CHAPTER 79

BEACH FILL PLANNING - BRUNSWICK COUNTY, NORTH CAROLINA

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ABSTRACT

Planning has recently been completed for a shore protection project along a 9-mile (14.5 km) reach of shoreline fronting the Towns of Yaupon Beach and Long Beach in Brunswick County, North Carolina. The investigative program related to this planning effort embodied numerous interrelated elements which, on integration, resulted in a rational engineering design having a continuous beach fill as the central feature. Specifically, the investigation included: (a) definition of the environment, viz, wind, waves, storm tide frequencies, beach profile characteristics, shore processes, and ecological habitats along the proposed project area as well as in potential beach fill sources; (b) Designs and cost estimates including establishment of various fill profile configurations, cost optimization of fill positions, evaluation of the frequency of shoreline retreat and the attendant displacement of fill materials, evaluation of the compatability of materials from various fill sources with the natural beach materials, environmental impact studies, and economic studies; and (c) Final plan formulation arriving at the optimum fill plan in terms of engineering functionality, economics, and minimal adverse environmental impacts.

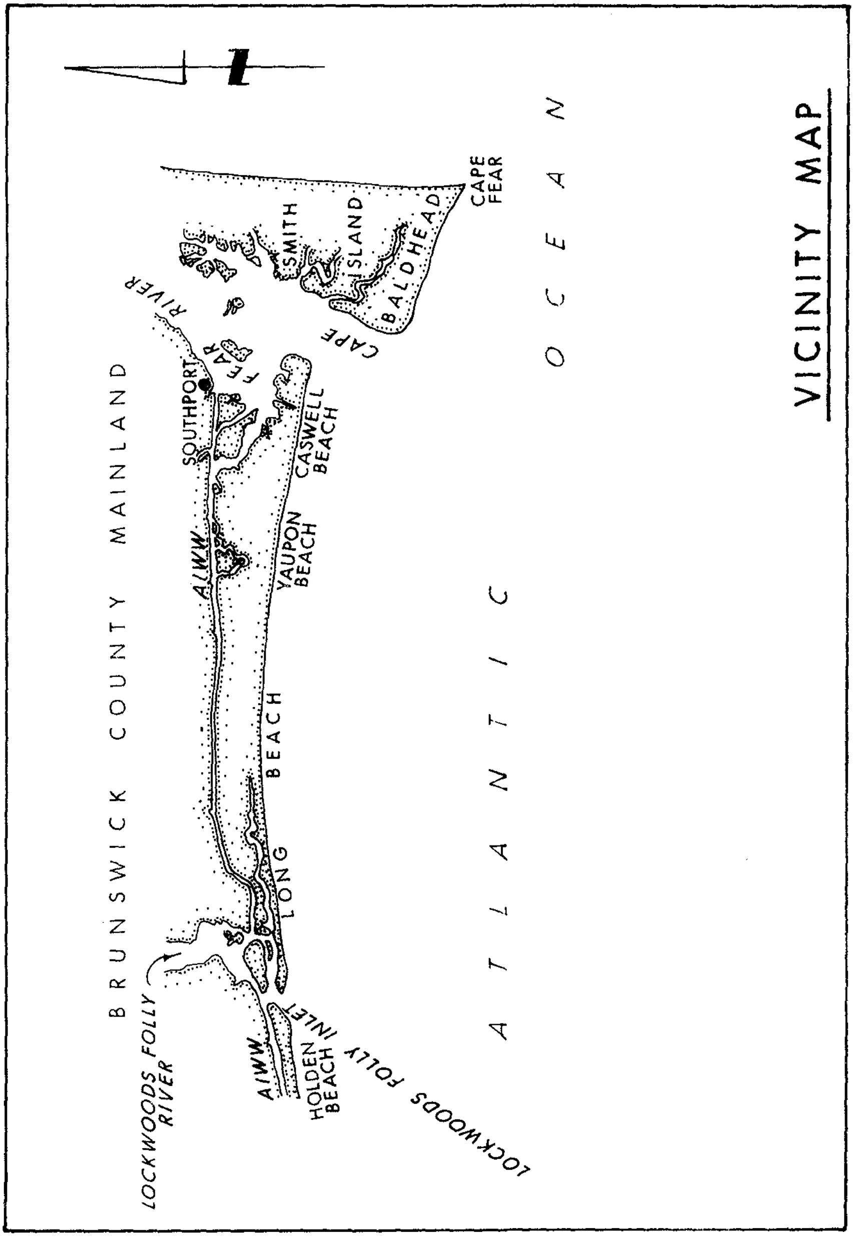
INTRODUCTION

The coastline of the State of North Carolina, U.S.A., is highly exposed to the effects of storm tides and waves attendant with the intense extratropical cyclones (hurricanes) that frequently pass over or near this particular coastal margin which is characterized, along its entire length, by a chain of low sandy barrier islands. Additionally, many sections of this coastline experience severe erosion problems even during relatively storm-free periods. Notwithstanding the hazards associated with beach erosion and hurricane generated tides and waves, development along the coast of North Carolina has, in the past quarter of a century, grown at an unprecedented high rate. It is remarked that similar conditions exist throughout other sections of the U.S. Atlantic and Gulf coasts. Accordingly, the Congress of the United States has authorized the construction of numerous projects to eliminate or mitigate the adverse effects created by major storms and/or beach erosion where such problems exist along highly developed shorelines. One of the sites for which a combined hurricane protection and beach erosion control project was authorized is located along a 9-mile (14.5 km) reach of shoreline fronting the Towns of Yaupon Beach and Long Beach in Brunswick County, North Carolina (see vicinity map). Preliminary planning for this project was accomplished in 1965 and resulted in recommendations to restore the dunes and beach strands in the project area by the artificial placement of fills, and to maintain the restored beach by a program of periodic beach replenishment. The required beach fill for initial project construction and subsequent replenishment was planned to be obtained from the marshlands backing the barrier island in the project area.

In 1971, funds were made available for the detailed preconstruction planning of the project for Yaupon Beach and Long Beach. At the outset of preconstruction planning, it was evident that the initially planned project would require extensive reevaluation due to changes in conditions following project authorization. Particularly important in this respect was the realization that beach-fill sources originally planned for project construction and subsequent beach replenishment would probably be unacceptable by current standards pertaining to the preservation of important ecological systems. These fill sources were exclusively located in biologically productive estuarine areas comprised essentially of intertidal marshlands. In addition to the important issues concerning fill material acquisition, another significant element favoring complete project reevaluation was the awareness that some fundamental changes in project design could possibly be found desirable in light of the increased knowledge and experience related to beach-fill design acquired subsequent to project authorization. Accordingly, a detailed assemblage of project alternatives was developed and fully examined in arriving at the final project recommendations.

The preconstruction planning effort, a portion of which is described in this paper, considered the feasibility of standard onshore engineering works, viz., seawalls, groins, dune-beach restoration fills, and combinations thereof. An examination of the possible extensive use of seawalls on the low barrier island topography indicated that such an approach would be too costly and esthetically undesirable. It is remarked that any functional plan involving seawalls would also require periodic beach replenishment as a minimum measure against long-term shore erosion. In addition to seawalls, a reexamination was made of the feasibility of using groins, exclusive of any other protective measure, to compartment the entire beach strand fronting Yaupon and Long Beaches. This approach was discounted due to the strong possibility of aggravating existing erosion along the unprotected shore situated immediately east of the project site. Furthermore, a groin system alone would provide only minimal protection against the effects of major storms. Accordingly, the assemblage of project alternatives developed for detailed examination involved, as a central feature, the utilization of dune and/or beach fill.

A total of 12 basic alternatives and 7 feature alternatives were completely analyzed during the investigation. These included: plain dune-beach fills varying in elevation; dune-beach fills in combination with groins; dune-beach fills and short seawalls at select locations with and without groin systems; and the stabiliza-

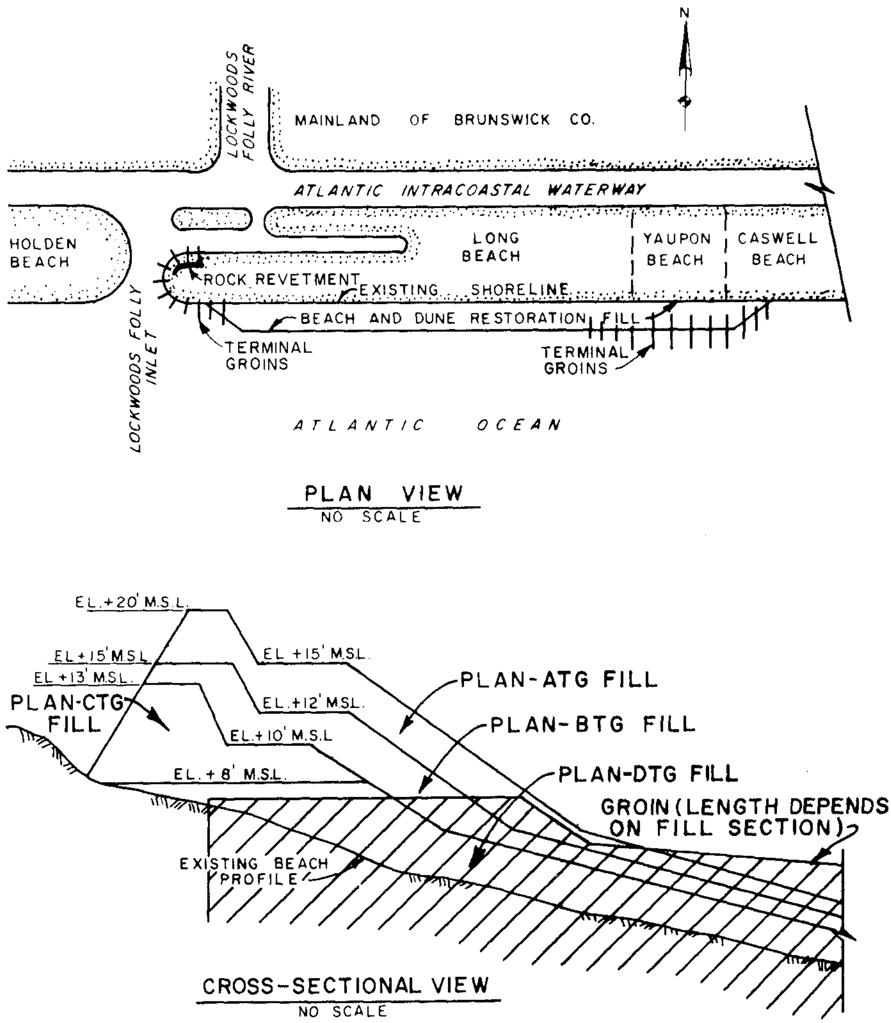

VICINITY MAP
BRUNSWICK COUNTY MAINLAND
ATLANTIC OCEAN
CAPE FEAR
SMITH ISLAND
BALD HEAD
CAPE FEAR RIVER
SOUTHPORT
CASWELL BEACH
YAUPON BEACH
AIWW
LONG BEACH
LOCKWOODS FOLLY RIVER
LOCKWOODS FOLLY INLET
HOLDEN BEACH

tion of Lockwoods Folly Inlet (see vicinity map) by major control structures in combination with the other shore protection project alternatives. The project alternatives were evaluated vis-a-vis nine potential sources of dune-beach fill, including two oceanic sources, for which detailed assessments were conducted in regard to the engineering quality of the sediments, cost of acquisition, and environmental impacts related to the fill acquisition.

The investigation resulted in the recommendation to construct a continuous dune and beach fill along the 9 miles (14.5 km) of project shoreline through the artificial placement of approximately 11,000,000 cubic yards (9,200,000 cubic meters) of fill. The east terminal of the fill would be stabilized by a system of 12 adjustable groin structures. Similarly, the west fill terminal would be stabilized by 11 adjustable groins. The dune portion of the fill, having an elevation of 15 feet (4.6 meters) above mean-sea-level, would be planted with a suitable grass to prevent the intrusion of wind-blown sands into the developed upland area. The project shore would be stabilized against erosion by a program of periodic beach fill replenishment involving fill placement at an average annual rate of approximately 402,000 cubic yards (305,000 cubic meters). Two basic sources of sediment have been selected for project construction and subsequent replenishment. Environmental studies indicate that there will be little or no adverse environmental impacts associated with the use of these two areas and that some environmental enhancement may result from the acquisition of the proposed fill by dredging operations. A schematic diagram of the proposed plan is given on Figure I. Note that the cross-sectional schematic shows four fill configurations. The selected plan is designated as PLAN-BTG.

ENVIRONMENTAL FACTORS AND CONDITIONS

As mentioned above, the area germane to the project study described herein is characterized by sandy barrier islands which back upon elongated lagoons comprised of marshlands and reptilian networks of tidal channels. These islands are narrow bands having widths varying from about 500 to 1500 feet (150 to 450 meters). The basic topographic relief of the islands is low and in general does not exceed an elevation of 10 feet (3 meters) above mean-sea-level (m.s.l.), except for scattered dunes and the frontal duneline which is hummocky and varies widely in elevation from 10 to 30 feet (3 to 9 meters) above m.s.l. The beach strands along the areas of particular interest here are narrow and offer only minimal protection to the dense ocean front development, even under conditions prevailing with moderate extratropical weather disturbances. Specifically, the beach strand widths at Long Beach and Yaupon Beach are only 66 feet (20 meters) and 44 feet (13 meters), respectively, at the mean stage of the astronomical tide. Typical conditions along the study area are illustrated on PHOTO-PLATE I. Brief descriptions of specific factors and conditions related to the beach and nearshore zone in the project study area are given below.



SCHEMATIZATION OF PLANS ATG THROUGH DTG

FIGURE I

LONG BEACH APRIL, 1971

YAUPON BEACH JUNE, 1972

PHOTO PLATE I

Beach Profile Characteristics. The natural beach berm in the study area is generally located at an elevation of 8 feet (1.4 meters) above m.s.l. The average geometric characteristics of the beach profile seaward of the berm crest are given below. The active beach profile terminates at a depth of approximately 28 feet (8.5 meters)

ELEVATION RANGE ± M.S.L.	+8 FT. TO M.S.L.	M.S.L. TO - 8 FT.	-8 FT. TO -18 FT.	-18 FT. TO -24 FT.	-24 FT. TO -30 FT.	-30 FT. TO -48 FT.
BEACH PROFILE SLOPE	IV:10H	IV:54H	IV:58H	IV:295H	IV:595H	IV:2,550H

below m.s.l. The granulometric properties of surficial sediments on the beach profile are generally characterized by the following tabulation of phi mean particle sizes and associated standard deviations.

Sample Profile Location in Feet ± M.S.L.	0	-4	-8	-12	-16	-20	-24	-28	-32
Sample Phi Mean Particle Size	1.45	1.68	1.42	2.16	2.45	1.99	1.26	1.11	1.57
Sample Phi Standard Deviations	0.51	0.47	0.48	0.51	0.45	0.67	0.51	0.46	0.51

Winds. On an annual basis, winds blow onshore 35.4 percent of the time and offshore 35.1 percent of the time, the remaining 29.5 percent of time accounts for alongshore winds or calm conditions. As regards onshore winds, 45 percent occur from the southwest, 33 percent from the south and 22 percent from the southeast. With respect to onshore wind speeds, 96 percent are less than 20 knots, 65 percent are less than 12 knots, and 33 percent are less than 7 knots.

Waves. Observed offshore wave data is well correlated with the overall wind data, as approximately 36.5 percent of all observed waves are directed onshore. The distribution of onshore deep water waves in terms of direction is as follows: ESE - 10%; SSE - 19%; S - 18%, SSW - 19%; and WSW - 34% . The percentage distribution of deep water waves approaching shore with respect to all deepwater waves in terms of wave height and period is given in the tabulation below.

ONSHORE WAVE HEIGHTS (FEET)	ONSHORE WAVE PERIOD (SECONDS)						
	< 6	6-7	8-9	10-11	12-13	>13	Total
PERCENTAGE OF ALL DEEP WATER OBSERVATIONS							
< 3	8.35	1.03	0.32	.06	0.01	0.60	10.37
3-5	10.20	6.08	1.25	.34	0.08	0.14	18.09
5-8	0.85	2.37	1.75	.46	0.08	0.06	5.57
8-12	0.19	0.50	0.61	.30	0.17	0	1.77
12-18	0.04	0.19	0.14	.23	0.04	0.04	0.68
> 18	0.04	0	0	.02	0	0	0.06
Total	19.67	10.17	4.07	1.41	0.38	0.84	36.54

The above tabulation shows that 78 percent of the waves which approach shore from deep water are equal to or less than 5 feet (1.5 meters) in height, and that 82 percent of the wave periods are equal to or less than 7 seconds.

Tides. The mean astronomical tide range in the study area is approximately 4.2 feet (1.3 meters), with a spring tide range of about 4.8 feet (1.5 meters). Tidal anomalies, particularly those associated with tropical cyclones (hurricanes), can be quite severe. For example, Hurricane "Hazel" (15 October 1954) generated a surge in the study area which reached a still-water-elevation of approximately 15 feet (4.6 meters) above m.s.l. Computed tide level-frequency relationships for the area, calibrated with storms tides of record, are given below.

TIDE LEVEL ABOVE M.S.L. (FT.)	4.3	4.7	6.5	9.2	11.2	12.4	13.5	14.8	15.6
PERCENT CHANGE OF OCCURRENCE ANNUALLY	30	20	10	5	2	1	0.5	0.2	0.1

STUDY INVESTIGATIONS

Investigations related to the study area and alternative solutions to existing shore problems were conducted over a period of 2-years and involved the following, briefly described elements.

Tide Level-Frequency Analysis. Hurricane-surge heights in the study area were computed for various wind fields having central pressure indices ranging from 27.36 to 29.00 inches (10.8 to 11.4 cm) of mercury. In determining the generalized hypothetical hurricane frequencies, consideration was given to the chance of occurrence of the storm paths based on hurricane-track records dating from 1887. Two basic paths of hurricane approach were established and tide level-frequency curves were computed for each path. A composite hypothetical curve was then obtained by adding the percent of occurrences of the two curves for given water levels. Finally, the composite curve was adjusted in accordance with the limited recorded tide data that was available. Basic data from the adjusted composite curve was presented in the previous section under "Tides".

Winds, Wave Climate, and Shore Processes. Wind data were only of casual interest in this study as the hindcasting of wave characteristics was not considered necessary due to the availability of sufficient wave data. Records of the U.S. Weather Service Station at Wilmington, N. C. were compiled for the period January 1948 through June 1960. These data were found to be generally well correlated with the direction of wave height data selected for use in the study. In regard to wave data, 3 sources of information were analyzed to obtain a representative wave climate for the study area. These sources included: recorded and visually observed wave information from a fixed lighttower located approximately 25 nautical miles (46 kilometers) southeast of the study area; shipboard observations from both a 1 degree and 10 degree offshore geodetic grid; and surf observations from two onshore locations near the study area. The information related to the 1° geodetic grid square 33° - 34° N., 77° - 78° W. was selected as the best representation of wave climatology applicable to the study area. These wave data were utilized for wave refraction and alongshore sediment transport analyses. The wave refraction analysis resulted in the development of approximately 1,460 wave orthogonals. The area covered by the analysis extended over a shoreline distance of 16 miles encompassing the study area. Wave rays were refracted toward this shoreline reach from deepwater directions E. 30° S., E. 60° S., South, S. 30° W., and S. 60° W. with wave periods of 4, 6, 8, 10, 12, and 14 seconds. For each set of refraction diagrams, representing a certain wave direction and period, alongshore sediment transport curves were developed relating the variability of sand transport to distance along the 16 miles (26 kilometers) of shoreline studied. This analysis resulted in the development of 144 sediment transport curves from which two composite curves were obtained that gave, respectively, easterly and westerly sediment transport quantities on an average annual basis. The sand deficit derived from the computed longshore transport regime was compared to a second and independent analytical computation of sand sediment deficit based on the assumption of an equilibrium profile, the magnitude of shoreline retrogression, and the attendant computed volumetric losses. The computed alongshore transport deficit added to the loss of sediment computed for the shore recession associated with sea level rise compared closely to the total sand deficit based on overall volumetric losses. Shore recession due to sea level rise was determined generally in accordance with the method proposed by Bruun, see reference 1.

Designs and Cost Estimates. Important elements of these investigations included: (1) Establishment of design fill profile configurations on the basis of existing natural profiles obtained by field surveys; (2) cost optimization of the position of alternative project fills considering cost impacts resulting from the interrelationships of volumetric requirements, rights-of-way and relocations and dune back-slope bulkheads for fill containment; (3) analytical determination of the relationship of shoreline retreat to frequency of occurrence (based on storm-tide frequency) for each basic alternative fill; (4) analytical determination of frequency of occurrence of volumetric displacement of fill material due to storm action; (5) analytical determination of the probability of storm-displaced fill returning to shore under poststorm wave action; (6) wave overtopping on fill sections; (7) subsurface exploration in potential fill source areas including six estaurine, one upland, and two oceanic areas; (8) granulometric analysis of surficial beach profile samples and potential sediment source samples; (9) cost analysis of dredging from potential fill sources; (10) selection of fill sources on basis of interrelated factors of cost, sediment quality, and environmental considerations; (11) beach replenishment cost studies in regard to plain beach fills and beach fills compartmented with groins; (12) designs and cost estimates for groins, seawalls, and revetments; and (13) establishment of right-of-way values and relocation costs.

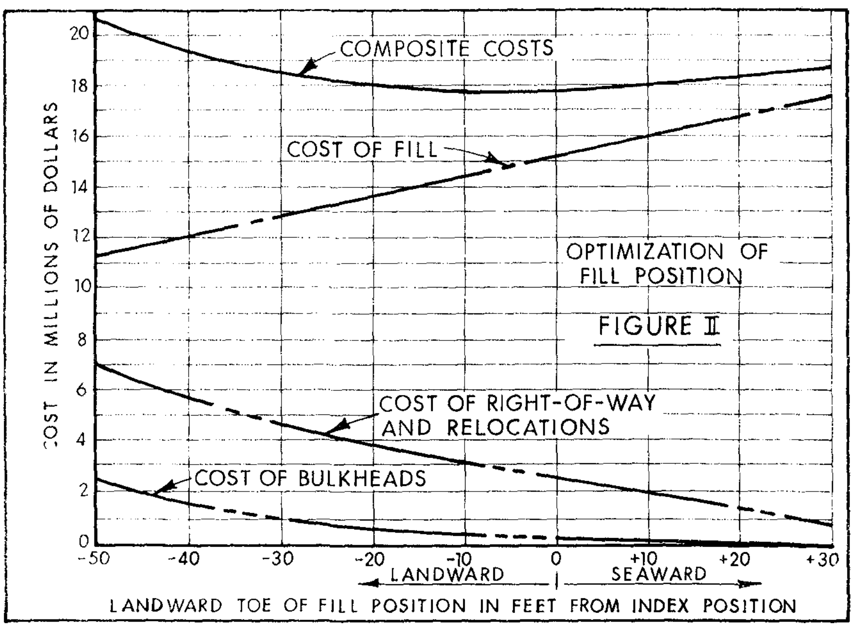
Economic Analysis. The economic analysis involved the evaluation of: (a) physical damages to structures prevented along the upland zone by each of the basic project fill alternatives in accordance with water level-frequency and water level-damage relationships established for the study area; (b) benefits from recreational use of the restored beach strand areas with respect to the diminishing benefits from recreational use of the existing dry beach areas which are presently eroding; (c) land loss prevention benefits for properties which presently back the existing beach strands-these properties would, in time, be subject to erosive conditions in the absence of erosion-control measures depending on the rates of shoreline retrogression which are 3.6 feet (1.1 meters) and 5.7 feet (1.7 meters) per year at Long Beach and Yaupon Beach, respectively; (d) benefits resulting from a higher utilization of land in those areas in which development is presently hindered by an obvious threat of beach erosion; and (e) local redevelopment benefits computed as the amortized value of wages of workers hired locally for initial project construction and subsequent project operations.

Environmental Analysis. The environmental analysis involved the results of investigations necessary to establish the characteristics of the existing natural setting, the type and value of the natural resources therein, and the impacts on the setting and its resources as a result of project construction and operation. An extensive resource inventory was developed by literature reviews, field studies, and consultations with authoritative environmental interests. The study area and its surroundings were divided into distinct units, each of which was assessed in terms of ecological considerations with respect to project-related influences. A significant amount of the environmental analysis pertains to the evaluation of potential project fill sources, leading to the selection of areas in which acquisition of sediments for project construction and operation would not result in unacceptable environmental impacts. For those areas selected as fill sources, precautionary procedures related to dredging operations were developed to protect adjacent areas from possible adverse effects of dredge-generated turbidities. In addition to fill acquisition, the environmental analysis assesses all other aspects of project construction and operation including the short- and long-term environmental impacts of fill placement on the shorelines and the construction of groins.

FILL PLAN FORMULATION

The degree of protection afforded by a given fill depends on its geometry in terms of elevation and volumetric characteristics. The particular above-water configuration of a fill is chosen to approach the basic shape of a natural beach; to wit, the fill profile is comprised of a high landward portion resembling a frontal dune and/or a flat lower form which has the appearance of a natural beach strand. Seaward of the limits of normal wave run-up on the beach face, nothing can be done in the way of artificially shaping the fill profiles, as this area is molded in accordance with the interaction of wave forces and attendant nearshore circulations and the physical characteristics of the fill materials. The designs of the restoration fills are based on the concept that materials placed as fill will be sorted, by wave action, into restricted size ranges along the active profile in a fashion similar to that existing on the natural beach profiles. The degree to which the sorted fills would approach the same characteristics as the natural beach profiles depends on the overall granulometric characteristics of the fills, presuming there are no differences in the densities and particle shapes of the fill and natural materials. All potential fill sources investigated did possess those characteristics which would allow for the natural development of profiles approaching those currently existing along the shore and nearshore zones of the study area. Accordingly, the design fill profiles were based on the natural beach profile measurements conducted during the investigation. The resulting average slope characteristics selected for design purposes are those described under the preceding section entitled "Environmental Factors and Conditions". The active beach profile in the study area was found to extend to seaward depths of about 28 feet (8.5 meters) below m.s.l. Failure to provide sufficient material volume for entire coverage of the active profile would result in material being displaced from higher to lower portions of the in-place fill (following initial placement) making it impossible to develop the design profile. This would result in a recession of the design fill shoreline and a reduction in the quantities of material in the beach berm or dune sections of the fill. The net volumetric quantity of material required to fulfill the needs of a particular fill section depends on the desired amount of seaward advance of the fill with respect to the existing profile. In the case where the sorted fill is expected to develop characteristics similar to the natural beach profile, a sufficient amount of net fill must be provided so that every point on the sorted fill profile will be equidistant from a corresponding profile point on the existing natural profile. For example, if the design profile is to advance the mean-water line a seaward distance of 100 feet, each point on the active profile must also be advanced seaward a distance of 100 feet in order to attain the design fill cross-sectional area. Though this is a seemingly obvious conclusion, it is, more often than not, overlooked in the design of beach fills.

The volumetric requirements and associated costs of each basic fill alternative depend on the position of its landward limits. If, for example, the landward toe of the dune fill were placed at the existing high-water line, the volume and associated cost of the fill would be higher than if the toe of the fill were placed in the upland area. On the other hand, if the landward toe of the dune is placed in the upland areas, high costs are incurred due to the necessity to purchase expensive rights-of-way, relocate structures, or to construct back-slope bulkheads to retain the dune fill. In order to arrive at the most economical position of each of the basic fill alternatives, a cost optimization scheme was employed that involved a family of four curves, three of which give, respectively, the relationships of cost of fill, costs of rights-of-way and relocations, and cost of back-slope bulkheads, each with respect to various positions of a given fill as measured from an arbitrary index position. The fourth curve is a composite of the three curves mentioned above, that is, the fourth curve represents the total cost of the protective fill for any location. The minimum point on the total cost curve gives the most economical position of the restoration fill. An example of the optimization scheme is given in FIGURE II.



In regard to the degree of protection provided by each of the basic alternative fills, this aspect of plan formulation was accomplished by an analytical determination of the relationships of fill shoreline retreat with respect to the frequency of occurrence of various tide levels. The method utilized to determine shoreline retreat-frequency relationships was similar to the procedure presented by Edelman in 1968, see reference 2, revised in this case to fit local conditions. These relationships are presented graphically in FIGURE III. On the basis of FIGURE III, the alternative fill Plans ATG, BTG, CTG and DTG have design capabilities associated with storm tide and wave action having frequencies of occurrence of 0.2, 1.5, 4.0, and 8.0 percent per year, respectively. The short-term but large-scale shoreline fluctuations occurring with storm action, as demonstrated graphically on FIGURE III, are accompanied with the offshore displacement of sediments. The relationships of volumetric displacement with respect to frequency of occurrence of storm tides and waves are given on FIGURE IV. It is of interest to note that analytical results indicate that the volumetric displacement of dune and/or beach material in an offshore direction is independent of the fill configuration. These findings agree with general observations that dunes function as sand reservoirs during storm retreat of beach profiles and thereby reduce the recessions that would occur in the absence of dunes. The frequency of volumetric displacements is particularly important in determining project maintenance costs on an average annual basis. Natural poststorm restoration is a well known phenomenon. However, the degree of natural beach restoration for a particular site is generally unknown. For the Yaupon and Long Beach project, analytical investigations were conducted to determine the capabilities of the normal wave climate to return materials to the shore following storm displacement. The analysis was conducted in accordance with methods presented by Johnson and Eagleson in reference 3. In this case it was found that, for all practical purposes, materials displaced by storms would return to the shores. Of course, the hydraulic restorative agents cannot return materials to the higher portions of a dune and beach fill. In a purely natural situation the lower beach forms are restored over relatively short periods of time (several days to several months) depending on the severity of a particular storm and the characteristics of the poststorm wave action. The natural dunes generally recover from storm effects at a slower rate than the lower beach zone as their restoration is dependent on wind speed, direction, and the availability of finer fractions of the beach sediments. Since it would be desirable to attain project protection as soon as possible following storm recessions, the average annual amounts of material displaced from the basic alternative fill sections, above the natural beach berm level of +8 ft. m.s.l., were determined and costs computed to mechanically redistribute that material to the higher portions of the design profiles.

Beach materials and fill sources. All potential sources of fill in the general vicinity of the project site were investigated. These

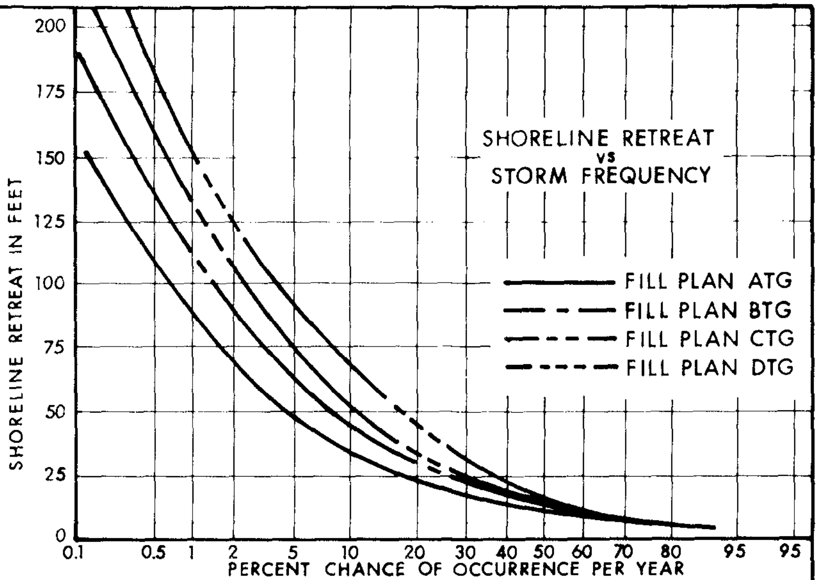


FIGURE III

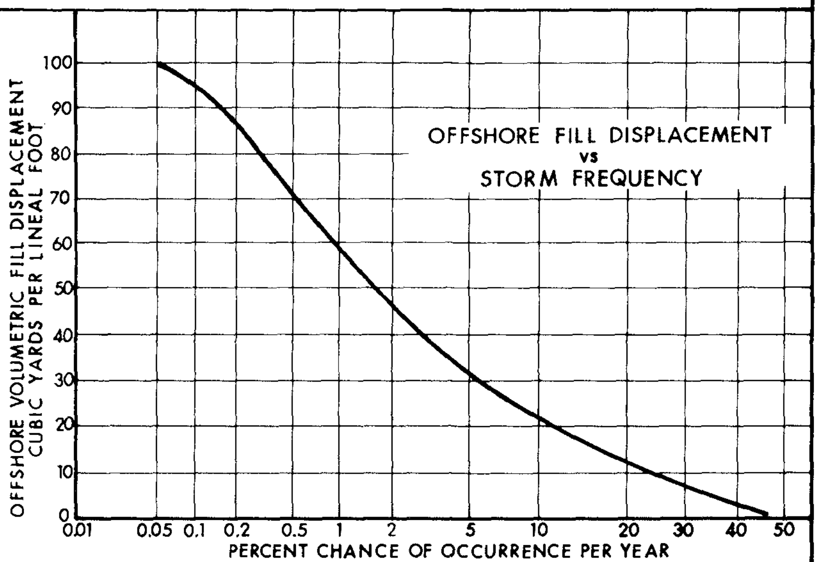


FIGURE IV

sources are referred to as potential borrow areas and are designated by the abbreviation PBA. A total of nine potential borrow areas, designated PBA-A through PBA-I, were involved in the investigation. The subsurface exploration of materials contained in the various potential borrow areas has been mentioned. The collection of a representative set of material samples was required in order to conduct a comparative analysis between the granulometric properties of the fill sources and the natural or native beach materials, and thereby determine the compatibility of the fill materials with respect to the nearshore environment. In this connection, the wave-sorting phenomenon - involving the segregation of the discrete particles comprising the beach and nearshore bottom into restricted size ranges along the active profile - is of prime importance in the conceptual formulation of beach fills. Since the natural beach, including the nearshore bottom, is the end product of a distribution process which acted upon a particular source of material over some period of time, it is reasonable to assume that if a composite material possessing the average characteristics of beach material were placed along the shore, the prevailing hydraulic forces would tend to sort that composite material into a distribution having the characteristics observed on the natural beach. Accordingly, the first part of the fill-source material analysis involves defining the general characteristics of the native material. The second part of the analysis involves the determination of the characteristics of the various source materials and their compatibility with the nearshore environment as reflected by the distribution characteristics of the native beach material.

The native beach material characteristics were determined from 170 surficial samples obtained from 10 profile range lines spaced at intervals of 6,000 feet (1.8 km) along the project and adjacent shorelines. The samples were obtained from 17 discrete profile points located between the beach berm crest and the 32-foot m.s.l. depth contour on each range line. Samples from the PBA's were obtained from 79 subsurface and submarine cores, from which 750 samples were selected for laboratory analysis. Locations of submarine cores were determined by an analysis of a sonic geophysical survey. The basic statistical parameters describing the characteristics of beach and fill-source particle size distributions are mean particle size, standard deviation, and variance. These parameters are applied to the "Log Normal Size Distribution Model" (see reference 4) which defines the compatibility of a particular fill material with respect to beach material in terms of a value referred to as the "critical ratio." This value is the ratio of the total volume of material placed as fill to the net volume of fill remaining in-place after natural hydraulic sorting action has taken place. In arriving at the gross volume of material required from a given source to obtain a net design volume in the fill section, it is also necessary to consider the quantity of silts and clays within the basic material source that would remain in suspension after discharge from the dredge pipeline and not deposit within the fill section. Therefore, the quantity of sandy material within the potential fill sources was determined and the respective "critical ratios" were based only on these settleable fractions of the source material. Accordingly, a net unit volume of material in the fill section, following initial placement and subsequent hydraulic sorting action, would require the removal of the number of unit volumes of source material given by the ratio "critical ratio"/fraction sandy material. For example, if the "critical ratio" is 1.4 and the percent sand (settleable material) in the fill source is 70 percent, approximately 2.0 cubic yards of source material are required to obtain 1.0 cubic yard of net fill in the design section. Therefore, if the unit cost of dredging and placing material on the project shore is $1.00 per cubic yard for a borrow area having the material characteristic described above, the cost of an effective unit volume of material from that borrow area would be $2.00 per cubic yard.

The selection of a source or combination of sources for the acquisition of project fill was dependent on environmental considerations as well as the cost and interrelated material suitability aspects mentioned above. The cost estimate computations involved a detailed analysis of each potential borrow area (PBA) including the cost of mobilization and demobilization of primary and booster pumping units and the direct cost of pumping on a unit cost basis. The cost of an effective unit volume for the design section was then determined for each PBA on the basis of the respective "critical ratios" and fraction of settleable materials. The full results of environmental investigations are too lengthy for explanation herein; however, it will suffice to state here that: (a) PBA's -E, -F, -G, -H, and -I are ecologically important to the natural resource base of the Southeastern Coastal Zone of North Carolina, and that acquisition of sediments in these areas for project construction and/or subsequent beach replenishment would be highly injurious to the ecosystems involved; and (b) PBA's -A, -B, -C, and -D are areas in which dredging activities would have little or no significant short- or long-term environmental impacts. A summary of the elements necessary for the rational selection of project fill sources is given below in table 1. On the basis of the information summarized in table 1, PBA's -A and -B were selected as the project fill sources.

TABLE 1

Potential borrow area (PBA)	Gross unit volumes of material per unit volume of net fill	Cost of an effective unit volume of net fill ($)	Adverse impacts on environmental resources if area is dredged
A	1.40	0.45	Not significant
B	1.24	0.81	Not significant
C	1.51	1.86	Not significant
D	4.93	2.66	Not significant
E	1.62	0.63	Significant
F	3.32	1.30	Significant
G	4.80	1.58	Significant
H	3.90	1.29	Significant
I	2.45	0.81	Significant

The gross volume of material available within PBA-A amounts to approximately 1,900,000 cubic yards. The remaining quantity of material required for a given basic alternative fill must be obtained from PBA-B. The volumetric relationships are given in table 2.

TABLE 2

Fill plan	Gross volumetric requirements (cu. yds.)	Gross volume of material in PBA-A (cu. yds.)	Gross fill requirement from PBA-B (cu. yds.)
ATG	17,620,000	1,900,000	15,720,000
BTG	11,000,000	1,900,000	9,100,000
CTG	8,670,000	1,900,000	6,770,000
DTG	8,350,000	1,900,000	6,450,000

Selection of fill plan BTG was based on the comparison of excess annual benefits of the various fill plans. Excess annual benefits are defined as the difference between total annual benefits and annual costs which include the capitalized cost of initial construction and annual operating costs.

Beach replenishment (nourishment). Beach nourishment requirements were determined on the basis of computed average annual shoreline recession rates. To convert shoreline recession to corresponding volumetric loss, the entire beach profile, extending from the berm crest to the 28 ft. m.s.l. offshore depth contour, was assumed to retrogress at the same rate as the shoreline. In other words, an equilibrium profile was assumed to exist. The assumption of the existence of an equilibrium profile condition was supported by the close comparison of the results of the two independent sediment deficit computations. The first computational approach utilized the historic shoreline changes and the second approach combined alongshore transport deficits with sediment losses due to a rise in sea level. On the assumption of an equilibrium profile condition and the average characteristics of profiles surveyed in the study area, the computed loss of beach material attending a shoreline recession of 1 foot is 1.54 cubic yards (1.2 cubic meters) per lineal foot (0.3 m) of beachfront. Applying this volumetric loss quantity to the average annual recession rates of 3.6 feet and 5.7 feet for Long Beach and the general Yaupon Beach area, the respective average annual volumetric losses are 5.54 cubic yards (4.2 cu.m.) and 8.78 cubic yards (6.7 cu.m.) per lineal foot of shore. On the basis of shoreline distances, the average annual beach replenishment demand would be 288,600 cubic yards (221,000 cu.m.) for a continuous fill extending from Lockwoods Folly Inlet to and including the shores of Yaupon Beach. The replenishment rate given above is based on the existing shoreline, and in order for the estimated replenishment value to be valid for a project fill, the fill must have an alignment which follows, as closely as possible, the natural shore alignment. The natural coastline configuration is the product of a long-term process involving the interaction of sediments comprising the shore and the nearshore hydraulic forces. If a fill alters the basic coastline orientation, there will be a natural reaction tending to restore the shore to its prior alignment. Usually, such a reaction results in higher erosion rates than had been experienced by the natural shore. Accordingly, in positioning the basic alternative project fills, care was exercised in maintaining the same shoreline configuration existing along the natural coast. However, adherence to this basic approach is not possible at the extremeties of a fill which must terminate at some point beyond which the natural coast continues. At such a point, a transition to the natural coast must be effected which necessarily requires a deviation from the natural shore alignment. The differences in alongshore transport at and near a fill transition were analyzed on the basis of fill transition and wave angularities. In general, if the fill transition is very gradual the difference in alongshore processes between the natural shore and the transition will be relatively small. Conversely, a sharp transition results in significant changes in alongshore transport rates resulting in rapid erosion of the transition. However, the relationships of different transitions in terms of cost are not simply functions of transition angularity with respect to normal shore alignment. For example, a very gradual transition is lengthy and the initial cost of fill to develop the transition is high. Also, though the erosion rate per unit length of transition may be only slightly higher than the normal shore erosion rate, the large length of a gradual transition could require a considerable periodic replenishment rate. On the other hand, a somewhat sharper transition having a shorter length and lower initial costs could also have a lower overall replenishment requirement due to its shorter length, notwithstanding the possibility that the erosion rate per unit length of this transition is greater than the more gradual transition. In view of the possibilities mentioned above, a cost optimization scheme was required to determine the most economical fill transitions. The optimum east and west transitions of a continuous fill along the shores of Yaupon and Long Beaches were found to be, respectively, 4,240 feet (1290 m.) and 4,000 feet (1220 m.) in length and to have computed replenishment requirements of 87,200 cubic yards and 115,000 cubic yards per year. The alternative to a plain beach transition zone is to employ a small, tapered groin system which allows for shortening of the transition sections. Such groin systems were evaluated and found to be the most economic means of effecting the fill transitions, based on the assumption that the compartmented transition fills would adjust to normal shore alignments and, therefore, could be maintained by a beach replenishment rate equivalent to the natural erosion rate in the vicinity of the proposed transitions. Accordingly, terminal groin systems were adopted for the overall fill plan. The total volumetric beach replenishment needs for the proposed fill along Yaupon and Long Beaches, amounts to 289,500 cubic yards (220,000 cu.m.) per year. Of this amount, 30,000 cubic yards (23,000 cu.m.) would be obtained from PBA-A which represents the estimated deposition of littoral materials flushed to and deposited in that area by tidal flow through Lockwoods Folly Inlet. The remaining 259,500 cubic yards (197,000 cu.m.) per year would be obtained from materials in PBA-B. On the basis of the material characteristics in PBA-B, the gross volume of material required to yield 259,500 cubic yards of sorted beach fill would be 321,800 cubic yards (245,000 cu.m.). Thus, the gross average annual volume of beach replenishment materials to be obtained from PBA's - A and B would amount to approximately 402,000 cubic yards (305,000 cu.m.). The tentative schedule is to accomplish periodic beach replenishment at 3-year intervals, with each operation involving the placement of 1,206,000 cubic yards along the project fill.

CONCLUSIONS

In the course of his professional practice, this writer has perused numerous documents pertaining to the planning or design of large beach fill projects. In so doing, it has, all too often, been evident that many engineers have given little more consideration to such plans than one would give to a common land-fill in a stable upland area. This revelation is particularly dismaying on considering that beach fills are generally major engineering works involving sizable capital expenditures for initial construction and subsequent operation.

This paper has identified some of the important, complex, and interrelated elements which can and should be evaluated by the engineer in arriving at a rational plan to place a sedimentary fill for the purpose of coastal protection. Admittedly, the present state of knowledge concerning shore processes, at best, allows for only rough approximations of beach fill behavior; but, for this very reason, if for no other, the engineer must exert every reasonable effort to establish a base of analyses from which sound judgments can be made. Moreover, it is only through the comparison of rational initial design assessments with actual beach fill behavior that the engineer can fully evaluate a given fill performance, design future project modifications if necessary, or define those areas in which future research is needed to develop or refine engineering criteria.

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