CHAPTER 45

COASTLINE CHANGES NEAR A TIDAL INLET

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ABSTRACT

Extensive coastline changes around the Ponce de Leon Tidal Inlet, Florida, are described, discussed and explained. These changes started developing immediately after the beginning of the construction of two jetties on both sides of the inlet forming part of a plan to stabilize the inlet, improve navigation conditions and bypass sand effectively. The mean annual littoral transport of sand was considered to be from north to south.

Rapid sand accretion south of the south jetty started immediately after the beginning of its construction in 1969, reaching by November, 1971, a volume of approximately 1,400,000 cu. yds. Aerial photographs suggest that the sand was transported there from the south during the summer periods of northerly drift and from the offshore bar by refracted waves from the north. The accumulated sand is well protected by the south jetty during the winter storms from the northeast. Coastline and duneline recession occurred north of the inlet due, at least partially, to the described sand retention.

It is concluded that for inlets where the littoral drift reverses its direction, the net annual rate of littoral transport is not a unique design criterion. Instead the total sand volumes transported annually in either direction should be considered.

INTRODUCTION

The importance of estuaries and bays as centers of population growth and industrial development is well-known, and man's historical development has been closely linked with these two geomorphological features. It is sufficient to only mention that about one-third of the population of the United States lives and works near estuaries and that most of the world's large metropolitan areas, such as London, New York, Tokyo, Shanghai, Buenos Aires, San Francisco, Osaka, Montreal and New Orleans, border estuarine and bay areas.

Estuaries and bays are semienclosed water bodies with one or more free connections with the open sea through which the tidal energy and the sea salts are transmitted. When the discharge of fresh water derived from upland sources is sufficient to measurably dilute the sea water within the semienclosed body then the latter is called an estuary, (1),* otherwise it is referred to as a bay.

Geomorphologically bays and estuaries can be classified into the following four subdivisions (1): (a) drowned river valleys; (b) fjords; (c) bar-built and (d) generated by tectonic processes. The first, and most common, type has been formed by the inundation of an alluvial plain by sea water during the postglacial period. It is normally characterized by an abundance of fresh water supply and river born sediment, flat slopes and relatively low depths. The second, encountered predominantly in zones subjected to heavy glaciation, are inundated U-shaped valleys gouged out by glaciers. They have narrow long shapes, high depths, a shallow entrance sill in certain cases and steep ground slopes. Fresh water supply may or may not be significant. The third type is formed where offshore barriers, sand islands and spits build above sea level forming a chain between headlands broken by one or more inlets. The enclosed water body has generally an elongated shape parallel to the main coastline. Similar sand barriers can be formed across the mouth of drowned river valleys in the presence of intense littoral sand transport. The fourth subdivision is very general and it encompasses all these coastal indentures formed by faulting and local ground subsidence.

Navigation is particularly critical through tidal inlets between sand barriers due to: (a) gradual shifting of the inlet in the dominant direction of sand transport; (b) shoaling and shifting of the natural channels; (c) existence of an offshore bar, completely or partially submerged with relatively shallow depths and intense wave breaking and (d) intense currents due to tides and to wave action.

Stabilization of such tidal inlets and improvement of navigation conditions has been one of the major problems confronting coastal engineers. The normal method of inlet improvement has been to provide jetties flanking the inlet channels. Such jetties, however, obstruct the littoral transport of sand, so that sand accretion at the updrift side of the inlet and erosion at the

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*Numbers in parenthesis indicate references at the end of the paper.

downdrift side may develop. Eventually at the updrift side the accumulated sand may reach the offshore tip of the jetty and enter into the channel, whereas at the downdrift side the erosion may reach objectionable proportions. The reestablishment of the sand balance can be accomplished by bypassing the sand artificially from the updrift accretion zone to the downdrift depleted beaches (2,3).

An optimum inlet stabilization system should provide maximum safety to navigation at the lowest possible construction and maintenance cost. A relatively new design consists of two jetties, a submerged weir, forming the near-coast portion of the updrift jetty, and an impoundment basin close to the weir, between the updrift jetty and the entrance channel. The main objectives of the design are: (a) to control the sand accretion at the updrift side of the inlet, by allowing sand to pass over the submerged weir portion of the jetty and (b) to collect any sand passing over the weir into the protected impoundment basin from where it can be conveniently dredged and placed on the downdrift side.

Such a system has recently been completed at the Ponce de Leon Inlet in Florida, U.S.A. A project supported by the Coastal Engineering Research Center of the U.S. Army Corps of Engineers was initiated in the summer of 1970 at the University of Florida in order to determine the effect of the jetties on the adjacent coastline and to estimate the percentage of littoral transport passing over the weir and entrapped into the impoundment basin. The coastline changes to February, 1972, north and south of the inlet are herein presented and discussed. These changes already provide valuable information regarding the function of a jetty-weir-impoundment basin system at inlets where the littoral transport periodically reverses its direction although the net drift is always unidirectionally the same on an annual basis.

BACKGROUND INFORMATION

Location and Physical Characteristics

The Ponce de Leon Inlet is located in Volusia County on the east coast of Florida, about 65 miles south of St. Augustine Harbor and about 57 miles north of Canaveral Harbor. Figure 1 shows an aerial photograph of the inlet and of the immediately adjacent area. The inlet connects the Atlantic Ocean with the Halifax River and the Indian River North. The former extends from the inlet northward about 24 miles whereas the latter extends southward from the inlet to the Mosquito Lagoon (4). Both rivers, however, are essentially bar-built tidal estuaries.

Fig. 1. Ponce de Leon Inlet on April 4, 1967.

The mean tidal range is 4.1 ft. in the ocean and 2.3 ft. just inside the inlet. Spring ranges are 4.9 ft. and 2.7 ft., respectively. The estimated mean and spring tidal prisms are 8000 acre-feet and 9000 acre-feet, respectively. The beach is low and flat and, prior to the construction of the jetties, it was 400 to 500 ft. wide just south of the Ponce de Leon Inlet (4).

The beach sand is, like for the most part of the Volusia County, clean, fine, relatively uniform with a mean grain size around 0.2 mm and hard packed. The shell content is very small but it begins to increase about 8 miles south of the inlet resulting in a steeper profile and a softer beach. Past records (4) indicate an average annual recession in the 2-mile reach immediately north of the inlet of about 7 ft. per year. For the 4-mile reach immediately below the inlet shoreline recession is accompanied by accretion of the offshore part of the profile. This phenomenon could be caused by displacement of material from the upper part of the profile offshore into the lower or seaward part of the profile and by similar displacement of drifting material by the "jet effect" of the ebb tide. Moreover, there are indications that the shores in the neighborhood of the inlet underwent periodic revulsions whereby material accumulated on the north beach over a period of some years disassociated itself from the mainland and was transported across the inlet to the south beach, thereby creating an apparent eroding condition north and an accreting condition south of the inlet.

The movement of sand along the ocean shoreline of the South Atlantic coast of the United States varies seasonally. During the summer months gentle winds from the south create waves and swells which move the sand in a south to north direction. However, the more violent northeast waves and storms generate a higher littoral transport rate from north to south so that the predominant annual drift is to the south. The estimated average annual littoral transport rates (4) for the zone between Oregon Inlet, North Carolina,to Key West, Florida vary widely from negligible to a maximum of 500,000 cu. yds.; however, the volume of material being transported past a fixed point onshore in one direction can amount to well over 1,000,000 cu. yds. annually. According to the same estimates the net annual littoral transport in the neighborhood of the Ponce de Leon Inlet is 500,000 cu. yds., i.e., one of the highest. Gross annual drift rates are estimated to be about 600,000 cu. yds. southerly and 100,000 cu. yds. northerly.

Navigation

Navigation through the original natural inlet had always been difficult and hazardous; nevertheless,according to historical accounts, the inlet has been used for navigation for more than two hundred years. A typical fan shaped sandbar lies across the ocean entrance over which intense wave breaking takes place. Inadequate depths across the bar and continuous shifting of the channel crossing that bar cause the principal difficulties and hazards to navigation. In fact prior to the jetty construction the bar-channel shifted so rapidly and so often that it was difficult for the Coast Guard to maintain channel markers in proper positions (5). Substantial shifts have been reported by boatmen occurring between their outbound and inbound passages on the same day. The situation becomes particularly hazardous during periods of low tides and high seas or swells. At least six lives have been reported lost between 1957 and 1963 as a result of boat capsizing in the inlet.

Prior to the present improvement plan, engineering operations to improve navigation conditions in the Ponce de Leon Inlet have been minimal. The earliest engineering structure is a lighthouse provided by Congress in 1882 and constructed shortly after on the north shore of the inlet. From 1936 to 1949 occasional dredging operations were attempted; however, any newly dredged channel filled very rapidly. In September, 1962, the inlet channel extended in an easterly direction with depths ranging from less than 6 ft. across the bar to 35 ft. in the gorge (5).

The Present Inlet Stabilization Plan

In general the project plan, outlined in Fig. 2, consists of an entrance channel, a pair of jetties and an impoundment basin south of the north jetty. The north jetty contains a submerged weir section to allow the southward moving sand to pass over it and deposit in the impoundment basin. This basin would then be dredged periodically with the material being placed on the beach south of the inlet. This design was based on the previously mentioned mean annual rate of littoral southerly drift, an expected rapid accretion north of the north jetty, negligible accretion immediately south of the south jetty and beach erosion further south of the inlet. The design details are given in (6).

The north jetty is composed of 500 ft. of prestressed concrete sheet piling, 1800 ft. of weir and 1750 ft. of rubble mound section. The first 250 ft. section of sheet piling has a crest elvation of +10.00 ft. with the crest of the remaining 250 ft. sloping linearly to an elevation of +4.00 ft. The weir section is composed of a series of prestressed concrete king piles 3 ft. deep and 2 ft. wide with slots for the fitting of the beams. The latter, also of prestressed concrete, are properly keyed to each other. It was intended initially to have an adjustable crest weir; however, because of construction difficulties, the design was changed into a fixed crest weir. The first 300 ft. of the weir crest are at an elevation of +4.00 ft. whereas the crest elevation of the remaining 1500 ft. of the weir is 0.00, which is taken at mean low water level. The crest elevation of the 1750 ft. of the rubble mound offshore section of the jetty is +7.00 ft.

The south jetty has a total length of about 3800 ft. It is entirely rubble mound construction of variable composition (6).

The impoundment basin, shown in Fig. 2, is located between the weir and the channel. Its horizontal area is about 600,000 ft.^{2} and it is to be dredged to an elevation of -20.00 ft. The average natural bottom elevation at the location of the impoundment basin was about -2.00 ft. Thus an 18 ft. initial dredging depth is anticipated corresponding to about 400,000 cu. yds. of dredged material. The outlined design was based on an amount of littoral drift of 310,000 cu. yds. expected to pass over the weir annually.

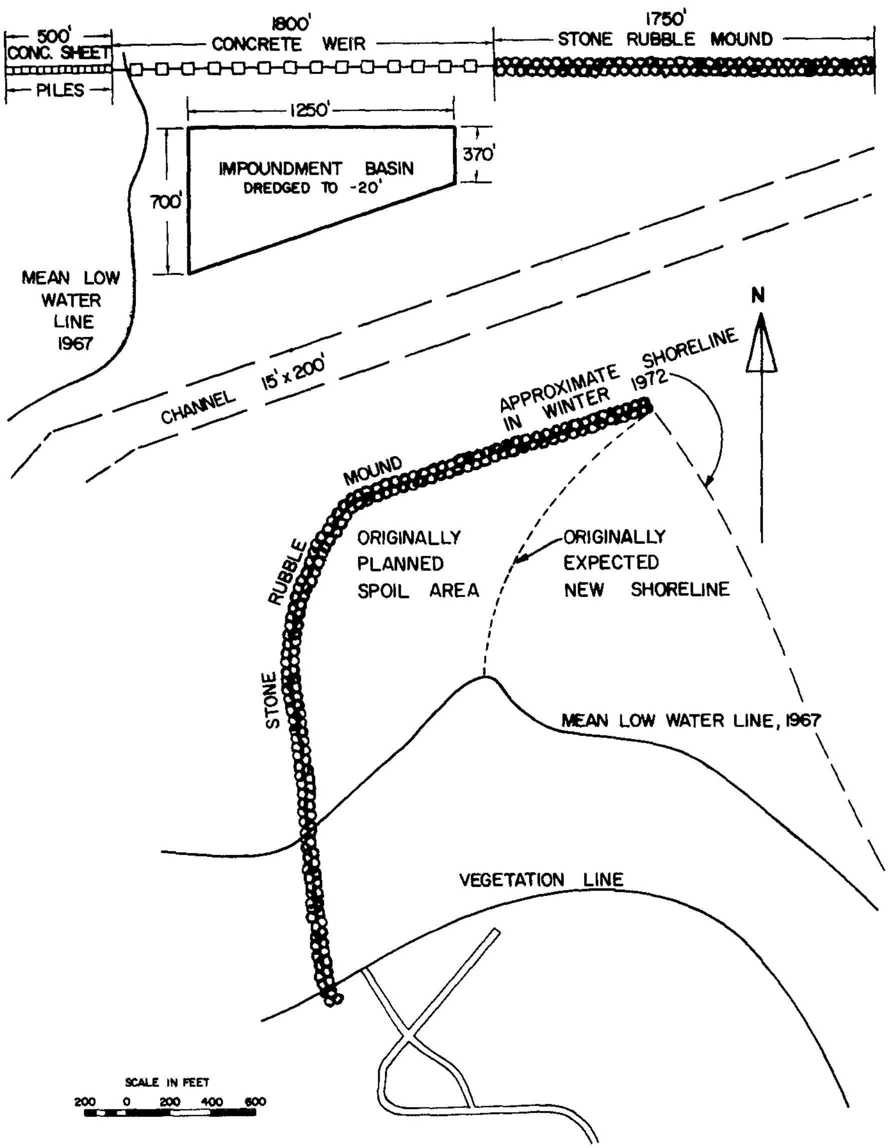

Fig. 2 Outline of the Ponce de Leon Stabilization System

A 7,200 ft. long entrance channel leads from the ocean to the Halifax and Indian River north, where it divides into two inner channels following these two rivers. The entrance channel has been designed with a width of 200 ft., a depth 12 and 15 ft., an overdepth of 2 ft. and a side slope (vertical on horizontal) 1 on 5. Its excavation quantity including the overdepth is 178,000 cu. yds. The inner channels have been designed with a width of 100 ft., depths of 7 and 12 ft., overdepth of 1 ft. and side slopes of 1 to 3. The excavation quantity including the overdepth is 74,000 cu. yds. The initial cost estimate for the entire project was approximately $3,000,000 (6).

The original plans provided distinct dredge disposal sites. Of interest to the present work is that material excavated from the entrance channel and the impoundment basin was to be disposed immediately south of the south jetty in order to assure a strong land connection between the west end of the south jetty and the existing barrier beach. Figure 2 shows an outline of the present shoreline at M.L.W. and of the expected new shoreline after the dredge disposal.

The following have been the various stages of construction in chronological order:

1. The construction of the south jetty started in July, 1968, and was completed in October, 1969.

2. The driving of the sheet piling section of the north jetty started in September, 1968, and was completed in October, 1968.

3. The driving of the king piles of the weir section started in October, 1968, and was completed in March, 1969.

4. The 1800 ft. rubble mound section of the north jetty began in January, 1970, and was completed in July, 1971.

5. The horizontal weir beams were placed between March and July, 1971.

6. The dredging of the impoundment basin began in August, 1971, and was continued to February, 1972, at which time it was interrupted due to bad weather conditions. It was resumed in May, 1972, and it was completed in August, 1972.

7. The dredging of the interior channel on the Indian River began in September, 1971, and was completed in February, 1972.

8. The dredging of the entrance channel started in July, 1971, but it was interrupted in February, 1972, also because of bad weather conditions. That dredging has not been resumed as of July 1, 1972.

THE COASTLINE CHANGES

Dramatic changes in the coastline south of the inlet started occurring immediately after construction of the south jetty. These changes can most readily be observed in a sequence of aerial photographs taken apart at low tides between April, 1967, and February, 1972, at an original scale of 1:9600. Some of these aerials are reproduced in this paper at a scale of approximately 1:21600.

Figure 1 shows the inlet on April 4, 1967, more than a year before the beginning of any engineering operations. The interior and exterior shoals and the main channel can be observed. The large number of breakers is, moreover, indicative of the low offshore bottom slope. The angle of the wave crests with the north coastline suggests a southerly wind direction; however, there is an obvious refraction pattern around the inlet modifying the direction of the wave crests and causing them to converge towards the inlet from both directions.

Figure 3 shows the beach developments at the inlet in August 1969, about a year after the beginning of the construction of the south jetty. The north jetty did not provide until that date any obstruction to littoral transport since only the king piles were driven and the construction platform placed, as shown. Thus, insignificant coastline changes occurred in the north coastline; however, the changes in the coastline south of the south jetty were enormous and spectacular. The coastline at low water level advanced by about 1500 ft. right next to the jetty, about 600 ft. at a distance of 1500 ft. south of the tip of the jetty and about 200 ft. south of the point where the original coastline bends to its north-south direction. The entrapment of water indicates that sand advanced from the south to the jetty bent over the originally shallow offshore zone with part of it passing through the jetty into the inlet. The refraction pattern with wave crests converging to the inlet from both directions is again obvious; so are the offshore shoals as demonstrated by the breakers. A patch of shoal just offshore of the new M.L.W. line and the refraction pattern suggests that sediment is being transported from the offshore shoals towards the beach. Likewise the near coast shoaling patterns immediately south of the north jetty and the direction of the wave crests suggest sand transport inside the inlet.

Fig. 3 Ponce de Leon Inlet - August, 1969

Fig. 4 Ponce de Leon Inlet - December 12, 1969

Figure 4 shows the situation around the inlet on December 12, 1969, i.e., shortly after the completion of the south jetty. The M.L.W. line at the jetty has advanced since August, 1969, by approximately 600 ft. The refraction pattern and the related direction of sand movement to the south coast are about the same as in Fig. 3.

Figure 5 shows the inlet on the 7th of April, 1970. The coastline at the jetty, during these last 4 months advanced only 150 feet seaward in contrast to the 600 ft. advancement during the previous 4 month interval. It appears, therefore, that the sand entrapped south of the south jetty is well protected against the storms from the north, which are dominant from late fall to late spring; in fact the refraction pattern indicates that these storms may even contribute to the building of the south beach by transporting sediment from the offshore bar, which, in turn, is supplied by sediment transported to the inlet from the north. In the same figure, a shoal can be observed creeping to the north, as suggested by its shape and by the pattern of the refracted wave crests. Other significant observations are the increased volume of sand deposited at the inlet west of the north-south section of the south jetty, the beginning of a sand build-up north of the sheet piling section of the north jetty and an initiation of beach erosion south of that sheet piling. Between August, 1969, and April, 1970, the beach immediately north of the sheet piling has advanced by 200 ft. whereas the average recession south of the sheet piling is about 100 ft.

The aerial survey of June 8, 1970, shown in Fig. 6, disclosed little change in the entire situation except some recession north and south of the sheet piling section of the north jetty, which is believed to be a short term phenomenon. However, as Fig. 7 indicates, during the summer of 1970 the beach at the south jetty advanced eastward by approximately another 500 ft. This was the result of a northward advancement of the previously mentioned shoal 2000 ft. south of the jetty first observed in April of 1970. When this shoal reached the jetty it entrapped water thus creating an internal lagoon. Waves and tidal currents initiated subsequently an erosion process with the eroded sand being washed through the breakwater into the inlet. The first 800 feet right south of the jetty from the bend point, which in July, 1970, were covered with dense sand, were submerged by December of the same year even at low tides. The only sand supply to the internal lagoon is wind blown. No significant changes are observed in Fig. 7 in the neighborhood of the sheet piling of the north jetty. The crest of the apparently light waves seem to push sand towards the beach right next to the north jetty platform, whereas the refracted waves further onshore seem to erode the beach south of the sheet piling transporting sand towards the entrance channel.

Fig. 5 Ponce de Leon Inlet - April 7, 1970

Fig. 6 Ponce de Leon Inlet - June 8, 1970

Fig. 7 Ponce de Leon Inlet - December 22, 1970

Fig. 8 Ponce de Leon Inlet - April 9, 1971

By April 9, 1971, the south coastline advanced by only 100 ft. (Fig. 8). This is just about equal to that which occurred between December, 1969, and April, 1970 (Figures 4 and 5). However, right north of the sheet piling the shoreline advanced by about 200 ft. whereas the beach south of the sheet piling remained practically unchanged. The area of the internal lagoon had been somewhat reduced apparently due to wind blown sand.

By July 18, 1971, the south beach advanced by another 50 ft. towards the tip of the jetty (Fig. 9) with negligible change in the internal lagoon. By the same date the beach north of the sheet piling advanced by another 100 ft. However, the erosion immediately south of the sheet piling started becoming obvious with an average recession of about 200 ft. in 3 months. Again the advancement of sand from the offshore bar to the inlet becomes obvious.

By November, 1971, the coastline reached the eastern tip of the south jetty. By that time the dredging of the entrance channel had begun by a pipeline dredge disposing the dredged material south of the south jetty and filling the internal lagoon.

The aerial of December 13, 1971, shows a similar situation to that of November, 1971 (Fig. 10) with an advancement of the coastline to the tip of the south breakwater. Little future advancement of the coastline may be expected at this location and the south beach appears to be near its new quasi equilibrium profile with seasonal localized erosions and accretions. This conclusion is confirmed by Figures 11 and 12 showing aerials taken on January 28, 1972, and February 22, 1972, respectively.

The approximate final coastline is outlined in Fig. 2 together with the original one and the coastline which was initially expected by the designers to develop after the disposal of sand from the dredged entrance channel and the impoundment basin (6). The comparison of these three coastlines is indicative of the difference between the expected and the actual behavior of nature in certain cases.

Figures 13 and 14 show the approximate location of the M.L.W. lines at the indicated dates north and south of the inlet as obtained by field surveys. Some data on dune recession north of the inlet are included in Fig. 13. Thus a net coastline recession, ranging approximately from 100 to 200 feet, has occurred up to January, 1972, between stations 28N and 50N. The accretion right north of the sheet piling section of the north jetty and the erosion southwest of the same section can also be observed.

The total volume of sand accumulated south of the south jetty between September, 1967, and November, 1971, has been estimated to about 1,400,000 cu. yds., of which only about 100,000 cu. yds. of

Fig. 9 Ponce de Leon Inlet - July 18, 1971

Fig. 10 Ponce de Leon Inlet - December 13, 197

Fig. 11 Ponce de Leon Inlet - January 28, 1972

Fig. 12 Ponce de Leon Inlet - February 22, 1972

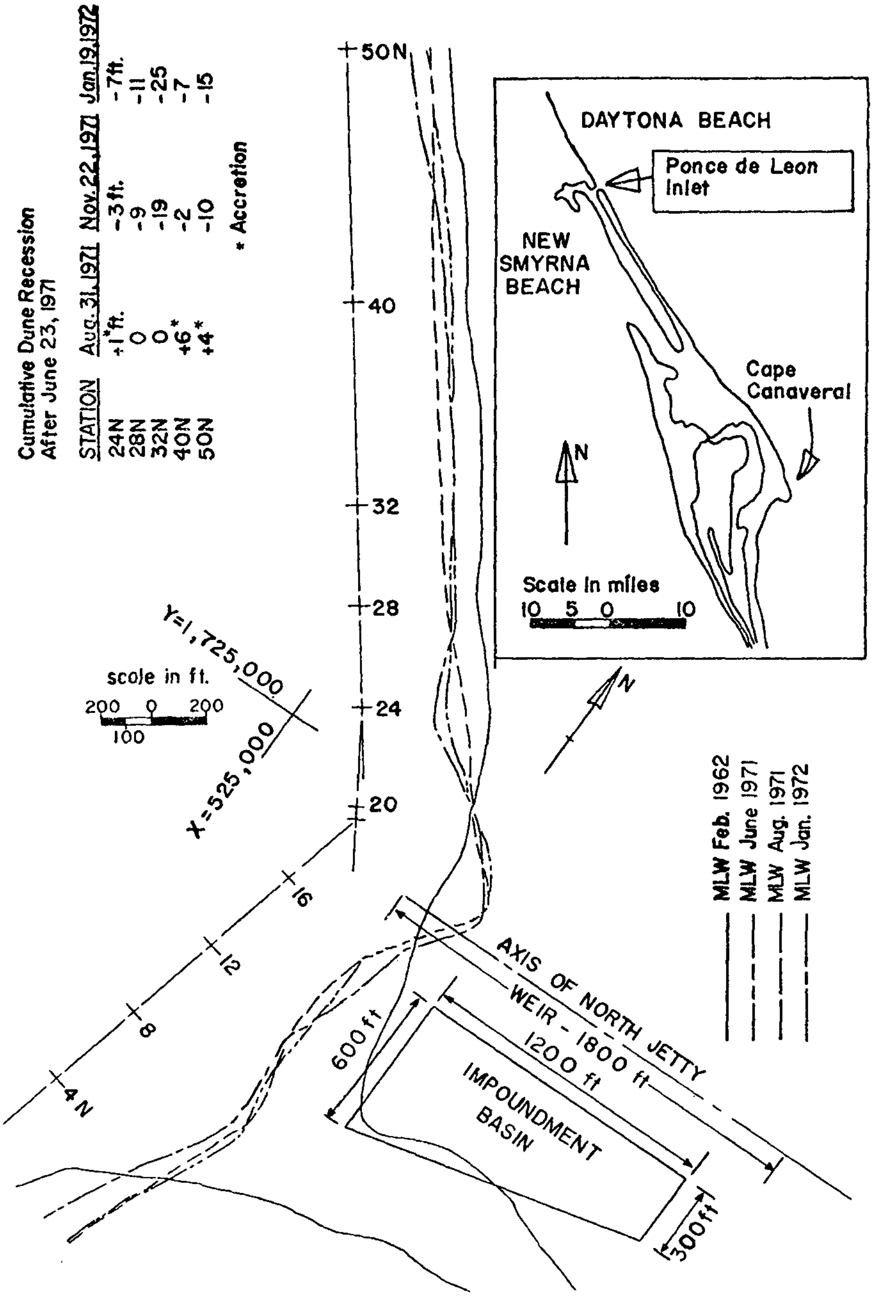

Fig. 13 Coastline Changes North of the Ponce de Leon Inlet

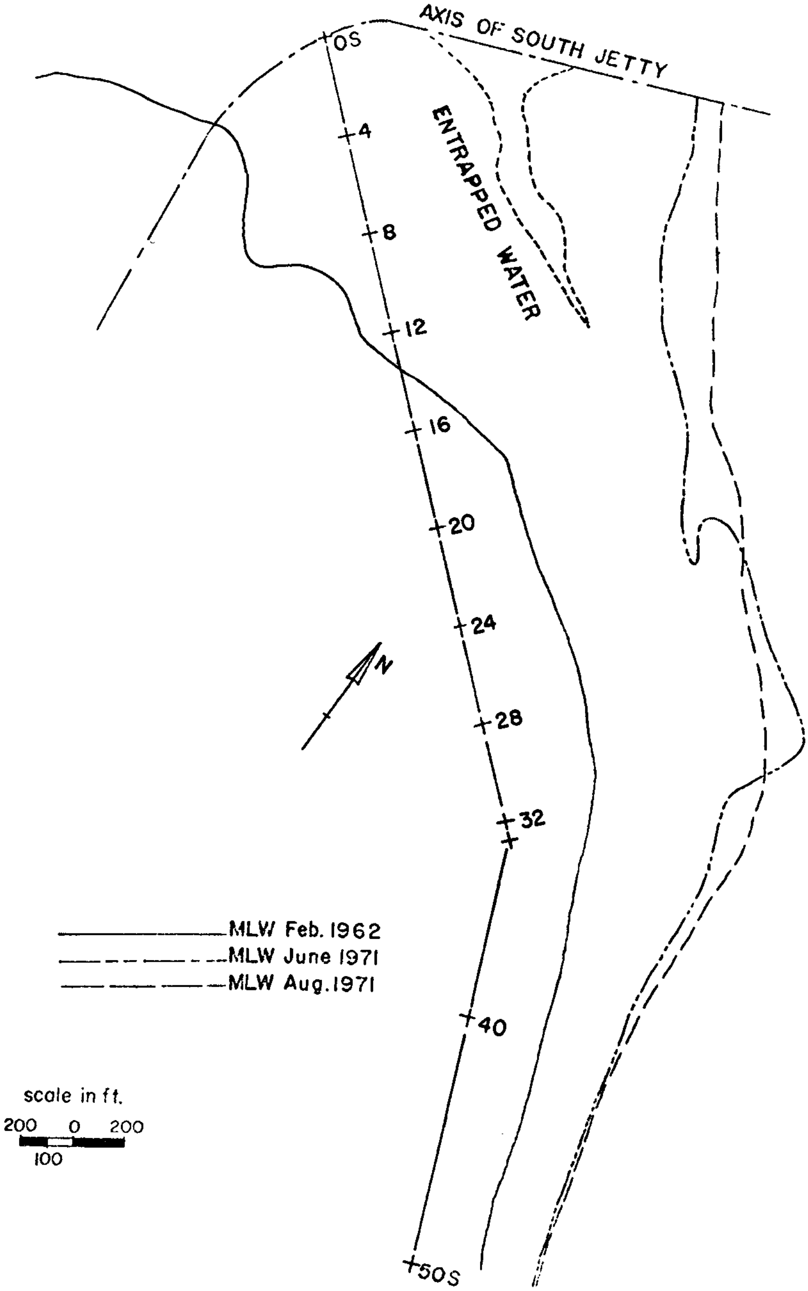

Fig. 14 Coastline Changes South of the Ponce de Leon Inlet

sand have been accumulated between June, 1971, and November, 1971. A minor portion of these volumes comes from the dredged material since little dredging had been done to that date. It should be pointed out, however, that these figures have been based on limited ground-elevation data before the jetty construction and limited field surveys and should be considered only as approximate estimates representative of the order of magnitude of the total accretion and indicative of the littoral process in the neighborhood of the inlet.

It is of interest that recent estimates of the littoral transport rates along the coast of Florida by Walton (7) based on ship wave observations have indicated a net northerly annual drift rate of 309.000 cu. yds. and a net southerly drift rate of 386,000 cu. yds. in the neighborhood of Ponce de Leon Inlet. These volumes are drastically different from those assumed in the design of the stabilization system. According to them if all the northerly moving sand is assumed to be entrapped south of the south jetty then the total accretion volumes from the beginning of construction to date (occurred predominantly during 4 summers) would have been close to 1,2000,000 cu. yds., a figure much closer to the one obtained from the field surveys.

Much additional work is needed for a reasonably accurate and dependable prediction of littoral transport rates. Our stage of knowledge on littoral processes is still incomplete and direct estimates of sand drift by field measurements and tracings are very time consuming and expensive. All that can be said at this point is that the unexpected high sand accretion south of the south jetty is most likely due to both underestimates of the northerly sand drift and to a change of the refraction pattern, which causes southerly moving sand to be deflected in a westerly direction towards the area protected by the south jetty.

SUMMARY AND CONCLUSIONS

Rapid and unexpected changes of the coastline near the Ponce de Leon Inlet during and after the construction of two jetties have been presented and discussed. The most important and spectacular change has been the rapid sand accretion south of the south jetty in spite of the estimate of a net annual littoral transport of 500,000 cu. yds. of sand from north to south. The total accretion volume from the summer of 1968 to the late fall of 1971 amounts to approximately 1,400,000 cu. yds. Evidence from a series of aerial photographs suggests that the sand was transported predominantly in a northerly direction during the summer months and from the offshore bar by the action of refracted waves.

It appears that the sand entrapment south of the inlet reduced the sediment supply to the beach north of the inlet during the periods of northerly drift thus upsetting the preexisting balance between sediment supply and erosion. As a result the recession of the coastline and duneline north of the jetty after its construction have been considerably higher than the mean annual recession before the jetty construction. Sand accretion, however, immediately north of the weir has already started.

The described changes lead to a number of fundamental conclusions regarding the design of inlet stabilization systems, the most important of which are the following:

1. The net annual rate of littoral transport cannot be used as a unique criterion in designing stabilization and sand bypassing systems in inlets where the littoral drift reverses its direction. Instead the total sand volumes transported annually in either direction should be considered.

2. The refraction pattern of waves in the immediate neighborhood of the inlet as well as the effect of jetties on that pattern should carefully be studied. Refracted waves may transport sand locally in a direction opposite to that of littoral transport along a nearby straight beach. This may be particularly important in bar-built estuaries and bays with extensive offshore bars.

3. There is a need for more precise techniques for the estimate of littoral transport of sand and for the correlation of the latter with the wave climate.

4. In cases where development of new beaches and/or extension of existing ones is anticipated as a byproduct of an inlet stabilization by jetties, appropriate filters should be designed to prevent washing of sand through the jetties and avoid erosion of the beach internally by waves and tidal currents.

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REFERENCES

1. Prichard, D. W., "What is an Estuary: Physical Viewpoint," Estuaries, Edited by Lauft, G. H., Publication No. 83, American Association for the Advancement of Science, Washington, D.C., 1967.

2. U.S. Army, Coastal Engineering Research Center, "Shore Protection Planning and Design," Technical Report No. 4, Third Edition, 1966.

3. Ippen, A. T. (Editor), "Estuary and Coastline Hydrodynamics," Chapter 10, McGraw-Hill, 1966.

4. U.S. Army Engineer Division, South Atlantic Corps of Engineers, Atlanta, Georgia, "National Shoreline Study and Regional Inventory Report, South Atlantic - Gulf Region, Puerto Rico and the Virgin Islands," August, 1971.

5. U.S. Army Engineer District, Jacksonville, Corps of Engineers, Jacksonville, Florida, "Survey Review Report on Ponce de Leon Inlet, Florida," Serial No. 61, September 30, 1963.

6. Department of the Army, Jacksonville District, Corps of Engineers, Jacksonville, Florida, "General and Detail Design Memorandum, Ponce de Leon Inlet, Florida," Serial No. 17, November 29, 1967.

7. Walton, T. L., Jr., "Littoral Drift Computations Along the Coast of Florida by Use of Ship Wave Observations," Thesis presented to the University of Florida at Gainesville in Partial Fulfillment of the Requirements for the Degree of Master of Science in Coastal and Oceanographic Engineering, June, 1972.