SOFT DESICNS FOR COASTAL PROTECTION AT SEABROOK ISLAND, S.C.

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ABSTRACT

To gain a better understanding of the cycles of shoreline changes on Seabrook Island, South Carolina and advise a private developer on how to deal with localized erosion problems, a detailed field survey and historical study were completed. The data base included historical charts dating from 1661, vertical aerial photographs from 1939, field surveys of beach profiles and nearshore bathymetry over a six-month period, and sediment cores through the entire Holocene section. Seabrook Island, less than 6 km in length, is bounded by tidal inlets with extensive seaward shoals. With a 2 m tidal range for the area, changing exposure and orientation of the shoals over time has had a profound effect on the adjacent shoreline of Seabrook Island. Historical evidence points to the importance of offshore shoals which act as natural breakwaters and sediment storage systems. At various times in recent history, these shoals have supplied sediment to Seabrook beaches by means of bypassing mechanisms around tidal inlets. On the other hand, migration of shoals has allowed excess wave energy to strike portions of the shore causing local erosion. Along a portion of the shoreline, short-term erosion is jeopardizing the development. Based on the present study, a set of "soft" engineering designs was proposed which attempt to manipulate offshore sand bodies in a way that will be beneficial to the development and preserve the inherent beauty of the shoreline. Remedial measures recommended for the developer included dredging new inlet channels and construction of a breakwater in the position of a former protective shoal.

INTRODUCTION

Seabrook Island near Charleston, South Carolina, U.S.A. (Fig. 1) is a typical mesotidal (tidal range 2.0 m) barrier island consisting of vegetated beach ridges and low frontal dunes bounded by tidal inlets and a marsh-tidal creek system. Within the past 5 years, it has been developed as a private vacation resort. Due to its proximity to a major tidal inlet and the presence of numerous shifting offshore shoals, the ocean shoreline has tended to change rapidly in response to local variations in wave energy. This has presented significant problems to portions of the existing development. Several homes and the community center are located in erosion zones and have required seawalls or rubble mound rip-rap for protection; whereas, some nearby beaches are presently accretional.

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While coastal protection works are providing immediate relief to certain highly erosional areas of the development, they are causing long-term adverse effects, including acceleration of erosion in unprotected areas and destruction of the natural character of the island. This latter effect is of great concern since the key attraction of this and other South Carolina coastal developments is their unspoiled beaches.

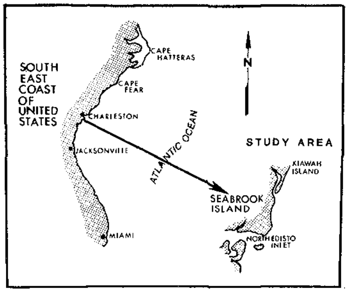

Figure 1. Location map of Seabrook Island, S. C. (30 km south of Charleston, S. C.).

To gain a better understanding of the cycles of shoreline changes on Seabrook Island and advise the development company on how to deal with localized erosion problems, a detailed field survey and historical study were completed. Solutions were sought which would allow natural sedimentation processes of the adjacent inlet shoals and beaches to work in harmony with proposed engineering modifications. Large volumes of sand are stored in the ebb-tidal deltas (outer shoals) of the inlets at either end of Seabrook Island. It was hypothesized that manipulation of these shoals would modify the distribution of wave energy along the shore and reduce or eliminate the erosion problem. Thus, the approach taken was to utilize geologic and coastal process information and determine appropriate "soft" engineering solutions which would have the aesthetic advantage of preserving the character of the Seabrook beaches.

DATA BASE

A combination of laboratory analysis of historical data and a variety of field observations completed during a six-month period between June and December, 1978 are available. The data base included:

1. Historical charts from 1661, 1853, 1867, 1919, and 1914.

1. Vertical aerial photographs from 1939, 1949, 1954, 1957, 1963, 1973, and 1978.

3. Nine permanent beach profile stations monitored monthly for six months.

4. Monthly wave process data at 8 stations (wave height, breaker angle, longshore currents, and wave period).

5. Monthly surveys of two cross-sectional bathymetric profiles of N. Edisto Inlet (Fig. 1).

6. Preparation of a detailed bathymetric map of the seaward shoals of the inlet.

7. Sediment cores through the entire Holocene section along two transects across Seabrook Island.

COASTAL PROCESSES

Winds

Seabrook Island is influenced by prevailing winds from the SW (36% of the time) and storm winds generally from the NE (28% of the time). In general, the NE winds, though less frequent, are stronger, causing waves and longshore transport directed SE along the island. Hurricane force winds have a return period of approximately one event every 14 years (Myers, 1975). While hurricanes are relatively rare along this portion of the South Carolina coast, they have been known to cause extensive damage to property from high winds and associated storm tides.

Tides and Storm Surges

The mean tidal range at Seabrook Island is approximately 1.7 m (5.2 feet), with spring tides ranging up to 2 m (6.1 feet). These tides generate strong currents in North Edisto Inlet (south end of Seabrook) and Kiawah River Inlet (north end of Seabrook) as well as in major tidal creeks. This moderately large tidal range allows a wide portion of the beach to be exposed to wave action. Storm surges superimposed on normal astronomic tides occur during extratropical and tropical storms and have produced tides up to 12 feet (3.7 m) above normal along the South Carolina coast.

Waves

Wave energy along the Seabrook Island shoreline varies widely due to a combination of factors, including: 1) the direction of wave approach whether from the E or SW, and 2) the position of offshore shoals. The intertidal shoals act to dampen waves, reducing wave heights along the corresponding lee shore. This has an important effect on the distribution of sediment transport along the coast since longshore transport is related to wave energy and the angle of wave approach.

Between June and December 1978, representative monthly wave measurements were obtained at 8 stations on Seabrook Island (Fig. 2). Although these data are not detailed enough to establish a seasonal trend, they allow comparison of relative wave energy at various points along the shore. Variables measured included wave height, breaker angle, longshore current velocity, and wave period.

Average wave heights ranged from a low of 11 cm at P8 in October to a high of 80 cm in July at station 3 located near the development's clubhouse. The bar graph inset in Figure 3 shows the average distribution of wave heights. Note that the highest average waves occur at stations 3 (49 cm) and 6 (42 cm), both of which are presently experiencing the most severe erosion. The wide variance in wave heights along the shoreline results from a combination of factors including: (1) the direction of wave approach, whether from the east or southwest, and (2) the position of offshore shoals. The intertidal shoals act to dampen waves, reducing wave heights along the corresponding lee shore. For example, stations 2, 5, and 8 are relatively protected by offshore shoals, accounting for their reduced average wave height; whereas, stations 3 and 6 are more exposed.

Longshore Transport

The variability in wave heights along the Seabrook Island shoreline produces different rates of longshore sand transport. This has important consequences to shoreline changes because where transport is reduced, as along lee shores protected by offshore shoals, sand accumulates. At Seabrook Island, two wave directions are most common. During summer, waves from the southwest and south produce longshore transport northeast along the beach. Storms, on the other hand, generally cause sand transport to the southwest. When averaged over the entire year, more sand moves southwest under the influence of storm waves. This fact is evident at Kiawah Island, located north of Seabrook, where a large recurved spit at the southwest end of the island continues to grow rapidly toward Seabrook as a result of the influx of sand from the north.

To determine relative transport rates, wave data from the 8 process stations were used to estimate daily longshore transport. These data do not indicate long-term rates, but they offer an explanation for the erosional and depositional trends discussed in succeeding sections.

Figure 3 gives the average daily transport rates at each of the 8 process stations, based on monthly wave observations between June and December. Highest transport rates occur at stations 3 and 6, which are least sheltered by offshore shoals and which have higher than normal erosion rates. The range of equivalent yearly rates are 75-300 x 10^3 m^3/year.

Modification of Coastal Processes by Artificial Structures

Coastal structures existing in 1978 at Seabrook Island included: (1) sand bag groins designed to trap sediment moving alongshore, (2) vertical poured-concrete seawalls to protect a clubhouse at station 3 and houses between stations 4 and 5, and (3) rubble mound rip-rap to anchor the shoreline between stations 2 and 3 (Fig. 4).

Sand bag groins. - The groins at Seabrook trapped some of the sand moving alongshore and initially caused minor reorientation of the shoreline as fillet beaches developed on the updrift (northeast) side and erosion on the downdrift side. However, after the reorientation to a new "equilibrium" shoreline, the erosional trend continued at stations 3 and 5 despite the presence of these groins.

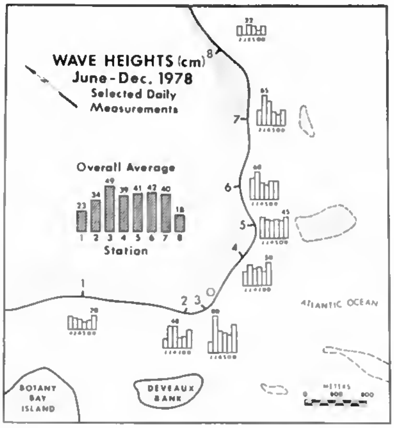

Figure 2. Distribution of wave heights measured monthly from June to December 1978 along Seabrook Island. Highest waves (inset) occur at station 3 at the southwest point of the island.

Figure 3. Net and (gross) longshore transport rates along Seabrook Island based on wave energy flux. Highest net rates at stations 3 and 6 correspond to erosion zones at the time of the survey.

Figure 4. Oblique aerial photograph taken in 1978 of the southwest point of Seabrook Island. View looking southwest. Note coastal structures, including a groin, seawall, and revetment built to protect a community clubhouse. Erosion of the adjacent shoreline has produced the shoreline offset.

Concrete seawalls. - The vertical seawalls at Seabrook have protected several houses and the clubhouse by retaining sand behind them. However, they have had some adverse effects including an apparently accelerated erosion along adjacent shorelines. Vertical seawalls also reflect wave energy back offshore rather than absorbing or dissipating it. This tends to cause scour and remove sediment from the nearshore area.

Rubble mound rip-rap. – The rip-rap built between stations 2 and 3 has been more successful than the vertical seawalls since it absorbs much of the wave energy and reduces the scouring effect of reflected waves. Its main disadvantage is eliminating a recreational beach if erosion continues. While protecting property, the rip-rap seawall at Seabrook is not solving the long-term problem of continued erosion due to lack of sediment supply from updrift.

SHORELINE CHANGES

Historicsl Charts and Maps

In order to learn about the more recent short-term shoreline changes on Seabrook Island, all charts and maps available were ssembled and studied. Particular attention was placed on the changing location of shoals and inlet channels. Five historical charts were available covering the period 1661 to 1924. One example, from 1867, is shown in Figure 5. Key reference points were located on each chart to estsblish shoreline and tidal inlet positions. It became apparent that two points warranted attention: 1) the spit at the southwest end of Kiawah Island which periodically overlapped much of the shoreline along Seabrook Island, and 2) an offshore supratidal shoal, referred to as Deveaux Bank, associated with the ebb delta of North Edisto Inlet which borders the southwest end of Seabrook.

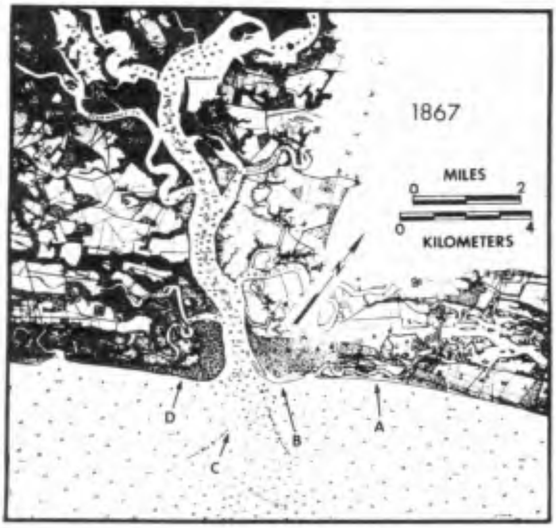

Figure 5. Bathymetric chart for 1867 (USC & GS Chart No. 154, Ed.1). Arrows indicate points of reference for comparison between charts. Note extension of recurved spit of southern end of Kiawah Is. at A.

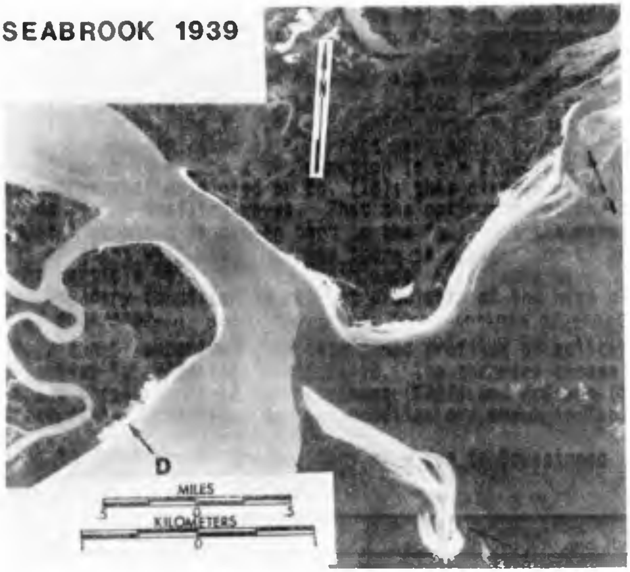

Figure 6. Mosaic of vertical aerial photographs for 1939 (National Archives). Note position of Kiawah spit at A and seaward extension of Deveaux Bank at C. Deveaux Bank effectively blocked all deepwater wave energy arriving from the south.

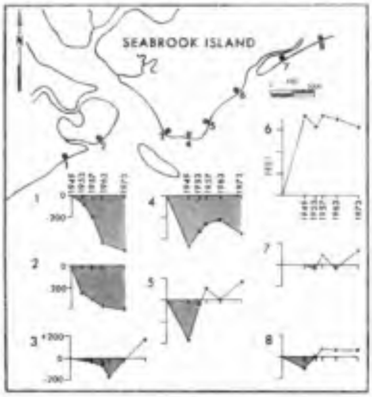

Figure 7. Erosion-deposition graphs for Seabrook Island, covering the period between 1939 and 1973, based on aerial photos (modified from Stephen *et al.*, 1975). Accretion is positive (up) on graphs. Units are in meters. Note considerable shoreline instability at all stations.

Vertical Aerial Photographs

A sequence of vertical aerial photographs was obtained, covering the period 1939 to 1973. These, of course, provide much greater detail of the shoreline changes of the island than the older maps and charts. Unfortunately, no detailed bathymetric surveys were conducted during the interval between 1934 and 1978. An example from 1939 is shown in Figure 6. Based on this sequence of aerial photographs, Stephen et al. (1975) constructed graphs of erosion-deposition trends for the island (Fig. 7). Historical shoreline changes dating to 1853 are shown in Figure 8. Note that Seabrook was largely accretional until 1973.

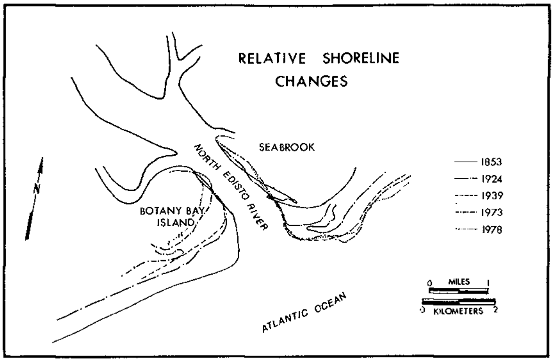

Figure 8. Relative changes of the shorelines of Seabrook and Botany Bay Islands between 1853 and 1978.

Changes of Kiawah River Inlet

The maps, charts, and aerial photographs studied indicate that the recurved spit affiliated with the Kiawah River undergoes a cycle of change that has occurred at least four times since 1661. The cycle (Fig. 9) includes:

(a) breaching of the spit at the neck (where Kiawah River crosses the island perpendicularly) during a major storm;

(b) migration of the spit southwestward at the rate of approximately 30.5 m (100 ft.) per year;

(c) extension of the spit up to as much as the entire distance from the spit neck to the southwest end of Seabrook Island; and

(d) breaching of the spit by another storm.

As the spit-inlet complex migrates, the affiliated ebb-tidal delta complex migrates with it. As waves refract around the moving ebb-tidal delta, the beach downdrift of the inlet tends to build out.

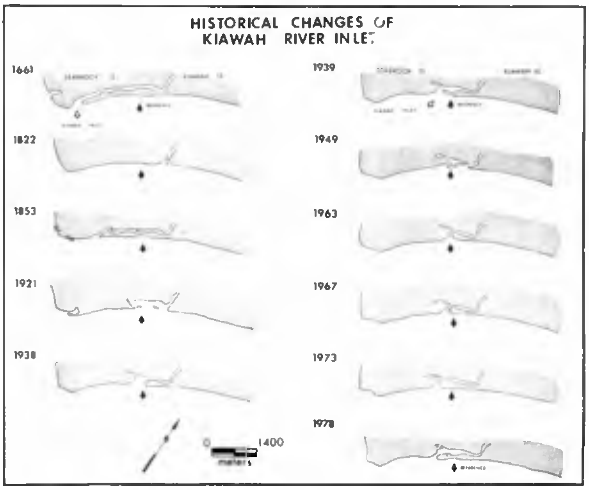

Figure 9. Historical changes of Kiawah River Inlet since 1661. Note cyclic response of spit growth over time (modified after Hayes et al., 1975)

Changes of Deveaux Bank

One of the most important discoveries of the historical analysis was the fact that Deveaux Bank has retreated a phenomenal amount since 1939 (over 1000 m ([illegible],030 ft.)). From 1939 to approximately 1970, Deveaux Bank was an effective natural offshore breakwater that sheltered the shoreline in the vicinity of the southwest point from direct wave attack. In recent years, however, the bank is too far landward to provide this protection, a fact which has, no doubt, contributed significantly to the increased rate of erosion of the Seabrook shorefront. In recent years, the rate of erosion appears to have accelerated. Figure 10 shows the changes to Deveaux Bank, and Figure 11 is a photograph of the bank in 1978 at the time of the present study. The supratidal portion of the bank underwent rapid landward migration and erosion. The small intertidal shoal remaining in the former location is relatively ineffective in blocking wave energy at high tide.

Bathymetric Surveys

Since the study area is located adjacent to North Edisto Inlet, one of the largest tidal inlets on the South Carolina coast, bathymetric surveys of the main channel were compared from historical re-

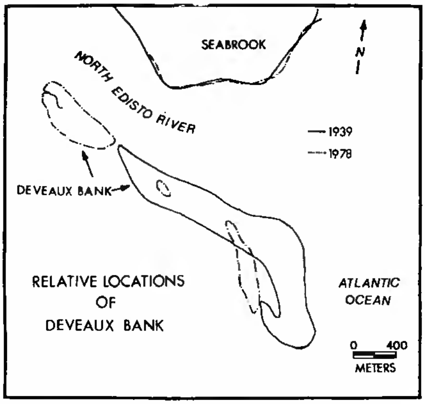

Figure 10. Comparison of aerial extent of Deveaux Bank between 1939 and 1978. The center of the bank retreated 1500 m (4922 ft.), and the bank decreased to roughly one fourth its original size between 1939 and 1978.

Figure 11. Oblique aerial photograph of Seabrook (foreground) and Kiawah Islands, taken on 7 December 1978. Note position of Deveaux Bank (foreground), located 1500 m landward of the 1939 position. View looking northeast.

cords to determine if the channel had migrated north. Such channel migration would undoubtedly contribute to erosion of the adjacent shoreline. However, the surveys found no evidence to suggest channel meandering was occurring in the vicinity of the southwest point. There was evidence, however, that the northern marginal flood channel (a secondary channel dominated by flood currents) which flanks the main channel had shifted slightly landward toward the southwest point. This probably helped cause the observed increase in erosion.

CAUSES OF EROSION

The historical evidence indicates that until 1973, Seabrook Island had undergone long-term accretion. This indication that Seabrook Island is basically a regressive barrier (seaward building) in a geological sense, as well as the fact that tremendous volumes of sand are stored in the North Edisto ebb-tidal delta complex (roughly ½ the volume of the sand stored in the entire Kiawah-Seabrook barrier island complex) (Hayes et al., 1976), suggests that localized erosion problems at Seabrook are reversible. It is primarily a matter of inducing an adequate amount of the sand available in the area to reside on the beach.

The foregoing analysis suggests the following major causes of shoreline change along Seabrook Island:

1. Southerly migration of the updrift (Kiawah River) inlet and inlet-affiliated ebb-tidal delta which causes erosion along the inlet shoreline and accretion in the lee of the delta.
2. Encroachment of the northern marginal flood channel of the downdrift (North Edisto) inlet against the SE point of Seabrook Island.
3. Erosion and landward migration of an offshore supratidal bank (Deveaux) which has allowed increasing amounts of wave energy to reach the shore.

Southwesterly Migration of Kiawah River Inlet

Tidal inlets are the most dynamic feature of barrier island shorelines such as the coast of South Carolina. The two aspects of this dynamic nature that are of greatest importance to coastal landowners are geographic and geomorphic instability. Geographic instability means that entire tidal inlet systems migrate in an alongshore direction. This is generally a long-term process, taking place over a period of years or decades. Geomorphic instability means that, within an inlet system at any given time, shoals, channels, and adjacent beaches are constantly changing their position and orientation. This is generally a relatively shorter-term process, taking place over a period of weeks or months. All inlets display both of these characteristics to varying degrees.

In response to the longshore transport of sand by waves, tidal inlets migrate alongshore in the direction of net longshore transport.

This is accomplished by spit accretion on the updrift side of the inlet, which forces the channel to erode the opposite bank. The history of Kiawah River Inlet is a classic example of this process, as shown by Figure 9. Note that westerly spit growth between 1924 and 1939 was interrupted in 1949 as the Kiawah River breached the neck of the spit. Since 1949, the cycle has repeated itself, and spit accretion has continued to date. Unfortunately, jetty construction to halt this geographic instability would deprive Seabrook Island of its major source of beach sand, which is material transported by waves across the mouth of the Kiawah River. The manner in which this sand bypasses the inlet comprises the geomorphic instability of the system and will be described below.

Figure 12 is a diagrammatic sketch of the short-term instability of inlets like Kiawah River. The three stages describe a process by which the inlet channel oscillates back and forth from its main point between the two islands (like a dog wagging its tail). This oscillation is simultaneous with inlet migration, so that while the inlet moves alongshore, the channel, through its outer shoals, is moving back and forth (the dog walking and wagging its tail at the same time). Beach erosion rates on the downdrift side of the inlet (the left side in the diagram -- analogous to Seabrook) are related to which stage of instability happens to be operating at a particular time. In stage two, with the bar extending, sand bypassing the inlet can remain offshore for a considerable distance before being carried up onto the beach, and downdrift beach erosion rates immediately adjacent to the inlet are at a maximum. When a new channel is cut in stage three, the entire bar migrates onto the beach which, in effect, provides a large package of natural beach nourishment material and minimizes beach erosion.

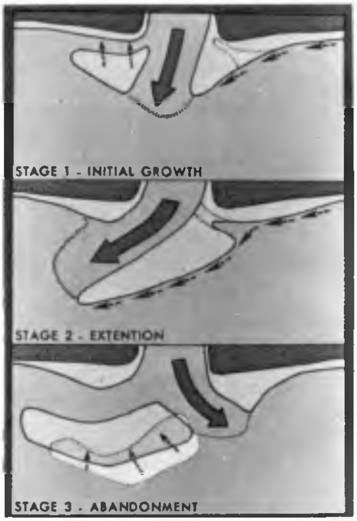

Figure 12. Diagrammatic sketch of the short-term instability of inlets like Kiawah River Inlet. Stage 1 and 2 show initial growth and extension of the ebb delta in the downdrift direction. In stage 3, channel abandonment occurs, allowing bypassing of sand onto downdrift beaches. (Diagram by Dennis K. Hubbard and Duncan M. FitzGerald.)

This process has occurred naturally at Kiawah River Inlet, as shown in Figure 13. These aerial photographs were taken over the eleven month period between March, 1975 and February, 1976. They document the evolution from the bar elongation (Fig. 13, upper) through channel abandonment (Fig. 13, middle) to eventual welding of the bar onto the beach (Fig. 13, lower). In 1978, during the present study, Kiawah River was in stage two (bar elongation).

Encroachment of Marginal Flood Channel

The large shoal system seaward of North Edisto Inlet comprises what is referred to as an ebb-tidal delta. Studies of numerous ebb-tidal deltas on the east coast of the U.S. (e.g., Finley, 1975; Hine, 1975; Hubbard, 1975) and reconnaissance studies on the coasts of Alaska, Baja California, and the Gulf of St. Lawrence by the Coastal Research Division of the University of South Carolina indicate that the morphology of these sand bodies is similar from place to place.

The components of a typical ebb-tidal delta include a main ebb channel, which usually shows a slight-to-strong dominance of ebb-tidal currents over flood-tidal currents. The main ebb channel is flanked on either side by linear bars, which are levee-like deposits built by the interaction of ebb- and flood-tidal currents with wave-generated currents. At the end of the main channel is a relatively steep, seaward-sloping lobe of sand called the terminal lobe. Broad sheets of sand, called swash platforms, flank both sides of the main channel. Usually, isolated swash bars, built by the swash action of waves, occur on the swash platforms. Marginal tidal channels dominated by flood-tidal currents, called marginal flood channels, usually occur between a swash platform and the adjacent updrift and downdrift beaches.

A well-defined marginal flood channel has existed for some time off the south-southeast end of Seabrook Island. By 1978, it had shifted toward the island at the southeast point (see aerial photograph in Fig. 11). Sediment eroded from the beach in that vicinity would be carried offshore into the channel where it is undoubtedly redistributed by the strong flood-tidal currents that exist in the channel. In 1978, it appears that the marginal flood channel was too close to the beach to allow for the natural onshore-offshore transfer of sand that normally occurs on beaches.

The Erosion of Deveaux Bank

As discussed in some detail previously, Deveaux Bank eroded over 1500 m since 1939. As the bank eroded, the area near the southwest point became more and more exposed to open ocean waves. This is probably the single most important factor in the increase of the erosion rate for that locality.

Figure 13. Bar-bypassing at Kiawah River Inlet.

Aerial photograph of Kiawah River Inlet in March, 1975. This is stage two - bar over-extension.

Aerial photograph of Kiawah River Inlet in November, 1975. Note that the channel has breached the updrift end of the bar.

Aerial photograph of Kiawah River Inlet in February, 1976, showing partial welding of the bar onto Seabrook Island. (Photograph by Dennis K. Hubbard.)

PROPOSED SOLUTIONS

Based on the above causes of erosion, a number of "soft" engineering solutions have been proposed to retard or eliminate local erosion problems at Seabrook Island. These include: 1) dredging of a new inlet channel north of Kiawah River Inlet to allow sand in the ebb delta to naturally migrate onshore at Seabrook, 2) dredging of a new northern marginal flood channel further seaward on the North Edisto River ebb-tidal delta to relieve the erosive pressure at the southeast point of Seabrook, and 3) reestablishment of a natural (or artificial) breakwater in the former position of Deveaux Bank. One possibility for the latter would be to construct a floating offshore breakwater. These solutions are outlined in Figure 14.

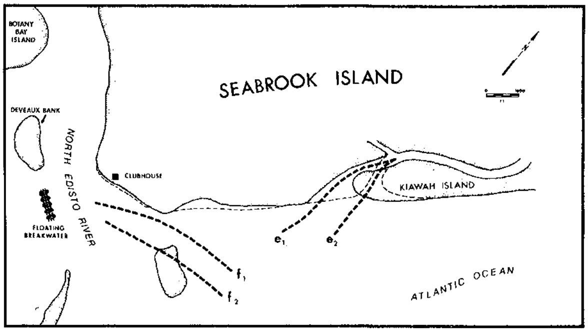

Figure 14. Proposed "soft" engineering solutions for reducing shoreline erosion along Seabrook Island, including: 1) dredging new channels at e_2 and f_2, allowing existing Kiawah River Inlet channel (e_1) and North Edisto Inlet marginal flood channel (f_2) to infill; and 2) construction of a floating breakwater (or hydraulic filling) in the former position of Deveaux Bank.

Although the proposed solutions do not have the permanence of "hard" engineering coastal protection works, their cost of implementation is at least an order of magnitude less than presently-used structures, and they have the aesthetic advantage of preserving the character of Seabrook beaches. Present plans are to implement at least two of these solutions. If successful, they will demonstrate the relevance of geologic and coastal process information not only for use in "hard" designs, but as a means for determining appropriate "soft" design solutions for coastal protection.

CONCLUSIONS

Erosion problems on Seabrook Island appear to be localized and due to three independent but related processes: (1) the migration of Kiawah River Inlet; (2) the encroachment of a marginal flood channel of North Edisto Inlet on the shoreline in the vicinity of the southeast point; and (3) increased wave activity caused by the erosion of Deveaux Bank. All of these processes are the direct results of the highly dynamic nature of tidal inlets and are common occurrences in similar environments elsewhere. None of the erosion trends were caused by Seabrook Island construction. Future construction activities on the island would benefit if these natural trends are considered. Several "soft" engineering solutions are available which would considerably retard or reverse present localized erosion trends.

ACKNOWLEDGEMENTS

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