CHAPTER 77

RECENT HISTORY OF EROSION AT CAROLINA BEACH, N C

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ABSTRACT

The reaction of shores adjacent to salient features which interrupt alongshore processes has long been recognized as an important consideration in connection with the investigation of engineering works to be undertaken on shores characterized by a littoral drift regimen Particular emphasis has been placed on the evaluation of shore changes related to major control structures at navigation entrances, however, manmade interruptions of small scope, which initially appear innocuous, can produce costly damage to the adjacent shores located on the downdrift side of the interruption

The town of Carolina Beach, a seaside resort on the Atlantic Ocean in southeastern North Carolina, is a classic example of an area experiencing inordinate and costly erosion associated with an initially small manmade interruption on the updrift shore In 1952, local boating interests excavated a channel through the updrift barrier beach to connect the Atlantic Ocean and a lagoonal area traversed by the Atlantic Intracoastal Waterway The channel, located 8,000 feet north of the Carolina Beach town limits, soon developed into a small, permanent coastal inlet having a width of approximately 550 feet and a depth of 15 feet In the ensuing 17-year period, 1952-1969, this inlet entrapped over 4 million cubic yards of littoral material, resulting in a concomitant downdrift erosion which progressed southward to the town of Carolina Beach A protective beach fill placed along the town's ocean front in 1965 has suffered considerable erosion damage

This paper develops and quantifies the cause and effect relationships of the problem generally in terms of the alongshore processes and, in so doing, also furnishes basic information in regard to the performance of the large-scale artificial beach fill placed along the ocean front of Carolina Beach in 1965

INTRODUCTION

In October 1962, Congress authorized the construction of a beach fill, for the purpose of hurricane protection and beach erosion control, to extend from the northern town limits of Carolina Beach, N C , to the southern town limits of Kure Beach, N C , a distance of about 26,000 lineal feet In April 1965, a portion of the project was completed by the placement of approximately 2,632,000 cubic yards of fill material along the 14,000 lineal feet of shore fronting the town of Carolina Beach (see FIGURE I) The geometric configuration of the fill consisted of a dune having a crest width of 25 feet, at an elevation of 15 feet above mean low water, fronted by a 50-foot-wide storm berm at an elevation of 12 feet above mean low water (see FIGURE II) Along the northernmost 3,700 lineal feet of constructed project, the storm berm was widened to 70 feet to provide an advanced beach-nourishment stockpile Construction of the authorized project south of the town limits of Carolina Beach was deferred due to the inability of local interests to finance a portion of the non-Federal share of the project costs Herein, reference to the authorized project applies only to the constructed section, specifically, that portion of the project fronting the town of Carolina Beach, N C

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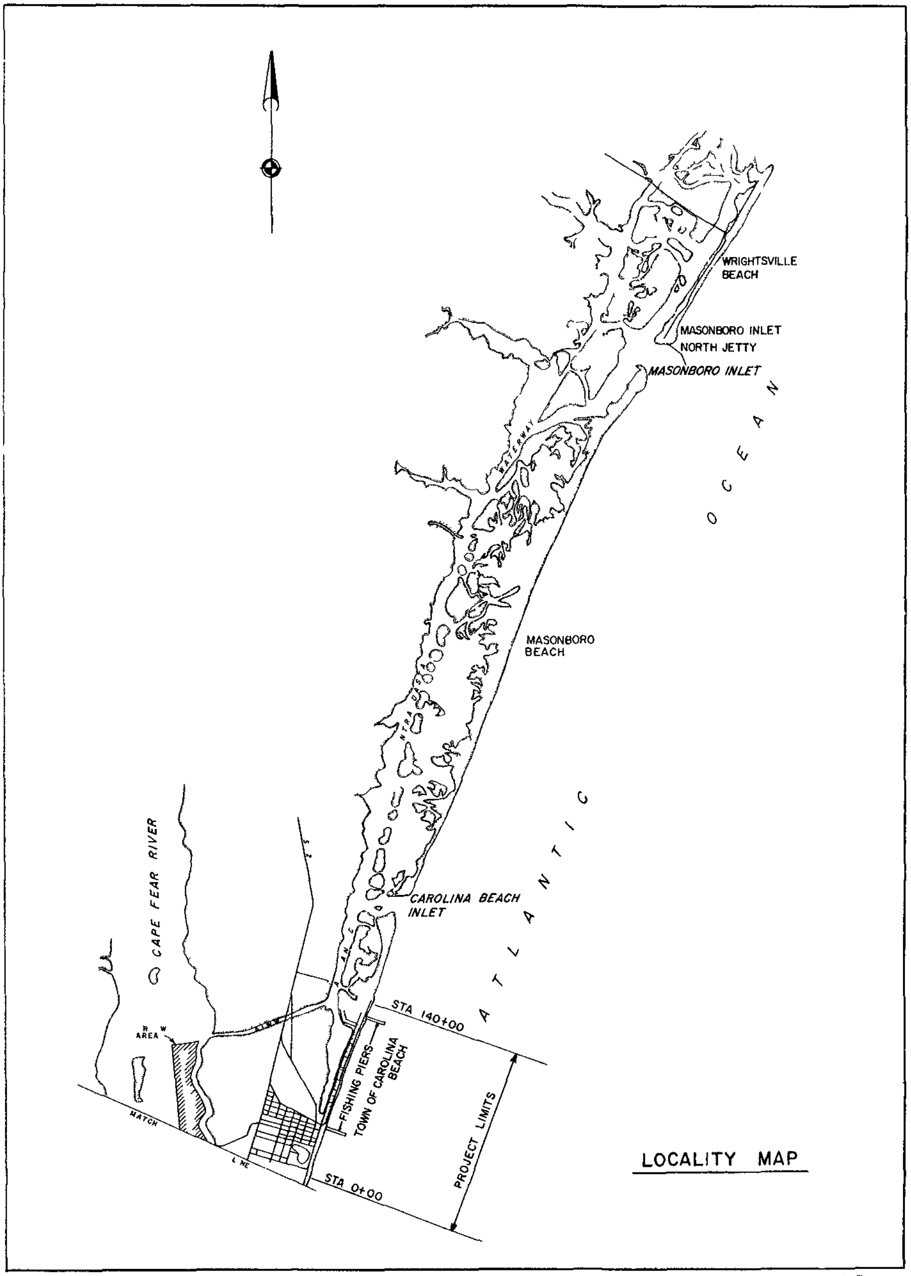


FIGURE I

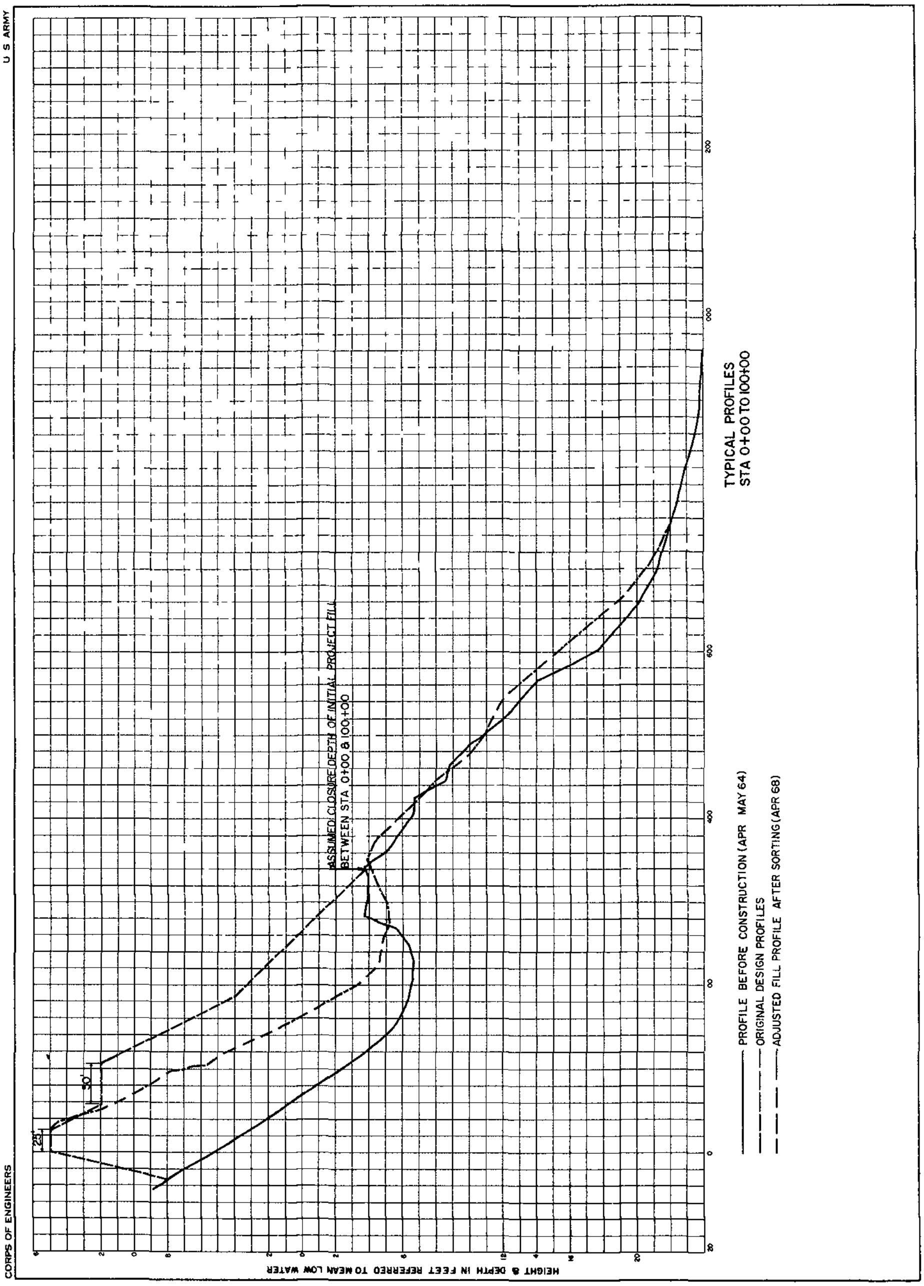

U S ARMY
CORPS OF ENGINEERS
TYPICAL PROFILES
STA 0+00 TO 100+00
ASSUMED CLOSURE DEPTH OF INITIAL PROJECT FILL
BETWEEN STA 0+00 & 100+00
25'
30'
PROFILE BEFORE CONSTRUCTION (APR MAY 64)
ORIGINAL DESIGN PROFILES
ADJUSTED FILL PROFILE AFTER SORTING (APR 68)
HEIGHT & DEPTH IN FEET REFERRED TO MEAN LOW WATER

FIGURE II

Immediately following the construction of the Carolina Beach project, rapid erosion was manifest along the entire length of the fill structure Though initial adjustments were expected, the actual changes, particularly those evidenced along the onshore section of the project, were much greater than anticipated during the planning and design phases of the project In the first 2 years of project operation, erosion was a persistent phenomenon along the entire length of fill, however, the rate of erosion along the southern 10,000 feet of project was considerably smaller than that experienced along the northern 4,000 feet

During the initial 2-year period, approximately 712,000 cubic yards of fill were lost from the entire profile, to seaward depths beyond the 22-foot mean-low-water contour, within the southern section of the project This volumetric loss represents about 43 percent of the total in-place fill initially placed along that section of the project, therefore, in terms of fill, the degree of project protection was reduced by 43 percent The attendant onshore changes resulted in an 82-foot recession of the high-water line in the initial 2-year period and the destruction of the horizontal storm berm of the design profile By the end of the second year of operation, the southern 10,000 lineal feet of project stabilized and have remained in more or less the same condition to the present

In the first 2 years of project operation, erosion along the northernmost 4,000 lineal feet of project was even more extensive than that which had occured in the 10,000-foot southern section Within the initial 2-year period, approximately 550,000 cubic yards of fill were lost from the active profile along this section of the project, which amounted to a 56-percent reduction in the total in-place fill By March 1967, 2 years after initial construction, the high-water line along this section of project receded 140 feet, resulting in the total destruction of 1,500 lineal feet of dune and storm berm and the severe deterioration of an additional 1,200 feet of onshore fill section This erosion was progressing rapidly in a southward direction and threatening the more stable southern section of the project Therefore, in March 1967, emergency measures were implemented to alleviate the problem These emergency measures involved restoration of the north end of the project by the placement of approximately 360,000 cubic yards of beach fill and the construction of a 405-foot-long groin near the north terminal of the project The groin was considered necessary, as there appeared to be a reversal in the predominant direction of littoral transport at the north end of the project In the year following the implementation of the emergency measures, approximately 203,000 cubic yards of emergency fill were lost to erosion and the major portion of the shoreline returned to about the same position it had prior to the emergency work The shoreline immediately south of the groin, for a distance of about 400 feet, has remained relatively stable, and the rate of loss of emergency fill along this small segment of shore was about 42 percent less than that experienced along the remaining emergency section

ENVIRONMENTAL FACTORS

Beach-profile characteristics Within the area of interest, the qualities of the normal beach profile are characterized by conditions existing along the southern 10,000 lineal feet of project Along this area, sufficient time has now elapsed for the borrow material, placed in 1965, to be sorted and to establish itself on the profile in more or less a condition of dynamic equilibrium, as discussed below in connection with shore processes Bottom-material characteristics are defined by the grain-size analysis of surficial sediment samples taken from two representative range lines along the active profile, contained between the backshore and the 30-foot-depth contour (see TABLE 1) It will be noted that the resulting composite phi mean diameter is 1 69 (0 31 mm) and that the phi standard deviation is 0.91

TABLE 1

Characteristics of material on profile at Carolina Beach (May 1967)

Station	Sample	Phi mean ($M\phi$)	Phi standard deviation ($S\phi$)	Phi variance ($S\phi^2$)
10+00	Top of berm	1 30	0 51	0 260
	Mean high water	0 85	0 58	0 336
	Mean sea level	1 46	0 40	0 160
	Mean low water	0 76	0 47	0 221
	-6	2 39	0 48	0 230
	-12	2 16	0 59	0 348
	-18	1 87	0 59	0 348
	-24	No sample		-
	-30	1 57	0 61	0 372
70+00	Top of berm	1 03	0 76	0 578
	Mean high water	1 00	0 54	0 292
	Mean sea level	1 25	0 39	0 152
	Mean low water	0 38	0 54	0 292
	-6	2 49	0 86	0.740
	-12	2 66	0 45	0 203
	-18	2 91	0 47	0 221
	-24	3 13	0 52	0 270
	-30	1 51	1 13	1 277

$M\phi$ = 1 69 S^2 = 0 37

$S\phi$ comp = 0 91 (see TABLE 4 for definition of $S\phi$ comp)

The associated average profile configuration, in terms of slope, is as follows

Depth range below mean low water	4 feet to 12 feet	12 feet to 18 feet	18 feet to 24 feet	24 feet to 30 feet
Average slope	1 22	1 29	1 50	1 167

The natural berm elevation is located at an elevation of about 8 feet above mean low water The foreshore slope, extending from the berm crest to a depth of about -2 feet mean low water, averages 1 on 8 Between the -2 and -4-foot contours, the profile is characterized by an alongshore trough and submerged bar Typical profiles are shown on FIGURE II

Winds On an annual basis, winds blow onshore 38 8 percent of the time and offshore 50 0 percent of the time, with 11 2 percent representing calm conditions With reference to onshore winds, 50 7 percent occur from the northeast and east Normal wind speeds range up to 20 knots

Waves During the fall and winter months, waves approach the area more frequently from the northeast and east, producing north to south littoral currents During the spring (March, April, and May), a transition period is observed during which waves attack the shore with almost equal frequency from all directions, resulting in frequent reversals in the direction of littoral transport During the summer, waves are more likely to come from the southeast and south and produce northward drift On an annual basis, the predominant direction of wave attack, in terms of energy level, is from the northeast and east, producing a net drift to the south The most frequent waves affecting the area have heights ranging from 1 to 5 feet and periods of from 5 to 10 seconds

Littoral currents Littoral current observations have indicated that during northeast and east wave attack, littoral currents north of station 140+00 are less than those south thereof During southeasterly and southerly attack, currents north of station 140+00 were observed to be stronger than those south of that location

Tides The normal tidal range in the vicinity of Carolina Beach is about 4 0 feet The average spring range is 4 7 feet Storms, particularly hurricanes, can cause considerable variation in these normal tides For example Hurricane Hazel (15 October 1954) generated a tide of 12 7 feet above mean-low-water datum, which is the highest recorded tide in the study area

SHORE PROCESSES - CAUSE AND EFFECT RELATIONSHIPS

General Prior to 1952, the shoreline between Masonboro Inlet, located 11 miles north-northeast of Carolina Beach, and New Inlet, located 9 miles south-southeast of Carolina Beach, constituted a continuous physiographic unit This shoreline reach was characteristic of the general coastline of North Carolina, being comprised of plain, unobstructed sandy beach areas subject to reversals in the direction of littoral transport, but with a predominant southward movement of littoral material The long-term average annual recession of the waterline was estimated to be of the order of magnitude of 1 foot

In September 1952, local interests excavated a tidal inlet at a point approximately 7,500 feet north of the town limits of Carolina Beach, thus providing for the immediate area a direct connection between the Atlantic Intracoastal Waterway (AIWW) and the Atlantic Ocean (see FIGURE I) This inlet, later to be known as Carolina Beach Inlet, rapidly developed as a permanent coastal feature having a low-waterline width of 550 feet and an associated cross-sectional area of 6,500 square feet The ebb and flood flows are 300×10^6 and 450×10^6 cubic feet, respectively Immediately following the development of this inlet, severe erosion was evidenced at the south shoulder of the inlet and has, over the 17-year period of the inlet's existence, progressed southward to the extent of seriously affecting the performance of the beach-restoration and hurricane-protection project constructed in 1965 along the 14,000 lineal feet of shoreline fronting the town of Carolina Beach Though the effects of the inlet on the downdrift shore have been recognized for some time, in a broad qualitative sense, the full assessment of the shore processes involved and the quantification of the phenomena required the detailed synthesis of data accumulated in the 17-year period, 1952-1969 (the bulk of which were obtained between 1965 and 1969), in connection with a survey monitoring program involving the shores of Carolina Beach northward to and including the inlet complex It has been through the collection of these data, as well as other recent information related to nearby shores, that a rational appraisal of the general problem can be made

The total length of shoreline germane to this discussion extends 21,100 lineal feet between Carolina Beach Inlet and station 0+00 at the southern terminal of the Carolina Beach project This reach of shoreline can be divided into three units, each of which has responded to shore processes in a distinctly different manner, though the causative factors are interrelated These units are designated herein as (a) Segment I - the 10 000 lineal feet of shore northward from station 0+00 at the south end of the Carolina Beach project to project station 100+00, (b) Segment II - the 4,000 lineal feet of shore extending northward from project station 100+00 to station 140+00 at the north end of the Carolina Beach project, and (c) Segment III - the 7,100 lineal feet of undeveloped shoreline between the Carolina Beach town limits and Carolina Beach Inlet

Segment I Survey records for the 19-year period, 1938 to 1957, reported in the original Carolina Beach project report show that the average annual recession rate was approximately 1 foot per year with a short-term maximum rate of 2 8 feet being observed in the period 1952-1957, during which the area had been exposed to four major hurricanes The volumetric loss of material for the entire active beach profile was estimated to be approximately 4 cubic yards per lineal foot of beach annually

Following the placement of artificial fill along Segment I, in connection with the construction of the Carolina Beach project, the effects of shore processes in this area were radically different during the first 2 years of project operation than those determined from historical records During these first and second years of project operation, April 1965-April 1966 and April 1966-April 1967, the shoreline receded at an average annual rate of 67 feet and 15 feet, respectively, with corresponding volumetric losses of fill material amounting to 370,000 cubic yards and 342,000 cubic yards In the third year of operation, April 1967-April 1968, a marked change occurred in the response of the artificial fill to shore processes, as the rate of shoreline recession decelerated to 5 feet per year and the volumetric change of material amounted to a slight accretion of about 17,000 cubic yards Shoreline movements and volumetric changes following project construction are given in FIGURE III and TABLE 2, respectively Surveys in 1969 indicate that the project is in essentially the same condition as observed in 1968 Full verification of the present project condition will depend on the results of surveys conducted in the summer of 1969 and winter period of 1970 However, on the basis of existing information, it can be assumed that the section of the Carolina Beach project within Segment I of the study area required 2 years of exposure to reach a state of dynamic equilibrium with the prevailing environment

The rapid recessions of the waterline in Segment I during the first 2 years of project operation were a result of profile adjustment along the active profile which terminates at depths between -22 and -30 feet mean low water, as well as net losses in material volume resulting from natural sorting action displacing fine material, which was incompatible with energy levels on the active profile, to depths seaward of the active profile Reference is made to FIGURE II, which shows the typical beach profile in Segment I prior to construction of the Carolina Beach project and the original design project profile It will be noted that the foreshore and offshore design profile slope of 1 on 20 terminates at a depth of 4 feet below mean low water and deviates from the natural profile by the exclusion of the offshore bar and trough situated at a depth of 4 to 6 feet below mean low water The adjusted project profile of April 1968 also given on FIGURE II, shows the actual profile closing at a depth of about 22 feet below mean low water, as well as the characteristic bar and trough Thus, displacement of the initial fill with the concomitant reduction of the onshore design section, was an inevitable eventuality of normal sorting action and the reestablishment of the normal profile configuration Note that the actual profiles shown on FIGURE II are for the month of April, during which average annual profile conditions obtain in the vicinity of Carolina Beach

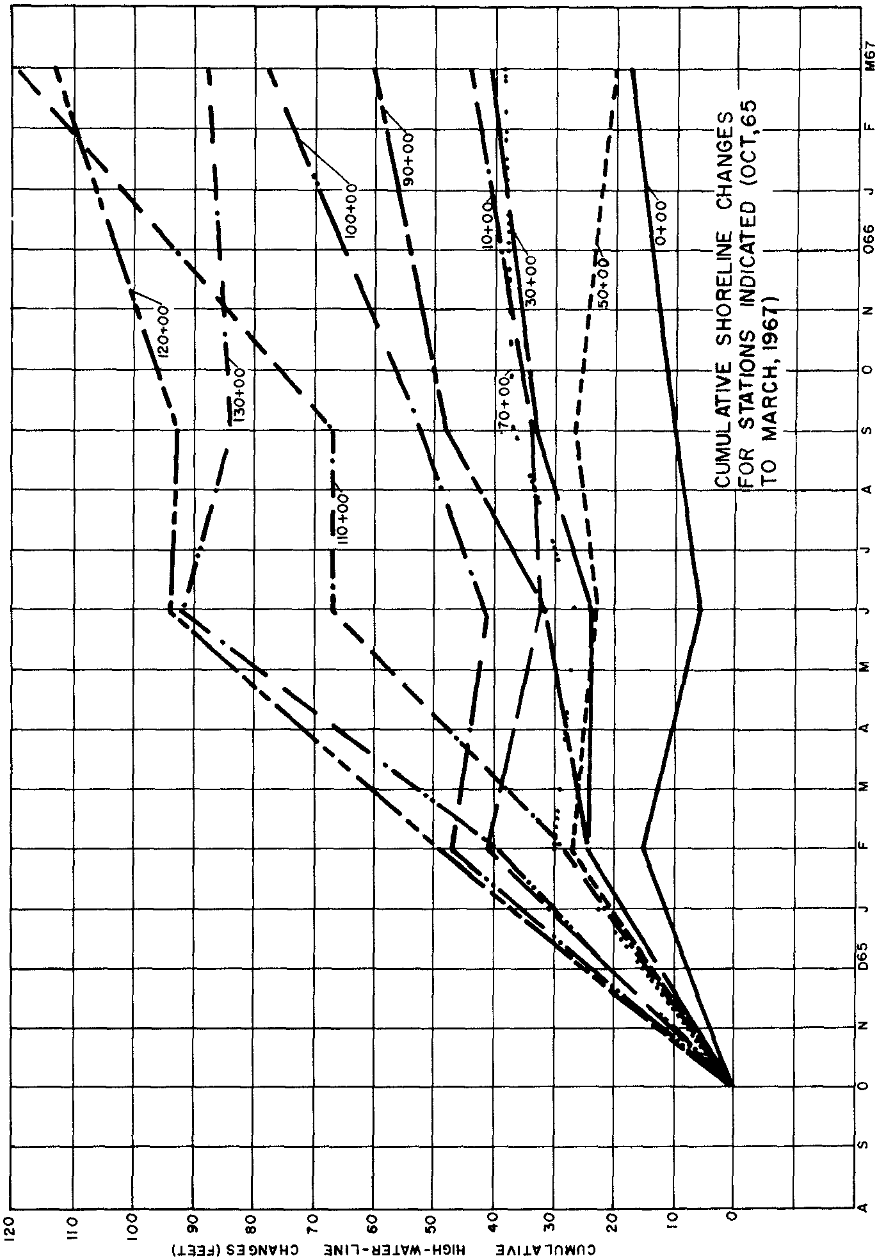

CUMULATIVE SHORELINE CHANGES FOR STATIONS INDICATED (OCT,65 TO MARCH, 1967)
CUMULATIVE HIGH-WATER-LINE CHANGES (FEET)
0
10
20
30
40
50
60
70
80
90
100
110
120
A
S
O
N
D65
J
F
M
A
M
J
J
A
S
O
N
D66
J
F
M67
0+00
10+00
30+00
50+00
70+00
90+00
100+00
110+00
120+00
130+00

FIGURE III

TABLE 2

Total volumetric change since construction of the project
(SEGMENT I - station 0+00 to station 100+00)

Period	Volumetric change during period (cubic yards)	Cumulative volumetric change by end of period (cubic yards)
As built to June 1966	-435,300	-435,300
June 1966 to September 1966	-143,800	-579,100
September 1966 to December 1966	-7,100	-586,200
December 1966 to May 1967	-172,000	-758,200
May 1967 to June 1967	+257,800	-500,400
June 1967 to October 1967	-29,000	-529,400
October 1967 to February 1968	-326,400	-855,800
February 1968 to April 1968	+156 700	-699,100
April 1968 to August 1968	+75,400	-623,700

NOTE + = accretion, - = erosion

Two computations were made in an attempt to determine the degree to which sorting of the original borrow material affected the rate of erosion of the project fill The first computation consisted of a mathematical comparison of the size characteristics of the original borrow material to the size characteristics of the material composing the beach profile The results of this computation indicated that for every cubic yard of borrow material remaining on the profile, 2 1 cubic yards of this material had to be sorted The ratio of the total material sorted to the amount remaining on the profile after sorting action has occurred, as defined by W C Krumbein and W R James[1], is referred to as the "critical ratio" ($R\phi crit$), where

$$R\phi crit = \left[\frac{S\phi_b}{S\phi_n}\right]\left[e^{-\frac{(M\phi_n - M\phi_b)^2}{2(S\phi_n^2 - S\phi_b^2)}}\right]$$

in which

$S\phi_b$ = standard deviation of borrow material, in phi units (1 28 in this case, see TABLE 3)

$S\phi_n$ = standard deviation of native material, in phi units (0 91 in this case, see TABLE 1)

$M\phi_b$ = phi mean of borrow material (0 88 in this case, see TABLE 3)

$M\phi_n$ = phi mean of native material (1 69 in this case, see TABLE 1)

[1]See U S Army Coastal Engineering Research Center Technical Memorandum No 16, "A Lognormal Size Distribution Model for Estimating Stability of Beach Fill Material "

TABLE 3

Characteristics of original fill material placed between stations 0+00 and 100+00 - Segment I

Range	Sample elevation (m l w)	Phi mean (Mϕ)	Phi standard deviation (Sϕ)	Phi variance (Sϕ^2)
10+00	11	0 52	1 27	1 61
	9	0 02	1 82	3 31
	7	0 62	1 43	2 04
	5	0 70	1 38	1 90
	3	1 30	1 25	1 56
20+00	11	0 70	1 20	1 44
	9	0 45	1 27	1 61
	7	0 70	1 20	1 44
	5	1 27	0 84	0 71
	3	1 50	0 80	0 64
30+00	11	0 99	1 14	1 30
	9	0 77	1 07	1 14
	7	0 33	1 54	2 37
	5	0 84	1 24	1 54
	3	1 70	1 10	1 21
40+00	11	1 67	0 72	0 52
	9	1 31	0 78	0 61
	5	0 68	1 18	1 39
	3	1 00	1 19	1 42
50+00	11	0 53	1 33	1 77
	9	0 56	1 22	1 49
	7	1 33	1 13	1 28
	5	0 78	1 20	1 44
	3	1 74	0 75	0 56
60+00	11	1 21	1 01	1 02
	9	0 66	1 86	3 46
	7	0 28	1 64	2 69
	5	0 39	1 41	1 99
	3	1 01	1 41	1 99
70+00	11	1 20	1 40	1 96
	9	0 85	1 37	1 88
	7	0 37	1 13	1 28
	3	1 10	1 10	1 21
80+00	9	0 68	1 51	2 28
	7	0 77	1 31	1 72
	5	1 20	0 85	0 72
	3	1 05	0 97	0 94
90+00	11	0 73	1 44	2 07
	9	0 70	1 50	2 25
	7	0 94	1 00	1 00
	5	1 04	1 06	1 12
Average		Mϕ = 0 88		S^2 = 1 56

The composite phi variance (Sϕ^2comp) and standard deviation (Sϕcomp) are computed by

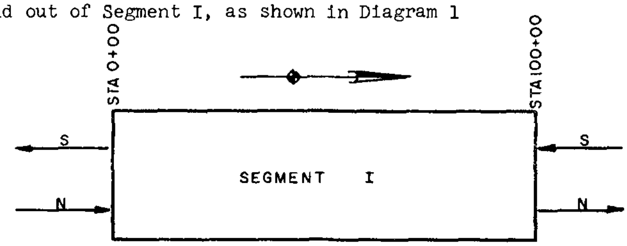
$$S\phi^2\text{comp} = S^2 + \frac{(B-A)^2}{12} = 1\ 56 + \frac{(0\ 92)^2}{12} = 1\ 63$$

$S\phi comp = 1\ 28$

Where A is the average of the minimum phi-mean values obtained along the various ranges The value B is the average of the maximum phi-mean values

The second computation consisted of a determination of the ratio of borrow material placed within Segment I, which was subjected to sorting action, to the amount of that material which remained on the profile at the end of approximately 2 years of project operation The ratio thus determined was 2 3, which compares extremely favorably with the computed "critical ratio " Since the two independent checks of this ratio resulted in essentially the same value, the implication is that most of the material lost from the project in Segment I was the result of sorting action displacing fine-grain material to depths seaward of the active profile It is remarked that the entire artificial fill was not exposed to hydraulic action during the 4 years of project operation and this fact was accounted for in the sorting computations Had the artificial fill been exposed to a storm of hurricane intensity with the attendant severe churning of the beach profile cover, larger quantities of fill would have been exposed to sorting action and the net losses of material would have, doubtless, been greater It is worthy of mention that the analytical procedure used in arriving at the value of the "critical ratio" was not developed during the design phase of the Carolina Beach project Had this procedure been available, the material losses experienced by the project in Segment I could have been predicted with a remarkably high degree of accuracy

Insofar as the present conditions are concerned, the relative stability of the project in Segment I is apparently due to the balance of alongshore transport into and out of Segment I, as shown in Diagram 1

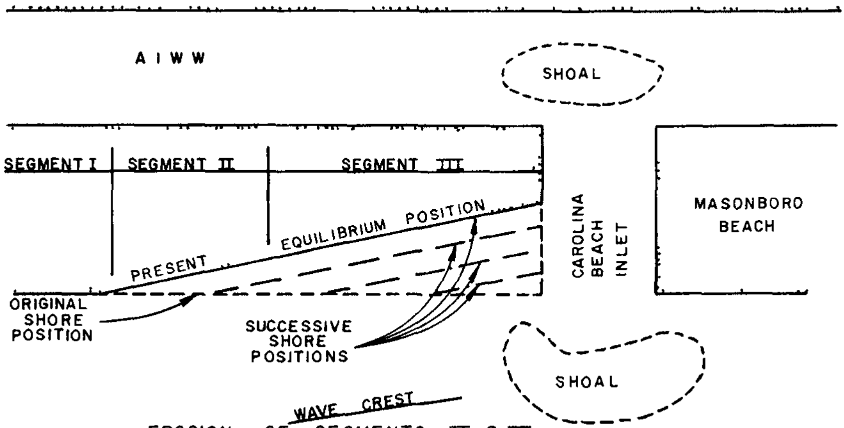


WHERE S=TOTAL SOUTHBOUND LITTORAL DRIFT
N=TOTAL NORTHBOUND LITTORAL DRIFT

PRESENT ALONGSHORE PROCESSES IN SEGMENT I

DIAGRAM I

Segment II and Segment III Prior to the opening of Carolina Beach Inlet in 1952, the shorelines of Segments II and III were continuous with, and on the same alignment as, Segment I Therefore, the behavior of the entire shore area was more or less uniform However, immediately following the opening of the inlet, dramatic changes began occurring in Segment III and, with time, progressed southward into Segment II In the period 1952-1963, prior to the construction of the Carolina Beach project, the high-water line receded 1,135 feet at the shoulder of Carolina Beach Inlet, the north end of Segment III, and 37 feet at station 100+00, the south end of Segment II The difference in the extent of recession near the inlet and at station 100+00 resulted in a change of alignment of the combined shoreline of Segments II and III with respect to Segment I This change of alignment, which was later to have a prominent role in the behavoir of the artificial fill in Segment II, was a natural development resulting from a deficit of littoral drift from the north, caused by material entrapment in the inlet shoal system By way of a brief qualitative analysis of this phenomenon, the following explanation is given The alongshore movement of littoral material results from the existence of an alongshore current generated by the obliquity of the wave crests attacking the shore, in other words, it can be assumed that, if the breaking-wave crests are parallel to the shore, little or no alongshore current exists and, consequently, there is no alongshore movement of beach material When there is a substantial reduction in the quantity of littoral material to a segment of shore, that shore will erode to the extent of reaching some new state of equilibrium with the eroding forces This was accomplished in Segment III, and to a smaller degree in Segment II, by the shore retrograding to an alignment approaching parallelism with the general approach of wave crests from the northeast sector of attack As any given section of shore attains near parallelism with the attacking wave crests, it ceases to supply large quantities of material to the adjacent downdrift section, resulting in a downdrift progression of the erosion, as shown in Diagram 2



EROSION OF SEGMENTS II & III

DIAGRAM 2

Of course, wave attack along the area of interest is neither uniform nor unidirectional and, moreover, there is some natural bypassing of material across Carolina Beach Inlet However, the generalization outlined above is not only rational, in a theoretical sense, but validated by the time - space relationships of the erosion in Segments II and III, presented in TABLE 4 PHOTOGRAPH 1 clearly shows the change of shore alignment

Immediately following the placement of artificial fill along Segment II in March 1965, severe erosion began and continued at an intense rate to March 1967 The cumulative shore recession in the 2-year period, March 1965-March 1967, amounted to 140 feet, with an attendant loss of 550,000 cubic yards of material, or an average annual loss in the 2-year period of 275,000 cubic yards As a result of this severe erosion, emergency measures were implemented for Segment II in March 1967 by the construction of a groin at station 136+75 and the addition of 321,000 cubic yards of fill, of which 284,000 cubic yards were placed south of the groin and approximately 37,000 cubic yards were placed north of the groin The emergency work was completed in May 1967 By May 1968,

PHOTOGRAPH 1 - VIEW NORTHWARD OVER CAROLINA BEACH PROJECT IN 1965. NOTE CHANGE OF SHORE ALIGNMENT CENTER BACKGROUND OF PHOTOGRAPH.

PHOTOGRAPH 2 - VIEW OF CAROLINA BEACH INLET IN 1969. NOTE OFFSET BETWEEN INLET SHOULDERS, AND WAVE REFRACTION PATTERN.

1 year after the placement of emergency fill, the net loss of this material amounted to 203,000 cubic yards, of which 175,600 were lost between stations 100+00 and 132+50 It is noted that, notwithstanding the groin, losses of emergency beach material in Segment II were extremely high, particularly in view of the fact that conditions observed in Segment I showed that the general area was experiencing some natural accretion in 1968 The rates of shoreline movements in Segment II, shown in comparison with shore-movement rates in Segment I, are presented on FIGURE III Volumetric changes in Segment II are given in TABLE 5

TABLE 4

Rate of shoreline movement at specified stations within Segment II and Segment III (1952-1963) (rate in feet per year)

Segment and station	Time period			
	1952-55	1955-57	1957-63	1952-63
SEGMENT II				
100+00	+3 0	-7 0	-5 3	-3 3
110+00	-3 7	-3 5	-7 8	-5 8
120+00	-9 7	-5 5	-9 0	-8 5
130+00	-12 0	-6 0	-13 0	-10 5
140+00	-14 0	-19 0	-43 0	-26 7
SEGMENT III				
150+00	-13 6	-25 0	-57 0	-39 4
160+00	-10 3	-60 0	-68 7	-51 0
170+00	-10 0	-107 0	-76 5	-63 9
180+00	-8 3	-139 0	-91 2	-77 2
190+00	-6 7	-156 0	-80 3	-74 0
200+00	-53 3	-100 0	-129 1	-103 2

NOTE + = accretion, - = erosion

TABLE 5

Total volumetric change since construction of the project (SEGMENT II - station 100+00 to station 140+00)

Period	Volumetric change during period (cubic yards)	Cumulative volumetric change by end of period (cubic yards)
As built to June 1966	-412,200	-412,200
June 1966 to September 1966	-64,300	-476,500
September 1966 to December 1966	-58,300	-534,800
December 1966 to March 1967	-15,200	-550,000
March 1967 to May 1967	[1]+284,000	(Fill)
May 1967 to June 1967	-54,400	-604,400
June 1967 to October 1967	-60,100	-664,500
October 1967 to February 1968	-158,000	-822,500
February 1968 to April 1968	+67,100	-755,400
April 1968 to August 1968	-9,300	-746,100

[1]Not included in cumulative total

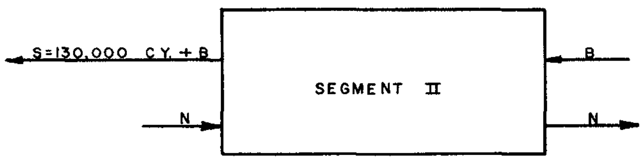
NOTE + = accretion, - = erosion

The quality of fill material placed in Segment II with the initial construction of the Carolina Beach project and later as part of the emergency measures was compared with the quality of borrow material used in Segment I, and it was found that all of the material was essentially of the same quality Therefore, it can be assumed that the "critical ratio" for all the material placed in Segment II was of the order of magnitude of 2 Considering that the total loss of material in Segment II during the 3-year period, May 1965-May 1968, amounted to 753,000 cubic yards, the average annual loss of material from this area can be taken as 251,000 cubic yards Of the total annual loss, a portion is allocated to sorting-action displacement to depths seaward of the active profile and the remaining portion is allocated to a deficit in the alongshore transport into Segment II This deficit in alongshore transport, which in fact is the deficit in material transport imposed by Carolina Beach Inlet, is easily computed by applying the "critical ratio" to the total average annual loss of material experienced in Segment II, that is

$$\begin{array}{c}\text{Alongshore deficit}\\ \text{in material transport}\\ \text{(littoral drift)}\end{array} = \frac{251{,}000}{2} = 125{,}500 \text{ cubic yards}$$

(say 130,000 cubic yards)

The shore processes in terms of annual alongshore movements in Segment II are represented schematically in Diagram 3 It is evident from Diagram 3 that the total annual alongshore transport phenomenon cannot be described without the development of two other conditions through which the values of B and N can be computed Such conditions can be developed, as demonstrated below, by making certain assumptions, one of which is that all observed annual values of littoral transport represent average annual values over a relatively long period, specifically, the 17-year period, 1952-1969, in which Carolina Beach Inlet has been in existence



S = TOTAL SOUTHBOUND DRIFT OUT OF SEGMENT II

N = TOTAL NORTHBOUND DRIFT INTO AND OUT OF SEGMENT II

B = MATERIAL BYPASSING INLET AND TRANSPORTED ALONG SEGMENT III TO SEGMENT II

ALONGSHORE MOVEMENTS IN SEGMENT II

DIAGRAM 3

In order to obtain a relatively accurate value of B, it is necessary to have a measured value of S, the total southbound drift Such a value is available for the period June 1966-June 1967 for the shore of Wrightsville Beach, located 9 miles north of Carolina Beach (see FIGURE I) It is remarked that Wrightsville and Carolina Beaches are exposed to the same wave climate and are composed of essentially the same material In June 1966, a 3,600-foot-long weir-type jetty was constructed on the south end of Wrightsville Beach, at Masonboro Inlet During the period June 1966-June 1967, approximately 150,000 cubic yards of littoral material were transported by natural forces across the weir section of the jetty and deposited in the lee-side deposition basin In addition, an estimated 70,000 cubic yards of material accumulated on the updrift side of the jetty in the form of an accretion fillet Therefore, the total southbound drift, S, was approximately 220,000 cubic yards, presuming that the accretion fillet, being small during the first year of jetty operation and in the shadow zone of the jetty, was not exposed to attack by waves from the southeast sector Referring to Diagram 3, B = 220,000 cubic yards minus 130,000 cubic yards, or B = 90,000 cubic yards

At this point, only the value of the northbound drift, N, remains to be computed For the determination of this value, conditions at Carolina Beach Inlet are used to develop a continuity relationship for the total alongshore movement of material Here, the assumption is made that, contrary to the natural southward bypassing of 90,000 cubic yards of material at Carolina Beach Inlet, there has been no significant northward bypassing at the inlet The rationale on which this assumption is based is as follows First, bypassing of material at an inlet is highly dependent on storm activity, as wave crests, encroaching on the sea shoal during normal sea conditions, are refracted to such an extent that they split and approach the inlet throat from both the updrift and downdrift directions, making bypassing difficult This phenomenon is easily observed in the field or from aerial photographs and, in fact, is the reason for the multiple, confused chop existing on shoals Moreover, the refraction phenomenon can, as at Carolina Beach Inlet, create permanent, but shifting, nodal zones on the shores near and adjacent to the inlet However, during storm activity with attendant storm tides, high-energy levels, and short-period waves which are not too susceptible to refraction, natural bypassing can be accomplished Therefore, since most storm activity to which Carolina Beach Inlet is subjected comes from the northeast sector of exposure, it can be assumed that the largest proportion of natural bypassing is in a southward direction The second reason that bypassing in a northward direction is assumed small relative to southward bypassing is that the ocean shoreline on the north shoulder of the inlet is offset seaward from the shoreline on the south side by a distance of approximately 1,500 feet (see PHOTOGRAPH 2) This offset doubtless restrains the northward movement of material across the inlet The phenomenon discussed above, insofar as normal sea conditions are concerned, is schematized in Diagram 4 Note that there would be no change in the general refraction pattern for normal conditions if the deepwater wave crest approached from the northeast quadrant under normal sea conditions The actual refraction phenomenon is readily discernible in PHOTOGRAPH 2

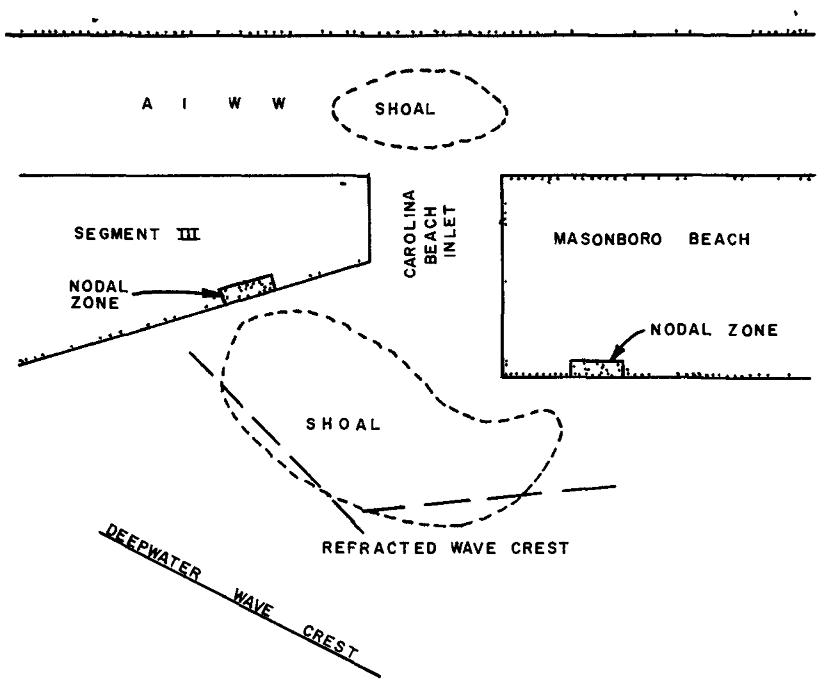


DIAGRAM 4

With acceptance of the assumption that northward bypassing at the inlet is insignificant, the value of the total northbound drift, N, can be computed by determining the total volume of material accumulated in the inlet complex during its 17 years (1952-1969) of existence The total accumulation was determined from hydrographic surveys, dredging records in the AIWW, at the inlet throat, and from aerial photographs This accumulation amounted to 4,160,000 cubic yards, of which 3,250,000 cubic yards were stored on the sea shoal, 680,000 cubic yards were deposited and removed from the AIWW, at the throat of the inlet, and 230,000 cubic yards were flushed into the marshes of Masonboro Beach at a point approximately 2,000 feet north of Carolina Beach Inlet as a result of a breakthrough which occurred during Hurricane Hazel in 1954 This breakthrough remained open as a small inlet for approximately 4 years, and was closed by natural forces With a total storage of 4,160,000 cubic yards in a 17-year period, the average annual accumulation rate is 245,000 cubic yards The value of N is determined from the continuity relationship

$$N + S - B = \text{Accumulation in the inlet}$$

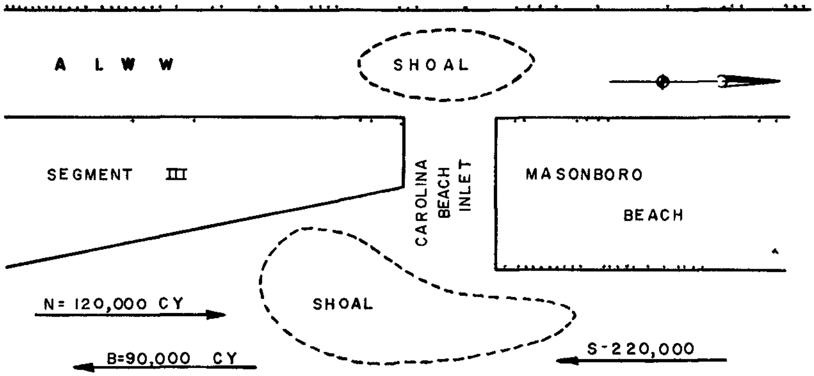
or

$$N + 220,000 - 90,000 = 245,000$$

$$N = 115,000 \text{ cubic yards}$$

$$(\text{say } N = 120,000 \text{ cubic yards})$$

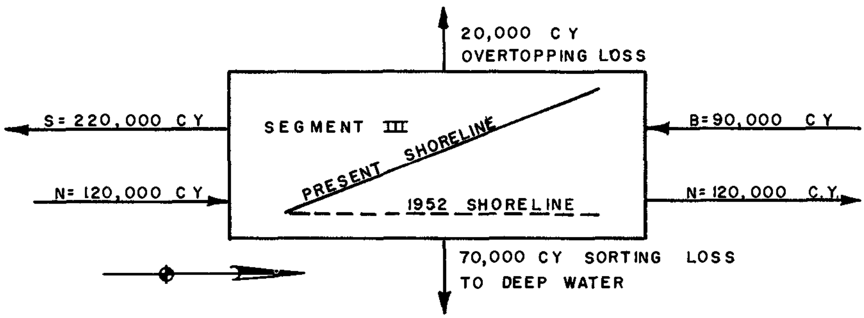
A schematic flow diagram of the computed average annual littoral process at the inlet is given in Diagram 5



LITTORAL PROCESSES AT CAROLINA BEACH INLET

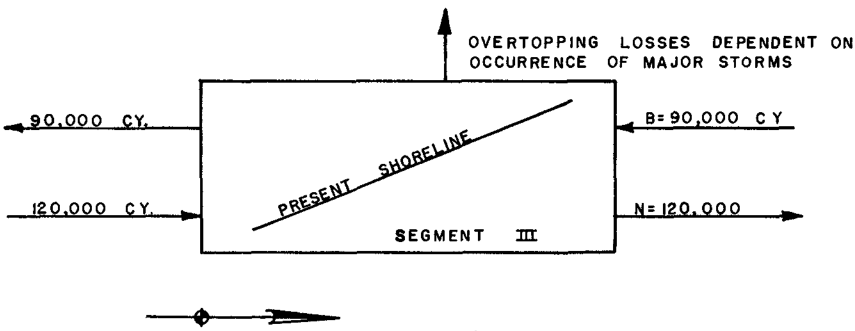
DIAGRAM 5

To formulate a complete shore-processes scenario for the Carolina Beach area, conditions along Segment III of the study area were also investigated Surveys indicate that the total quantity of material eroded from Segment III during the 17-year period, 1952-1969, amounted to approximately 3,670,000 cubic yards, which results in an average annual loss of about 220,000 cubic yards, however, it was shown previously that the average annual deficit of material imposed by the inlet amounted to only 130,000 cubic yards Thus, the remaining 90,000 cubic yards must be accounted for These losses can, with reasonable assurance, be attributed to material lost from the beach profile through wave and/or tidal overtopping of Segment III and the quantity of material displaced seaward of the active beach profile as a result of sorting action In connection with wave and tidal overtopping, Segment III is a low barrier ridge with a general maximum elevation between 4 and 5 feet above mean sea level Therefore, wave and/or tidal overtopping is a frequent occurrence in this area during any given year, however, major overtopping losses are associated with hurricane events From aerial photographs and existing topography, it was determined that the landward side of Segment III accreted westward into the adjacent marsh at a rate of approximately 20,000 cubic yards per year Thus, there remains a value of 70,000 cubic yards lost through sorting action In view of the severe erosion of the landmass in Segment III, it can be assumed that sorting losses were substantial The assumed sorting action loss of 70,000 cubic yards results in a "critical ratio" of $[220,000/(220,000 - 70,000)] =$ 1 47, which is not at all an unreasonable value It is also noted that the quantity of material attributed to sorting losses beyond the active profile represents approximately 32 percent of the total loss This corresponds closely to the "rule-of-thumb" value of 30 percent used, in the vicinity of Segment III, in determining the quantities of fine silt, peat, and clay lost in the placement of dredged fill It is remarked that exposed peat laminae are found along much of the Segment III shoreline The shore-processes scheme for Segment III is illustrated schematically in Diagram 6 It should be noted that the shore processes described above for Segment III relate to average conditions prevailing over the 17-year period that this section of shore was adjusting to a new equilibrium condition as a result of changes produced in the littoral regime by Carolina Beach Inlet As mentioned above, Segment III has generally attained a state of equilibrium through erosion and a reorientation of the shoreline At present, the major effects of the littoral material deficit imposed by the inlet have been transferred to Segment II



AVERAGE ANNUAL PROCESSES 1952 TO 1969

DIAGRAM 6(a)



PRESENT CONDITIONS

DIAGRAM 6 (b)

Verification of computed values A condition used to verify the computed values, specifically N and S, is taken at Masonboro Inlet, which is exposed to the same gross littoral drift as Carolina Beach Inlet In the 4-year interval, 1965-1969, two hydrographic surveys show that approximately 900,000 cubic yards of material have been deposited on the outer and inner shoals of Masonboro Inlet In addition, approximately 170,000 cubic yards were removed from the inlet by hopper dredges in the period 1965-1969 Therefore, the total accumulation within the inlet during a 4-year period amounted to approximately 1,070,000 cubic yards, resulting from the intrusion of southbound and northbound drift On an average annual basis, the deposition rate is about 270,000 cubic yards Furthermore, the growth of the accretion fillet along Wrightsville Beach, updrift of the Masonboro Inlet Jetty, has an accretion rate of about 60,000 cubic yards per year for the 2-year period 1966 to 1968 Construction of the jetty began August 1965 and was completed June 1966 If it is assumed that the average of the 2-year fillet growth rate is representative of an average annual growth rate for the 4-year period of 1965-1969, the gross drift toward the inlet would be 270,000 cubic yards + 60,000 cubic yards = 330,000 cubic yards, which compares extremely well with the value N + S = 340,000 cubic yards Note that natural inlet bypassing was not considered, as the inlet shoals are well shadowed by the jetty, also, the 1965-1969 period was free of major storm activity

Conclusion The analysis presented above results in a rational understanding of shore processes in the study area from 1952 to the present It is remarked that the quantitative values determined in the analysis represent only the average annual conditions for the data period of record used, and, moreover, insofar as shore processes are extremely nonuniform, wide variations from average annual values can occur in any given short-term period

In closing, it is remarked that detailed plans for solving the erosion problem described herein have been formulated and are presently under review