CHAPTER 84

VIRGINIA BEACH SAND SIZE AS BASIS FOR DESIGN OF ON-SHORE DREDGED MATERIAL DISPOSAL

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ABSTRACT

Analyses of sand samples collected along and across the Atlantic Ocean shore of Virginia Beach, Virginia, suggest that sand placed on the shore should have a minimum median diameter of 0.20 mm to efficiently benefit the beach. Size analyses and shoreline change data show that the existing long-term beach replenishment by mechanical bypassing across Rudee Inlet and by truck-hauled sand from land sources is effective and necessary to maintain the shore along the commercial segment of Virginia Beach. The data also indicate that the northern segment of Virginia Beach shore, occupying more than half the distance between Rudee Inlet and Fort Story, is gaining sand. About two million cubic meters of sand to be dredged from the Atlantic Ocean Channel offshore of Virginia Beach will be suitable for placement on the beach.

INTRODUCTION

Background. Channel depths at the entrance to the Harbor of Hampton Roads, Virginia, are insufficient to accommodate modern, fully-laden colliers outbound from the harbor's large coal terminals at Norfolk and Newport News. Achieving sufficient depths will require dredging large volumes of sediment, including dredging the Atlantic Ocean Channel which extends southeasterly from the mouth of Chesapeake Bay (U.S. Army Corps of Engineers, 1985). Ordinarily, the most economical disposal of these dredged sediments is dumping at sea, but sand in the dredged material is a resource that might usefully be placed on nearby beaches of the City of Virginia Beach, Virginia.

At the time this work started, it was not known how much sand would be available from dredging the Atlantic Ocean Channel, and what characteristics were required to make its disposal on the beach a useful operation. The investigation under discussion differs from a typical beach fill project in that dredging will produce sand as a byproduct, and we determine if it would be beneficial to dispose of this sand on

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the beach. The costs of such disposal are not treated here, but it is anticipated that the benefiting beach would bear the differential in cost (if any), compared to the cost of dumping at sea.

This particular investigation is the fourth of five similar investigations on the feasibility of disposing sand on beaches near two Hampton Roads entrance channels. These five investigations, performed under contract by Waterway Surveys & Engineering, Ltd (WS&E) with the Corps of Engineers, Norfolk District, include disposal from Thimble Shoal Channel on Fort Story beaches (WS&E, 1984a), on West Ocean View beaches (WS&E, 1984b), and on East Ocean View beaches (WS&E, 1984c), and disposal from Atlantic Ocean Channel on Virginia Beach (WS&E, 1986a), and on Sandbridge Beach (WS&E, 1986b). Previous technical reports on this study area include the beach profile study of Goldsmith, et al. (1977), four CERC papers by Harrison and associates all dated 1964, and engineering reports related to the Virginia Beach Erosion Commission work.

Purpose. This paper analyzes sand size along and across a ten-kilometer segment of the shore at Virginia Beach, Virginia. The analysis is used to understand how coastal processes affect the beach and, given this understanding, to judge whether sand to be dredged from the Atlantic Ocean Channel may be suitably placed there. The emphasis is on beach sand from Virginia Beach. Additional details on both the beach and Atlantic Ocean Channel sediments are in WS&E (1986a).

Location. The study beach is on the Atlantic coast of Virginia, south of the entrance to Chesapeake Bay (Figure 1). It extends from the south boundary of Fort Story, southward past the residential and commercial segments of Virginia Beach, across Rudee Inlet, to Croatan Beach (Figure 2). This shore trends about 10 degrees to 15 degrees west of north and is partially sheltered by the Virginia Barrier Islands to the north-northeast (Figure 1) and shoals at the Bay entrance. The effects of this shelter on the wave climate, along with the westerly trend of the shoreline, produce a net northward longshore transport at the study beach (opposite the regional southward trend of more exposed Atlantic sites). Mean annual breaker height is less than 0.6 meters and tide range is about 1.0 meters (Table 1). The Atlantic Ocean Channel is 6 to 12 kilometers offshore of the study beach (Figure 2).

Units. Metric units are used for distances, wave heights, and sand volumes (1 km = 0.6 miles; 1 meter = 3.3 feet; 1 cubic meter = 1.3 cubic yards). Since authorized project depths are given in feet, depths are identified first in feet, and then in meters. Two vertical datums are used: Mean Low Water (MLW) for channel depths and National Geodetic Vertical Datum (NGVD) for the beach and nearshore surveys. Sand sizes are given in millimeters (mm). The conversion from mm to phi units needed to design beach fills can be found in the Shore Protection Manual (U.S. Army Corps of Engineers, 1984). The Shore Protection Manual will be indicated hereafter as SPM.

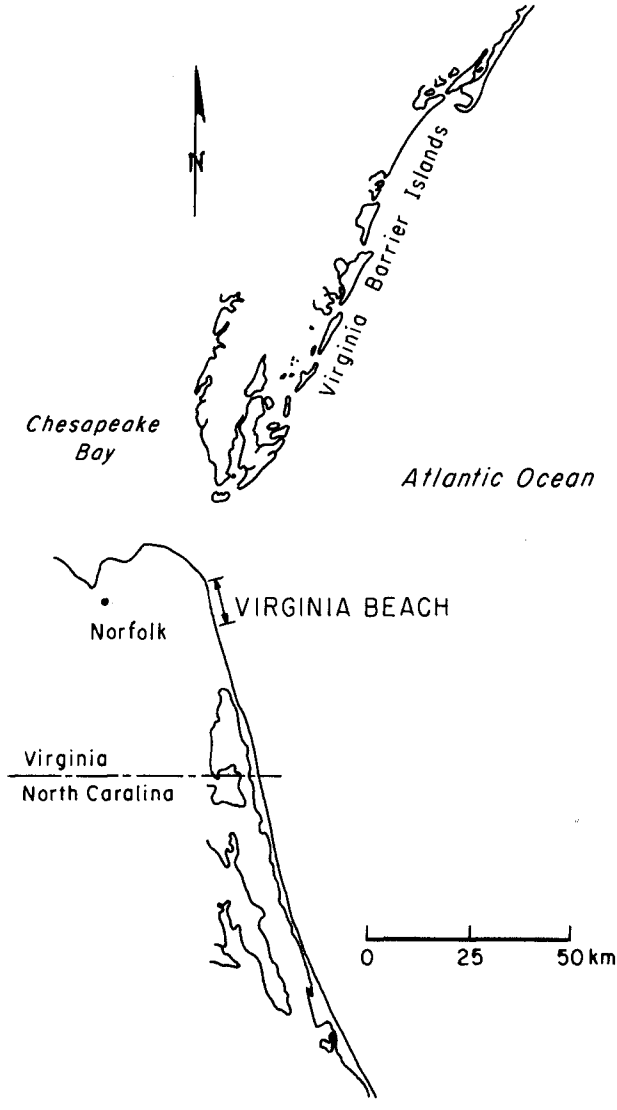

Figure 1. REGIONAL SETTING OF VIRGINIA BEACH STUDY AREA

Table 1. WAVE AND TIDE CHARACTERISTICS AT VIRGINIA BEACH*

Average Height	0.60 m	Mean Tide Range	1.0 m
Average Period	8.32 s	Spring Tide Range	1.2 m
Extreme Height (0.2%)	2.7 m	Tidal Currents (Flood)	0.26 m/s 350°
Extreme Period**	8 s	Tidal Currents (Ebb)	0.21 m/s 170°

* At 36°51'N, 75°58'W for waves (Thompson, 1977) and tide range (NOAA, 1985a); at 36°33', 75°52.1' for tidal currents (NOAA, 1985b)

** Extreme period is the wave period characteristic of the extreme height.

ATLANTIC OCEAN CHANNEL

Project depth in Norfolk Harbor Channel is -55 feet MLW (-16.8 m MLW), but due to sea conditions in the ocean, greater depths will be required in Atlantic Ocean Channel. The Corps of Engineers determined that, for the purpose of this investigation, it is assumed that the Atlantic Ocean Channel will be dredged to a depth of -62 feet MLW (-18.9 m MLW), including an allowance of 2 feet (0.6 m) for advance maintenance dredging. Channel width is taken as 305 meters.

For those design conditions, and the existing bathymetry, about 11.3 million cubic meters of sediment will be dredged from the Atlantic Ocean Channel (WS&E, 1986a).

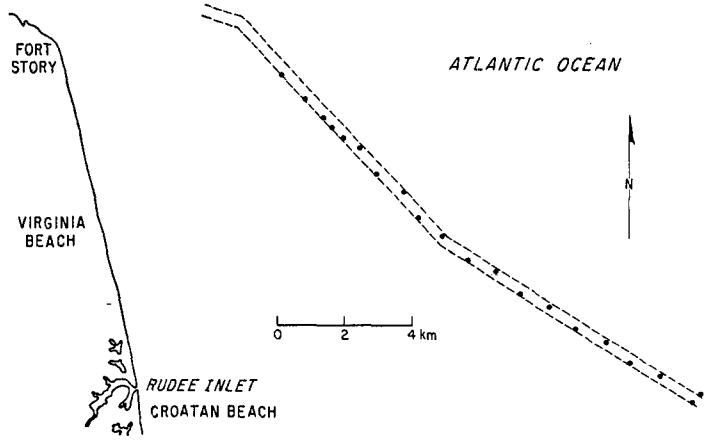

Figure 2. POSITION OF ATLANTIC OCEAN CHANNEL OFF VIRGINIA BEACH

To identify what types of material will be dredged, 21 cores were taken from the Atlantic Ocean Channel (Figure 2). Each core was logged and selected samples of the cores were sieved. These data were made available to WS&E for use in this investigation. Analysis of the logs indicates that about 54% of the material to be dredged is silty sand and sandy silt, 15% is sand and gravelly sand, 11% is a mixture of sand and silty sand, and the remainder is clay or other material.

Detailed examination of the logs and the sieve analyses indicates that about a third of the material to be dredged is sand with a median size of 0.20 mm or coarser, but at least a third of this 0.20 mm sand occurs in thin or isolated deposits that probably would not be economical to exploit, so that slightly less than 2 million cubic meters would be available for placement.

VIRGINIA BEACH

Because of the net northward longshore transport, the south end of the study beach is taken as the origin. The study beach begins at Croatan Beach, south of Rudee Inlet, even though the potential disposal area is north of Rudee Inlet (Figure 3), because Rudee Inlet interrupts northbound longshore transport. Inclusion of Croatan Beach permits an evaluation of the effect of that interruption on the reach needing the sand.

Rudee Inlet is a navigable inlet with a controlling depth of about -3 meters MLW under typical conditions. The inlet is bounded on the south by a jetty which serves as a breakwater and wier, providing shelter for a small hydraulic dredge to bypass sand coming over the wier section. A jet pump is also located north of the wier as a separate bypassing operation. The dredge and the jet pump are estimated cumulatively to bypass about 132,000 cubic meters per year (from Virginia Beach Erosion Commission, quoted in Langley McDonald, 1985). These estimates are based on hours of pumping time and an assumed concentration of sediment, rather than on direct measurement of the bypassed sand. The dredge does most of the bypassing.

North of Rudee Inlet is the highly developed 4-km commercial segment of the Virginia Beach shore where the beach is backed by a bulkhead or a seawall topped by a boardwalk. North of the boardwalk, the shore is backed by residential development and an increasingly broad strip of dunes.

The Virginia Beach shore has high value to the regional and state economy because of beach-related recreation. To maintain the beach, local and federal authorities have been replenishing the sand on a regular basis since 1951, at a long-term average rate from all sources of 190,000 cubic meters of sand per year. Sources include sand pits and stockpiles via truck hauls, and the littoral zone via dredging and the jet pump in Rudee Inlet. In the five years, 1981 through 1985, the average replenishment increased to about 260,000 cubic meters per year

(replenishment rates calculated from Langley McDonald, 1985). Placement by truck haul is usually done in the spring, and was done in April and May 1985, five months before the surveys and samples of this investigation. The dredge and jet pump operate intermittently all year.

The replenishment has had a marked effect on the condition of the beach, as can be seen by analyzing the shoreline change data of Everts, et al. (1983). Results of this analysis are shown in Figure 4 where the horizontal axis is distance north of Croatan Beach and the vertical axis represents accretion or erosion rates (erosion is negative). The long-term rate of change (1859-1980) is determined largely by conditions

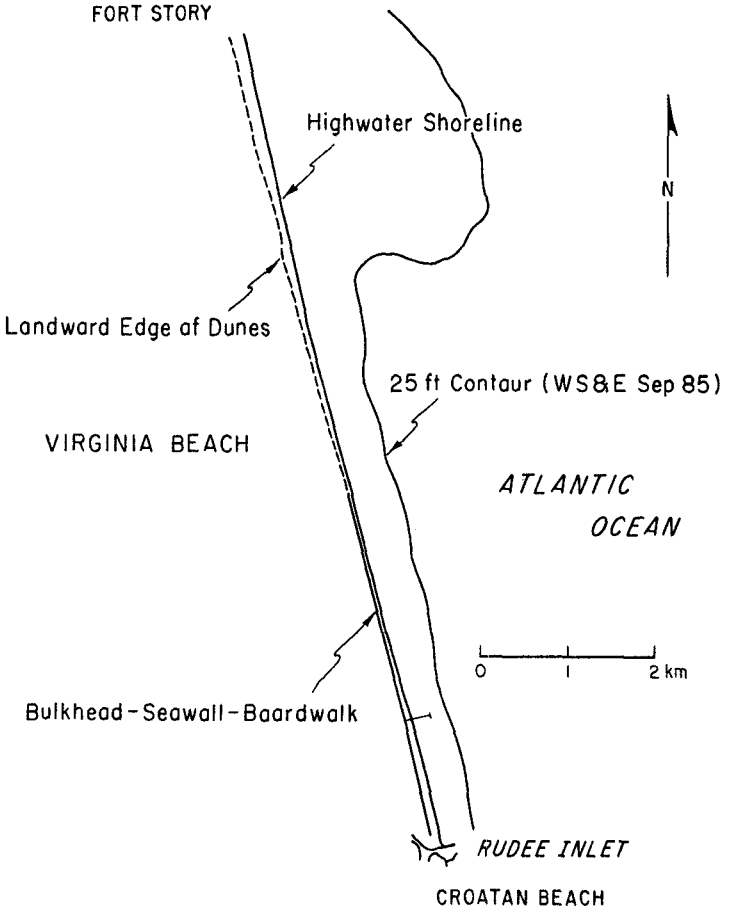

Figure 3. BOUNDARIES OF STUDY AREA

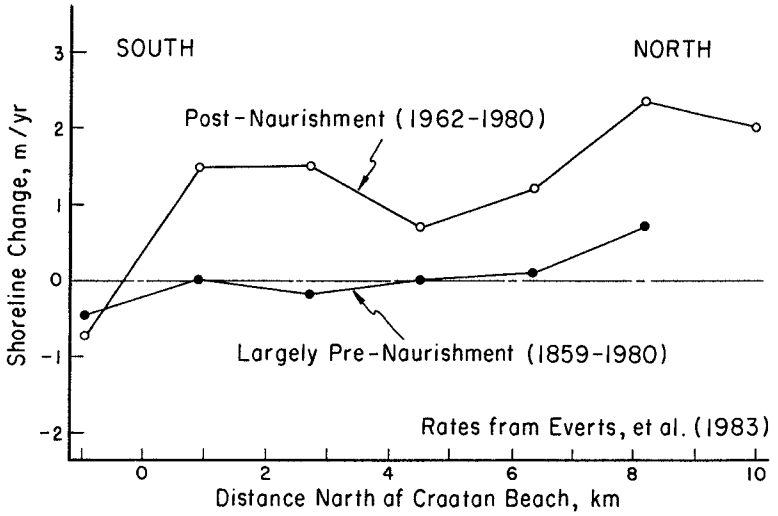

Figure 4. LONG-TERM RATES OF SHORELINE CHANGE

predating the beach replenishment, and the recent rate (1962-1980) is determined by conditions since the start of replenishment. The replenishment period clearly coincides with the onset of significant accretion (Figure 4).

The bathymetry offshore of Virginia Beach has a relatively normal slope from the shoreline to a depth of about -8 meters MLW (-25 feet MLW, Figure 3). At and seaward of this depth, the slope becomes unusually flat, typically 1 in 2000 for distances of at least 3 km. At the north end of the study area, there is a wide shoal (Figure 3) marked by the 25-foot depth contour. The origin of this shoal is probably related to the northward net longshore transport at Virginia Beach interacting with the tidal regime at the entrance to Chesapeake Bay. Whatever its origin, the shoal tends to shelter the study area from the full extreme of the Atlantic Ocean wave climate. This shoal may be responsible for the higher rates of accretion to the north of the study area in Figure 4.

The dimensions of the beach and the nearshore bathymetry are summarized on Figure 5, which is derived from surveys of profile lines performed by WS&E in late September and early October 1985. The horizontal axes of the figure indicates the relative south-to-north position of the surveyed profile lines, with tick marks indicating the even-numbered profile lines. The vertical axis of Figure 5 varies with the symbol, as discussed below.

Backshore width is indicated by open triangles on Figure 5, with each tick mark on the vertical axis equal to 50 feet (15.3 m). As

shown, backshore is widest at the north and south ends of the study area, but is absent over much of the central and southern half of the shore, in agreement with the history of erosion there.

Berm elevation is indicated by the filled triangles, with each tick mark equal to 5 feet (1.5 m) elevation above NGVD datum. The majority of the surveyed berms are at an elevation of about 2.0 to 2.2 meters (NGVD), with a tendency to be somewhat lower in the south and higher in the north.

Foreshore slope is indicated by open squares, with each tick mark on the vertical axis equal to 0.05. The range in slope is from about 0.05 in the south to between 0.10 and 0.18 in the northern half of the study area.

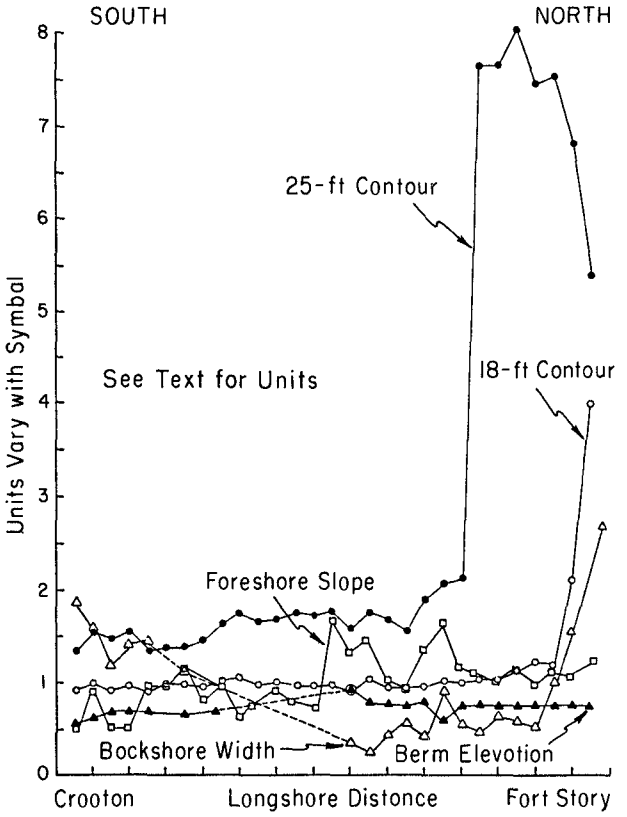

Figure 5. PROFILE CHARACTERISTICS AT VIRGINIA BEACH

The open and filled circles indicate distance to the -18 and -25 foot NGVD depth contours (-5.5 and -7.6 m), with each tick mark equal to 500 feet (153 m) from the shoreline. The abrupt seaward displacement of the contours off the north end of the study area indicates a relatively flat bottom where small changes in vertical elevation produce large changes in position of the contour.

SAND SIZE DISTRIBUTION

Experience with this and related sites (Ramsey and Galvin, 1977) suggests that sand on the typical beach profile can be adequately sampled from locations indicated on Figure 6 by surface grab samples taken during surveying. All 29 profile lines were sampled at the foreshore, and 11 of the 29 profile lines were sampled at the six sites indicated on Figure 6. A total of 86 surveyed samples were obtained in this way and sieved. Their median sand size is summarized in Table 2. A qualitative visual description of each sample is given in Appendix B of WS&E (1986a).

Figures 7 through 12 show longshore distributions of sand size for each of the six sample locations on Figure 6, beginning with the offshore sample (Figure 7) and moving landward to the foredune sample (Figure 12). The axes of these six figures are identical. The horizontal axis is distance north from Croatan Beach, in km. The vertical axis is sand size, in mm. Each figure shows three lines. The middle line is the D_{50}, or median, grain size of the sample; the top line is the size at which 16 percent of the sample is coarser; and the bottom line is the size at which 84 percent of the sample is coarser. The 16 and 84 percent sizes are shown because they are required for SPM beach fill design (in phi units).

Examination of the six figures shows similarities and differences in size from the different sample locations. The samples from offshore (-10 feet or -3 meters) are the most uniform in the longshore direction, have the lowest median size (about 0.18 mm), and the narrowest spread between D_{16} and D_{84}. The samples from the low tide terrace (Figure 8) and just seaward of the foreshore (Figure 9) tend to be more variable in the longshore direction, and show somewhat greater median sizes than the offshore samples, with a greater spread between D_{50} and D_{16} than between D_{50} and D_{84}, perhaps due to shell fragments and pebbles.

For nearly eight kilometers of the 10-km study beach, the foreshore samples (Figure 10) increase northward in median size. This is somewhat unusual in that size usually decreases in the downdrift direction. Several of the foreshore samples have the D_{50} size closer to the D_{16} size than to the D_{84}, a condition which is relatively uncommon in the population of sand samples. The mid-berm (Figure 11) and backshore (Figure 12) size distributions are similar to each other in overall shape, and differ from the foreshore size distribution (Figure 10). The similarities between mid-berm and backshore are shown by their relatively constant D_{50} and D_{84} sizes in the longshore direction and by the variation in D_{16} sizes (both have relatively high values of D_{16} between kilometers 1 and 4 and at kilometers 9 and 10). The dune samples tend

Table 2. SUMMARY OF MEDIAN SAND SIZE

Distance North of Croatan Beach, km	Median Size, D_{50}, mm					
	Foredune	Mid-Berm	Foreshore	Seaward of Foreshore	Low Tide Terrace	10-Ft Depth
0.0	0.34	0.32	0.38	0.57		
0.2						0.19
0.3	0.23	0.25	0.22	0.18	0.27	0.20
0.7			0.25			
1.0			0.22			
1.2			0.37			
1.5	0.30	0.33	0.22	0.16	0.17	0.17
1.6			0.22			
1.7	0.32		0.21			
1.8		0.30	0.22	0.17	0.21	0.16
2.0			0.24			
2.2			0.25			
2.5			0.31			
2.8			0.27			
3.0	0.25	0.38	0.26	0.35	0.30	0.17
3.3			0.33			
3.6			0.39			
3.8			0.34			
4.1	0.42	0.36	0.37	0.26	0.35	0.19
4.4			0.39			
4.8			0.39			
5.1			0.45			
5.5	0.25	0.35	0.48	0.47	0.18	0.18
5.8			0.45			
6.2			0.84			
6.6			0.70			
7.0	0.30	0.30	0.50	0.26	0.20	0.16
7.3			0.80			
7.5			0.28			
7.8			0.38			
8.2	0.25	0.27	0.36	0.35	0.34	0.15
8.8	0.38	0.44	0.43	0.20	0.24	0.16
9.5	0.30	0.48	0.27	0.53	0.17	0.16

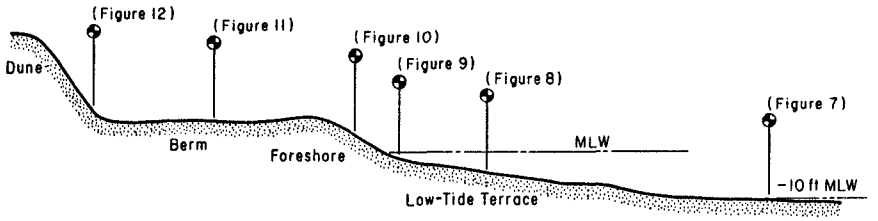

Figure 6. SAND SAMPLE LOCATIONS ON IDEALIZED PROFILE

to have slightly finer D_{50} sizes than the mid-berm samples, being finer in seven of the ten samples north of Rudee Inlet (Table 2), which is consistent with a slight amount of wind sorting.

The overall trends in D_{50} are compared in Figure 13 for the offshore, foreshore, and mid-berm samples. This figure shows clearly the relatively low and constant values of D_{50} found offshore, the higher and relatively constant values of D_{50} on the berm, and the unexpected northward increase of D_{50} on the foreshore.

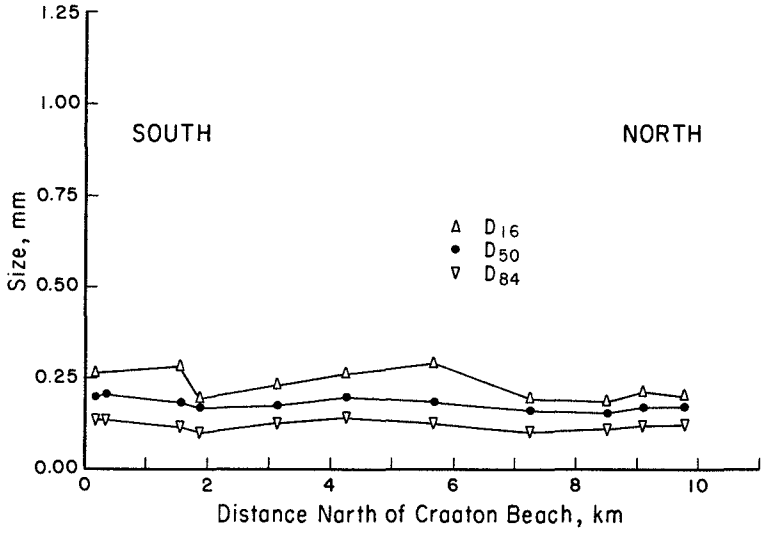

Figure 7. SAND SIZE AT 10-FOOT DEPTH

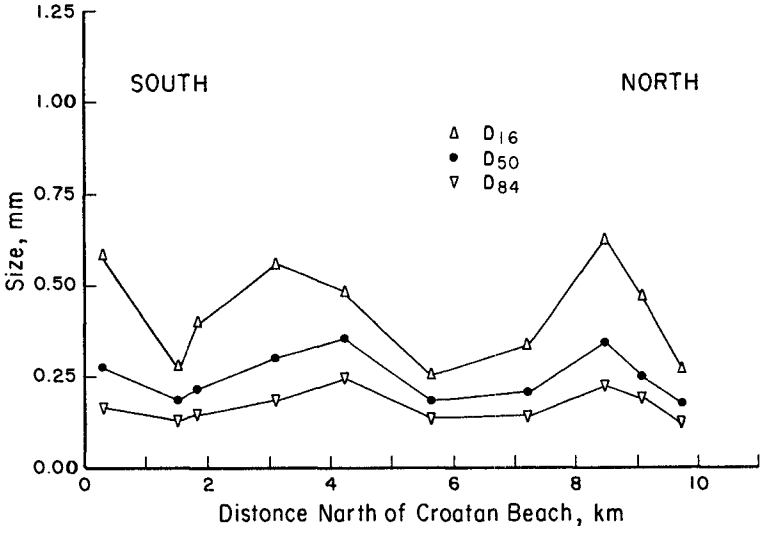

Figure 8. SAND SIZE ON LOW TIDE TERRACE

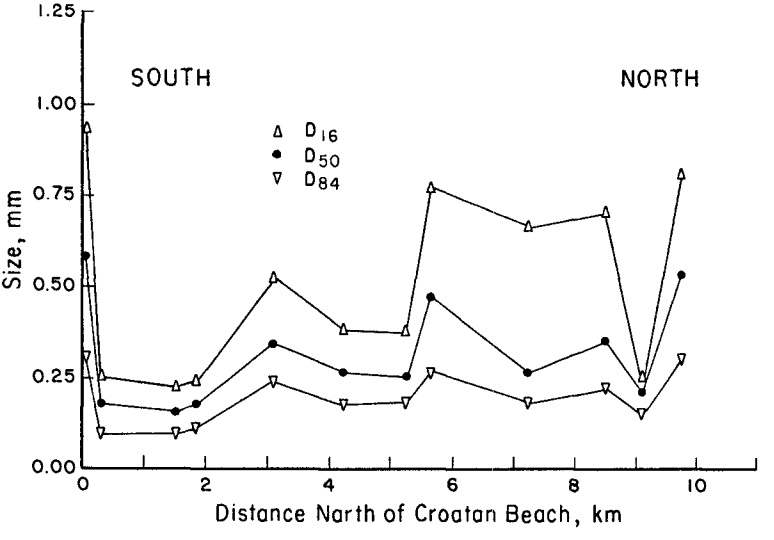

Figure 9. SAND SIZE JUST SEAWARD OF FORESHORE

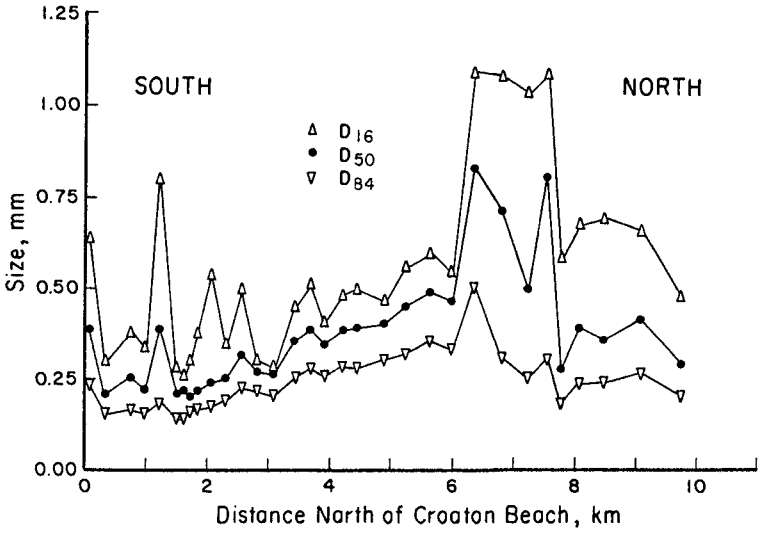

Figure 10. SAND SIZE ALONG FORESHORE

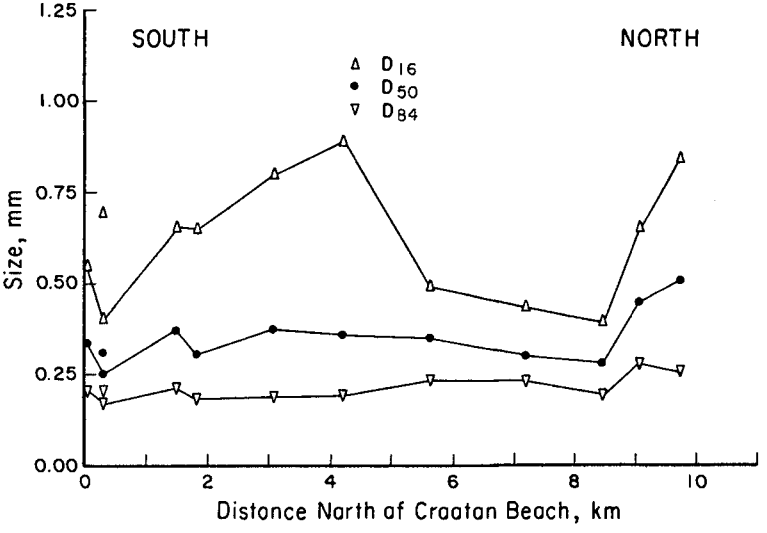

Figure 11. SAND SIZE AT MID-BERM

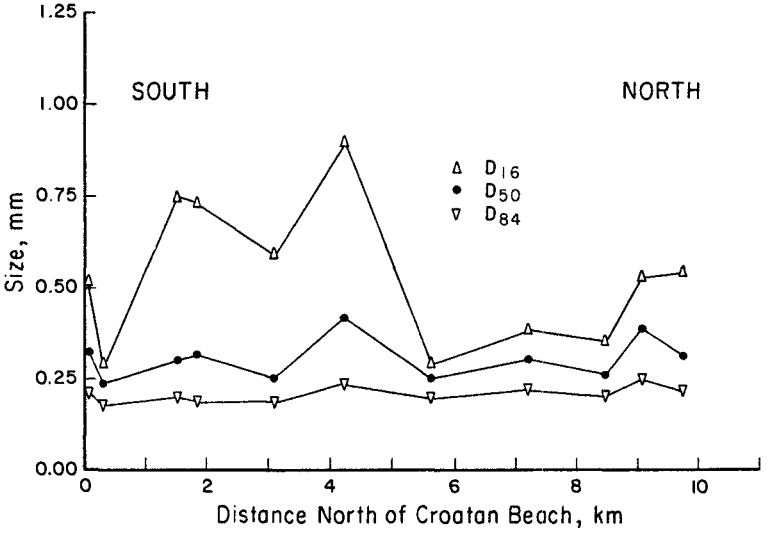

Figure 12. SAND SIZE AT BACKSHORE (TOE OF FOREDUNE OR IN FRONT OF BOARDWALK)

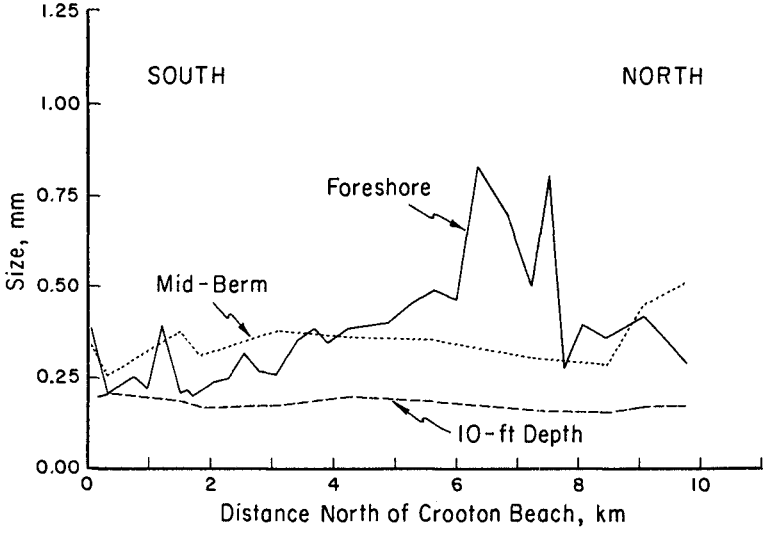

Figure 13. ACROSS-SHORE VARIATION IN SAND SIZE

INTERPRETATION

There are four classes of data which should be integrated for a consistent interpretation of how coastal processes will affect disposal of Atlantic Ocean Channel sand on the study beach. These four include the shoreline change rates (Figure 4), beach replenishment amounts and dates (Langley McDonald, 1985), the profile characteristics (Figure 5), and the sand size distribution along and across the beach (Table 2, Figures 6 through 13).

Bypassing experience clearly indicates net longshore transport is from south to north. Thus, a south placement will get most use from the sand. The shoreline change data indicate erosion has (historically) been greater in the south, which also suggests disposal in the south. The existence of Rudee Inlet at the south end of the study beach suggests that placement should be north of its immediate zone of influence, to avoid shoaling in the inlet.

None of 54 sand samples from the subaerial beach had a D_{50} size less than 0.21 mm (see backshore, berm, and foreshore in Table 2). Only 6 of 21 samples from immediately seaward of the beach had a D_{50} size less than 0.20 mm (see seaward of the foreshore and low tide terrace in Table 2). In contrast, at the ten-foot depth, the highest D_{50} in eleven samples was 0.20 mm (one sample), and the average of the eleven samples was 0.17 mm.

These size data are interpreted to mean that, under prevailing conditions at Virginia Beach, sand must have a D_{50} of at least 0.20 to remain on the subaerial beach, i.e., to add to that part of the beach used in calculating economic benefits. This interpretation is supported by closer analysis of the foreshore size distribution on Figure 10. The foreshore at Croatan Beach, which is the first sample plotted on the left end of Figure 10, has a D_{50} of 0.38 mm and is the only sample south of Rudee Inlet. Of the first ten foreshore samples north of Rudee Inlet, only one is coarser than 0.25 mm. This abrupt drop in foreshore sand size from one side of the inlet to another is interpreted as an effect of the bypassing by dredge and jet pump; these bypassing operations withdraw sand from below water in the inlet (the inlet sand size is the first point on Figure 7) and discharge it on the foreshore north of Rudee Inlet. Since the below-water sand is shown to be fine, the sand discharged on the foreshore will be relatively fine. The distribution on Figure 10 shows this. This interpretation is relatively consistent with profile characteristics on Figure 5, where both foreshore slope and berm elevation are lower in the south end of the study area, as expected from finer sand beaches.

The position of the 25-foot contour (Figure 3 and Figure 5) coincides with the higher long-term accretion rates at the north end of the study area (Figure 4). It is somewhat puzzling that the subaerial beach at this site also has the coarsest sand (Table 2). However, the data are consistent if the offshore shoal represents the finer fraction winnowed from the sand carried northward by longshore transport and the

subaerial beach is the residual coarse material. At any rate, it is clear that the north half of the study beach is not in need of replenishment.

CONCLUSIONS

a. The best location to place suitable sand from the Atlantic Ocean Channel is in the south half of the study area, approximately in the segment from kilometer 1 to kilometer 4 on the horizontal scale used for Figures 7 through 13.

b. Efficient beach replenishment will require sand that has a median (D_{50}) size of at least 0.20 mm, when placed on the beach.

c. Design berm heights should be about 2.1 m above NGVD and expected foreshore slopes will be about 0.05 to 0.10, depending on the coarseness of the sand placed there.

d. Size analyses of surface grab samples from along and across the study beach provide simple but strong constraints on beach disposal design.

Acknowledgements. This paper is based on work done under contract DACW65-85-D-0037 with the Norfolk District, U.S. Army Corps of Engineers (see WS&E, 1985a, in References). The Project Manager for the earlier work was Richard Klein, Waterways and Harbors Section, Norfolk District. Data collection and analysis were assisted by James L. Overton, Mark Ricketts, Robert Taliaferro and Naren Tayal. Greg Hamadock, Law Engineering (McLean Branch), supervised the analysis of the beach sand. Herbert J. Bruder prepared all illustrations and Sheila Zukor typed several versions of the manuscript. Preparation of this report was paid for by the firms of Cyril Galvin, Coastal Engineer and Waterway Surveys & Engineering, Ltd.

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