepts, relationships and ideas to test out in surf zone studies.

Longshore Transport Rate From Suspended Sediment Data

Figure 12, discussed in the two paragraphs above indicated the relationship between representative concentrations of suspended sediment and their respective wave height squared (a wave energy parameter). A further and interesting use of the CERC field and laboratory data on suspended sediment may be made by approximating longshore transport rates for comparison with the transport rates indicated by the TR-4 design curve of longshore wave energy flux versus longshore transport rate.(6) Computations may be made by a formula developed by Galvin and included in his abstract at the 12th Conference on Coastal Engineering.(7) This formula is as follows: $Q = DgcT(\beta H_b)^2 \sin \theta_b$, where g is gravity, c is suspended sediment concentration in ppt by volume, β is a wave breaker index d_b/H_b, taken as 1.3, H_b is wave breaker height, θ_b is the angle between a wave breaking crest and the shoreline and D is a coefficient equal to 11.68 which changes ft^3/sec into units of 100,000 yd^3/yr.

Seven values of the longshore transport rate have been computed, using Galvin's formula along with their corresponding longshore components of wave energy at breaking using the formula, $Ea/wave = 1/8\ \rho g H_b^2 \left(1 - M \frac{H_b^2}{L_b^2}\right) \sin \theta_b \cos \theta_b K_R^2$.(6)

In Figure 13 these seven rates and their corresponding longshore wave energies are shown as plotted points for comparison with the TR-4 design curve of longshore wave energy flux versus longshore transport rate.

Wave breaker angles used in the computations were obtained from a nomograph of d/Lo versus θ_o under the assumption that the deep water angle between wave crest and shoreline could be approximated by an average value of 30°. Wave breaker angles (θ_b) were observed in conjunction with the collection of suspended sediment samples at Ventnor, N. J. Values observed ranged from 3 to 10 degrees for low height swell waves (1-2 ft) with wave period of 7 seconds or more. Breaker angles were not observed in the collection of suspended sediment at Nags Head, N. C. Large wave tank values of θ_b are necessarily hypothetical, since this is a test facility where wave breaker angle (θ_b) is actually zero.

The plotted points of computed longshore transport rates in Figure 13 compare reasonably well with the suggested design curve. The dotted line in the figure paralleling the TR-4 design curve extends the comparison to include recent indications by Inman (8) and Das (9) that the curve should be changed to reflect rms values of wave height. The TR-4 (6) design curve (solid line) is based on the significant wave height. The author recognizes that significant though not unreasonable assumptions have been made to obtain this plot.

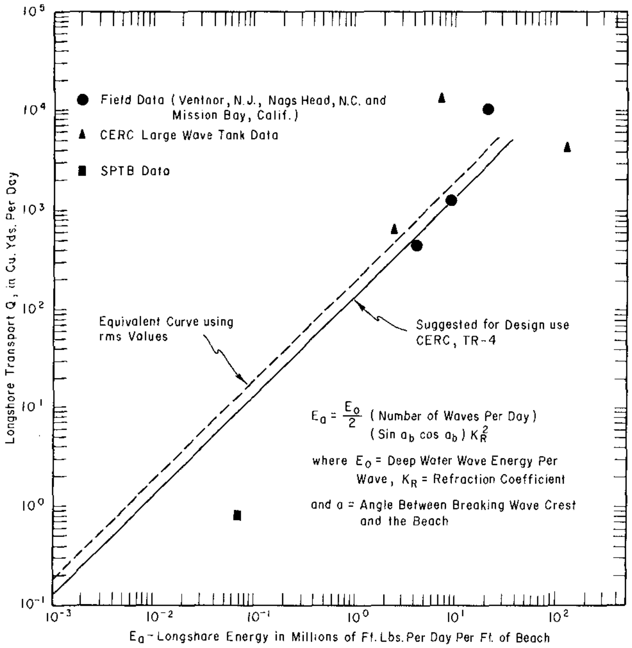


FIGURE 13. LONGSHORE TRANSPORT FROM SUSPENDED SEDIMENT DATA COMPARED TO CERC TR-4 LONGSHORE TRANSPORT CURVE

Summary and Conclusions

This paper has presented a summary of suspended sediment data from two Atlantic Coast sites with implications for its use in compiling longshore transport design criteria within the context of three main points as follows:

1. Discussion of the results from the field collections of suspended sediment at Ventnor, N. J. and Nags Head, N. C. These results show large variation in the suspended sediment concentration, but that the concentrations did depend on elevation above bottom, wave height, and position in the surf zone.

2. Comparison of these field results with earlier CERC field data (1) from Pacific Beach, California, and with CERC laboratory measurements (2) showed a trend when suspended sediment concentration was plotted against wave height squared. This comparison also included two sets of suspended sediment concentration measurements from unidirectional flow (5) - one in the Missouri River and one in a laboratory flume, under the assumption that to a first approximation the flow depth is analogous to the wave breaker height.

3. Reasonable correlation was found between longshore tranaport rates, computed from representative values of suspended sediment concentration and wave conditions, and the TR-4 design curve of wave energy flux va longshore transport rates.

The data and results presented and discussed appear to support the following conclusions:

1. Field data suggest that 3-minute averages of surf zone concentration in waves up to 4 feet high, show significant variation in concentration with elevation above the bottom. The higher the level of wave activity the less concentration varies with elevation above bottom, and hence the flatter the trend in the distribution curve.

2. Scatter configurations also suggest that for waves approaching their breaking depth, the concentration of suspended sediment rises sharply just before the wave breaks, peaking at a wave height-to-water depth ratio of about 0.78 (theoretical breaker index). Concentration then drops off more slowly shoreward of the initial wave breaking;

3. Concentrations measured in the field compare realistically with those obtained in CERC large and small wave tank tests;

4. Median size of the suspended sediment samples decreases gradually with increase in water depth and with increase in sampling elevation above the ocean bottom. There is some implication that a flatter distribution of sand size with nozzle height, as found in the smaller size Ventnor sand, may be indicative of higher concentrations for smaller more uniformly mixed sands;

5. An empirical check on longshore transport rates computed from field and laboratory data on suspended sediment compare reasonably well with the TR-4 suggested design curve.

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Data presented in this paper, Longshore Transport of Suspended Sediment, unless otherwise noted, were obtained from research conducted by the United States Army Coastal Engineering Research Center under the Civil Works research and development program of the United Statea Army Corps of Engineers. Permission of the Chief of Engineers to publish this information is appreciated. The findinga of this paper are not to be construed as official Department of the Army position unless so designated by other authorized documents.

REFERENCES

1. Watts, G. M., "Development and Field of a Sampler for Suspended Sediment in Wave Action," Beach Erosion Board Technical Memorandum No. 34, March 1953.

2. Fairchild, J. C., "Suspended Sediment Sampling in Laboratory Wave Action," Beach Erosion Board Technical Memorandum No. 115, June 1959.

3. Fairchild, J. C., "A Tractor-Mounted Suspended Sand Sampler," Coastal Engineering Research Center R. 4-66, Reprinted from Shore and Beach, June 1966.

4. Fairchild, J. C., "Suspended Sediment Concentration in the Surf Zone," Transactions Abstract (EOS), American Geophysical Union, April 1971.

5. "Sediment Transportation Mechanics: Suspension of Sediment" Progress Report, Task Committee on Preparation of Sedimentation Manual, HY 5, ASCE, Sept 1963.

6. "Shore Protection, Planning and Design," Coastal Engineering Research Center, Technical Report No. 4, Third Edition, 1966.

7. Galvin, C. J. Jr., "A Gross Littoral Drift Rate Formula," Abstracts, 12th Conference on Coastal Engineering, 1970.

8. Inman, D. L. and J. D. Frautschy, "Littoral Processes and the Development of Shorelines," Coastal Engineering, 1966, ASCE, p. 511-536.

9. Das, M. M., "Longshore Sediment Transport Rates," Coastal Engineering Research Center Miscellaneous Paper No. 1-71, Sept 1971.