CHAPTER 351

A Unique Look at Oregon Inlet, NC USA

Herman C. Miller[1], M ASCE, William A. Dennis[2], M ASCE, and Michael J. Wutkowski[2]

Abstract

Oregon Inlet (OI) in North Carolina (NC), the only inlet along a 170 km stretch of coast, supports an active commercial fishing and recreational boating industry. Severe erosion, because of the ongoing migration of OI, resulted in NC constructing a terminal groin to prevent the highway from being severed from the south side of the OI bridge. Construction of this structure provided a unique opportunity to monitor and assess project impacts which could be directly related to the twin jetties which are proposed for this site. The monitoring program included a directional wave gauge, aerial photography, and semi-annual sled-surveys extending 6 km north and south of the inlet. The terminal groin returned the shoreline to its pre-1986 position and has successfully protected the highway abutment to the bridge through many severe storms. This paper presents the results of 6 years of monitoring the morphologic changes. The results document how the coast has adjusted to the construction, a multi-year wave climate reversal, and placement of 1.5 million m^3 of dredged material on the beach. The surveyed area generally lost material both on the up and downdrift sides, much of which apparently has been deposited in the inlet. The effect of these changes on the coast and the inlet's stability are discussed.

Introduction

Oregon Inlet (OI) is the only inlet along a 170 km stretch of coast from Cape Hatteras, North Carolina (NC) to the south, to Rudee Inlet in Virginia to the north, as

[1]US Army Engineer Waterways Experiment Station Coastal & Hydraulics Laboratory Field Research Facility, 1261 Duck Road, Kitty Hawk, NC 27949, USA

[2]US Army Engineer Wilmington District, Coastal, Hydrology, & Hydraulics Section, PO Box 1890, Wilmington, NC 28402, USA

shown in Fig 1. The inlet provides an important link between the Atlantic Ocean water and the expansive estuarine Albemarle/Pamlico/Currituck Sound system. The inlet supports an active commercial fishing and recreational boating industry.

During the peak summer months, over 12,000 vehicles a day use the bridge across OI to work and enjoy the beaches in the Cape Hatteras National Seashore. OI and Roanoake Inlet before it, have been migrating south at a rate exceeding 2 km per century. By 1989 this ongoing southerly migration threatened to sever the southern abutment of the bridge to the highway that provides the only land route to the southern beaches. In 1990, NC Department of Transportation (NCDOT) constructed a 953 m rubble mound terminal groin to stabilize the south shoulder of OI. The terminal groin was intended to create a fillet in its lee and return the shoreline to the pre-1986 position. Documenting how the adjacent shoreline and nearshore waters adjusted to construction of the terminal groin was important to the local residents, NC, and the US Army Corps of Engineers (USACE).

This construction provided a unique opportunity to monitor and assess project impacts which could be directly related to the twin jetties which are proposed for this site. Although the function of the terminal groin and jetties (which provide for safe navigation through the inlet) is quite different, it was believed that information gathered concerning the project induced changes resulting from stopping the southerly migration of the inlet would be extremely beneficial in the planning and design of the jetties.

With local and state support for funding, the USACE Wilmington District and the USACE Waterways Experiment Station Coastal and Hydraulics Laboratory', Field Research Facility (FRF) jointly developed a monitoring program to assess the impacts of the terminal groin. The close proximity of OI to the FRF, located in Duck, NC, made it possible to take advantage of the equipment and experienced staff to conduct a long-term monitoring program.

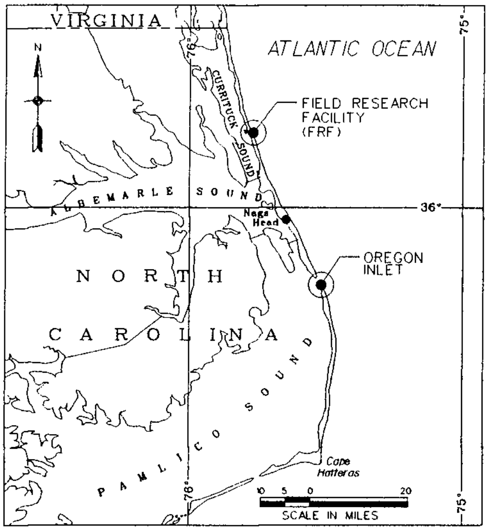

Fig. 1. Site Location. Note, location of USACE Field Research Facility 48 km north of OI. (Kilometers = Miles * 1.61)

This paper presents the results of 6 years of monitoring. In addition to the presence of the terminal groin during that time, there was an unusual long-term wave climate reversal, and material dredged from the inlet was disposed of on the beach on four occasions. The paper organization is generally as follows: monitoring program, monitoring results which document the response of the coast, a discussion of the effect on the inlet stability, and conclusions.

Monitoring Program

The OI area is subject to both hurricanes and northeasters and has one of the highest wave climates on the US east coast. The average annual significant wave height and period for the area are 1 m and 9 sec, respectively (Leffler, et al, 1996). The mean tide range on the open coast is 1.2 m and 0.7 m for the inlet gorge (NOAA 1996). OI separates Bodie Island to the north from Pea Island to the south. The monitoring program consisted of semi-annual nearshore sled-surveys along a portion of the coast extending approximately 6 km on both Bodie and Pea Islands. These surveys were conducted along 38 profile lines spaced at 300 m intervals, Fig 2. The profiles begin behind the dune and extend to the 9 m depth contour. All of the profiles are surveyed in January during the winter storm season and July during the summer recovery season. In addition to these surveys, a directional wave gauge has been operated at the inlet since 1990. Also, aerial photographs were collected approximately every other month.

The sled-survey system (Miller, 1991) consists of an amphibious vehicle and a sled with an 11 m tall mast, Fig 3. The sled, which slides across the ocean bottom virtually unaffected by waves and currents, carries a ring of reflective target-prisms. HYPACK software on a PC is used to collect position and depth measurements every 1 m along a profile using a Geodimeter 140T tracking total-station that is aimed at the prisms. Processing the profile data was facilitated by the Interactive Survey Reduction Program (Birkemeier, 1991). Summaries were generated using Intergraph Inroads/Insite software.

Results

By Halloween in October, 1991, the terminal groin was completed, the fillet had formed, and the shoreline had been returned to the desired location, just in time for a major storm, Fig 4. The road and bridge abutment was protected, accomplishing the primary function of the construction (Dennis and Miller, 1993). As can be seen, the breaking waves define a well formed ebb-shoal which is the main pathway for sand to bypass the inlet. Seeing that this natural pathway was well established, it was not expected that the terminal groin would have a major impact on sediment transport past the inlet. What was expected was that the inlet would narrow, since only the downdrift shoulder was stabilized. The effect of this realignment on the hydraulics of the inlet and on the adjacent coast was of primary interest.

The results are summarized by showing the changes that occurred from the winter of 1991 through the winter of 1994, then from the winter of 1994 through the winter of 1996. This separation shows the different responses of the coast to apparently different processes resulting from an infrequent long-term annual wave climate reversal during 1991 through 1993.

Figure 5 shows the elevation changes over 3 years on the Pea Island (south) side of OI. Every other profile is numbered starting with "15" closest to the inlet and ending with "239," 6.8 km to the south. The February, 1994 shoreline position is included to distinguish the sub-aerial from the

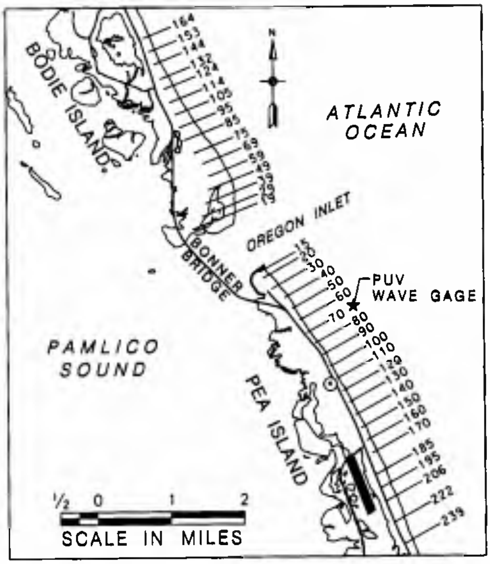

Fig. 2. Sled-survey profile lines. Note, directional wave gauge location at end of Profile #70 off of Pea Island. (Kilometers=Miles* 1.61)

Fig. 3. Survey sled and amphibious vehicle. The sled mast carries the prism array at an 11m elevation.

Fig. 4. OI during "Halloween Storm" on 31 October, 1991. Surge from 4 m, 22 sec. waves have flooded fillet behind the terminal groin at end of the old ferry landing road.

sub-aqueous portions. The terminal groin extends from the "Feb 94" shoreline position at "15" approximately 1 km to the west. The inlet would be to the north (right side) of the terminal groin. Positive elevation changes indicate accretion and are shown as light shaded contour areas. Negative contours in the dark shaded portion of the figure are areas of erosion.

From March, 1991 to February, 1994, near the inlet, there was inshore accretion and offshore erosion along the ebb-shoal. South of "140" there was nearshore erosion that resulted in shoreline retreat, overwash, and destruction of some dunes that were 60 years old. However, the overwhelming feature in the area during this time was the 1.5 million m^3 of dredged material disposed of on the beach between profile lines 50 and 130. As can be seen, much of the disposal material moved offshore. Material also moved north along the inshore bar and trough into the fillet and around the terminal groin into the inlet.

More recently, from February, 1994 to April, 1996, Fig 6, the pattern of changes is quite different in comparison to the earlier time shown in Fig 5. Now the inshore erosion is along the entire length of the survey area. However, there is accretion offshore along a pathway consistent with transport along the ebb shoal toward the south.

Corresponding changes on the Bodie Island (north) side of OI from March, 1991 to February, 1994 are shown in Fig 7. For orientation, the inlet is 0.6 km south (to the left) of "39." Clearly, changes during this time are quite different than those for the Pea Island side shown above. Erosion pervades almost the entire area with the exception of an area of sub-aerial accretion near "59."

An almost opposite response is seen from February, 1994 to April, 1996 as shown in Fig 8. During those 2 years there is sub-aerial and sub-aqueous accretion over most of the area. One exception is the shoreline retreat south of "85" which corresponds to a swing of the Bodie Island spit toward the west. To document what was responsible for these different adjustments before and after February, 1994, it is informative to look at the wave data.

Historic estimates of the annual rate of sediment transport along this portion of coast, (Jarrett, 1978, Birkemeier, et al, 1985, Inman & Dolan, 1989, USAEDW, 1995),

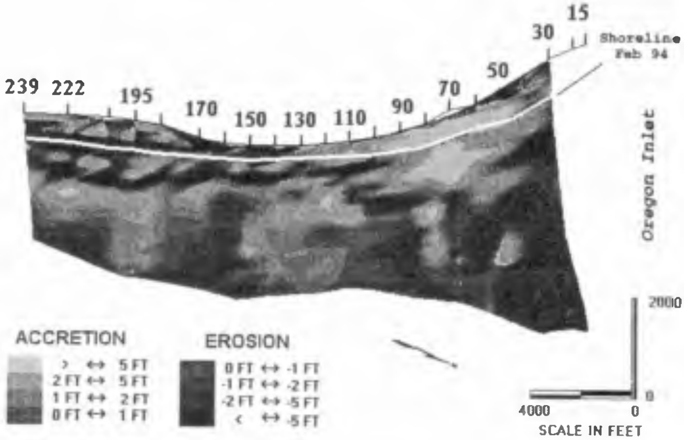

Fig. 5. Pea Island elevation changes from March, 1991 to February, 1994. Terminal groin is at profile 15; inlet is to the north (to right). (Meters = Feet*.3048)

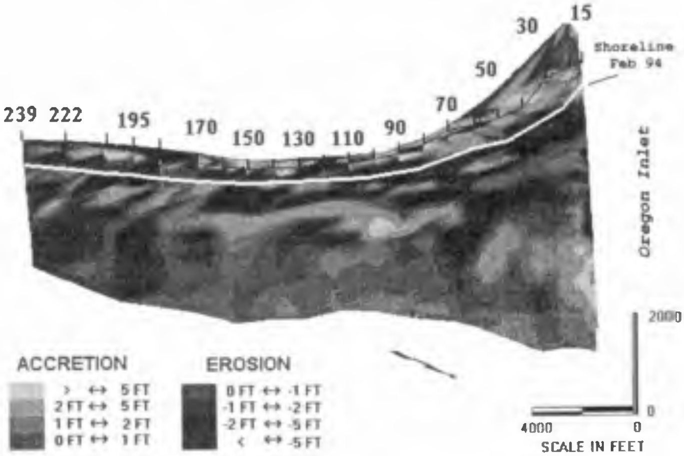

Fig. 6. Pea Island elevation changes from February, 1994 to April, 1996. (M=Ft*.3048)

show that annually approximately 1.5 million m^3 of sediment moves south primarily during the Fall and Winter storm seasons; 800,000 m^3 moves north during the Spring and Summer, for a net southerly transport rate of 700,000 m^3 per year. Potential longshore transport volumes using the energy flux method in the Shore Protection Manual (SPM, 1984) based on hindcasted wave data since 1956 (WIS, 1993), historic wave climatic summaries (Thompson, 1971), and FRF measurements (see FRF WWW page at HTTP://FRF.WES.ARMY.MIL) show that this trend of net annual southerly longshore transport has been consistent over the past 4 decades with one exception in the early 1980's when the southward and northward transport approximately balanced.

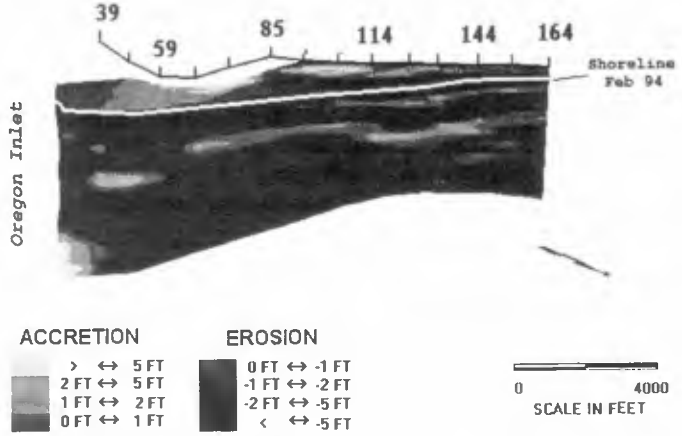

Fig. 7. Bodie Island elevation changes from March, 1991 to February, 1994. Inlet is 2 km south (to left) of Profile #39. (Meters = Feet * .3048)

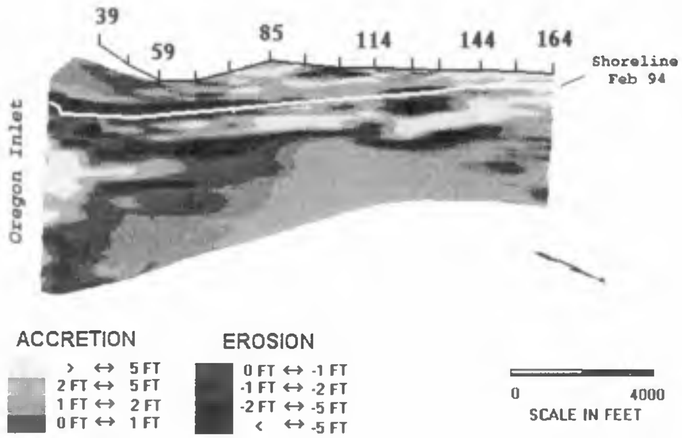

Fig. 8. Bodie Island elevation changes from February, 1994 to April, 1996. Shoreline retreat near inlet accompanied growth of spit toward south. (Meters = Feet * .3048)

Computations based on the FRF's linear directional wave array, (Long and Oltman-Shay, 1991), are shown in Fig 9. The complete data record from the FRF was used, instead of the directional measurement from the self-recording gauge at OI, because of intermittent gaps in the OI data. However, comparison of computations from both gauges, (Miller and Dennis, in prep.), show the wave climate summaries at the FRF are representative of the wave climate at OI. From January, 1990 through February, 1991 and from 1994 through 1996 there is southward transport during the storm seasons, consistent with historic trends. However, during 1991 through 1993, with only a few exceptions, each month the net transport is toward the north. It can also be seen that beginning with the Halloween 1991 storm, frequently, the northward transport rates were quite high. The annual net transport rates during these years approached 2 million m^3 toward the north. One explanation we have considered for this is that there was a long El Nino event in the Pacific Ocean during that time which may have diverted the "jet stream" across the United States causing mid-Atlantic extra-tropical storms to move inland south of OI instead of typically moving up the coast to the north. Whatever the cause, it provided a unique opportunity to study how the coast adjusted to the changing coastal processes.

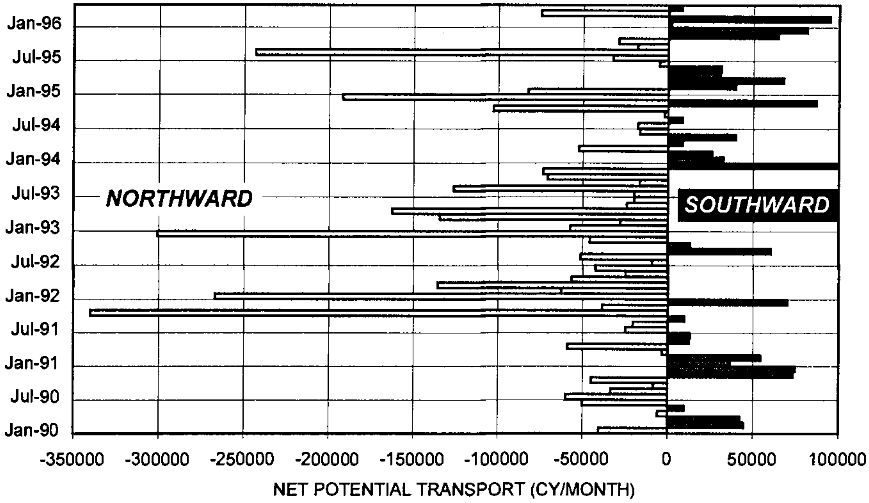

Fig. 9. Monthly net potential transport. Wave climate during 1991-1993 resulted in predominately northward net transport close to 2 million m^3 per year.(M^3=Yd^3*.028)

The effect of an inlet is often categorized in terms of the up drift or downdrift sides of the inlet. Figure 10 summarizes the adjustments of the coast at OI in light of the wave climate reversal that caused the up/downdrift categories to change during the monitoring period. Cumulative volume changes for each of the semi-annual surveys are presented for both Pea and Bodie Islands. During 1991 through 1993, Bodie Island is in the lee because of the wave climate reversal and shows a consistent loss of volume.

By the summer of 1994 the wave climate is more climatologically consistent and the volume shows signs of recovery. On the other hand, the Pea Island side remains approximately neutral through 1994 with some indication of a trend toward loss of material more recently while in the lee of the inlet. However, recall that 1.5 million m^3 of material was deposited on the Pea Island side prior to 1995, and so it too lost volume during the monitoring period. So both sides lost volume, particularly during the times when in the lee of the inlet. Where did the sand go? We believe it went into the inlet. Unfortunately, we do not have volume changes in the inlet. However, using the aerial photography it is possible to gain some insight into the inlet's stability during this time.

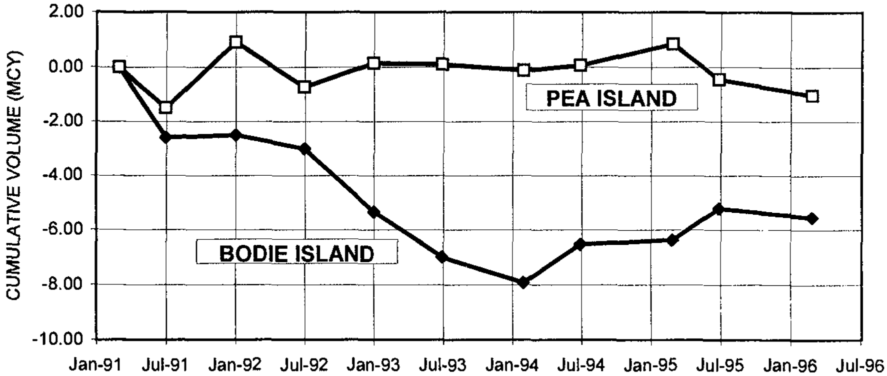

Fig. 10. Pea and Bodie Islands volume changes. Note, while Bodie Island shows loss of volume through July, 1994, Pea Island remains unchanged because of 1.5 million m^3 of dredged material placed on the beach. ($M^3 = Yd^3 * .028$)

Figure 11 was constructed from photography taken on 13 April, 1992. Notice the width of the channel under the bridge. For reference note the "dark spot" on the bridge. This is a repaired section caused by a dredge that washed through the bridge during a storm in October, 1990. Also, note the shape of the ebb shoal. It has a parabolic "flattened bell" shape with a wide base that is asymmetric on the Bodie Island side.

Figure 12 is 1.5 years later on 11 November, 1993. The spit has grown to well south of the repaired bridge section. The Bodie Island side continues to move south as has been the tendency for the past 150 years since OI opened. The narrowing and realignment of the inlet can be seen in the shape of the ebb shoal, which now has an "arrow head" form, less wide at the beach and asymmetric on the Pea Island side. However, the shoal does not extend any further offshore. Higher currents associated with a decreasing inlet cross-section would tend to wash the shoal further offshore which is not seen at this time. The pond in the middle of the fillet behind the terminal groin is the result of mining 250,000 m^3 of sand which was placed on the beach south of the monitoring area.

Fig. 11. Mosaic of aerial photography of OI taken on 13 April, 1992.

More recently, as seen in Fig 13 taken on 23 May, 1996, the spit is very near the navigation span under the bridge and an island has formed between the south "Davis" slough and the main OI channel. The volume of material in the inlet, although unknown, appears to have increased dramatically in comparison to Fig 11. We believe this accounts for a large part of the volume losses off of Pea and Bodie Islands.

Inlet Stability

The growth of the Bodie Island spit and development of the shoals have had an effect on the inlet stability. The effect of the shoal under the bridge is that instead of having to dredge to keep the authorized 4.3 m depth in the navigation channel at the bridge, as during the 1991 disposal projects, the depth has now approached 20 m. This equates to approximately 15 m of scour primarily over the past 3 years. Although scour in the navigation channel is unusual, scour has been a problem at OI in the past and has required that remedial measures be taken to reinforce the bridge at "Davis" slough on the south end. The deep scour has not, as yet, been measured in the inlet on the ocean side east of the bridge. In May, 1996 the inlet width, using the traditional method of measuring the minimum distance from the Bodie Island spit to the south side of the inlet (now to the terminal groin), is 820 m. This is the narrowest it has been since 1983, yet the inlet has been more narrow, on a few occasions, such as in 1975 when it was just 640 m wide(USAEDW, 1977). Since the inlet in recent years appears to have maintained a consistent cross-sectional area, (McCafferty, 1996), and is expected to continue to narrow, additional scour can be expected.

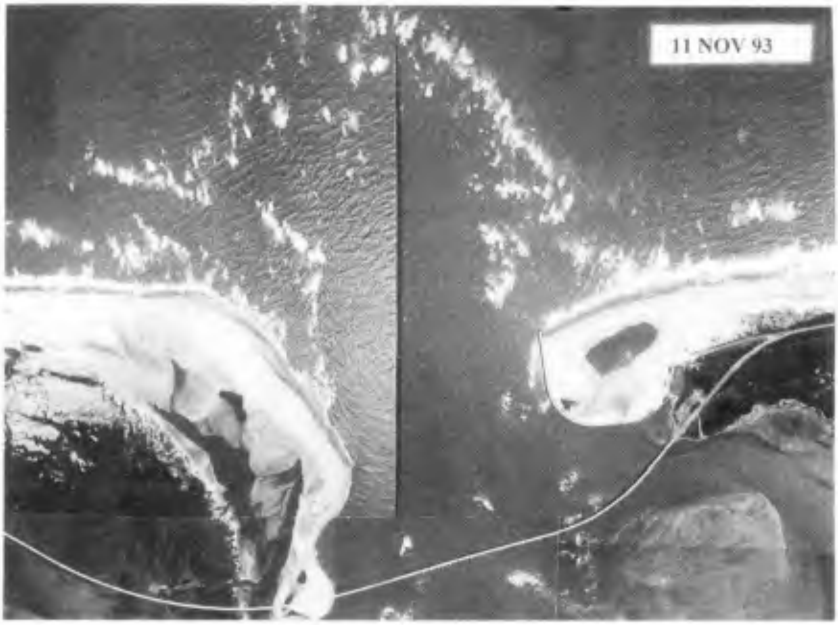

Fig. 12. Aerial photography of OI taken on 11 November, 1993. Note spit now well south of "dark spot" on bridge.

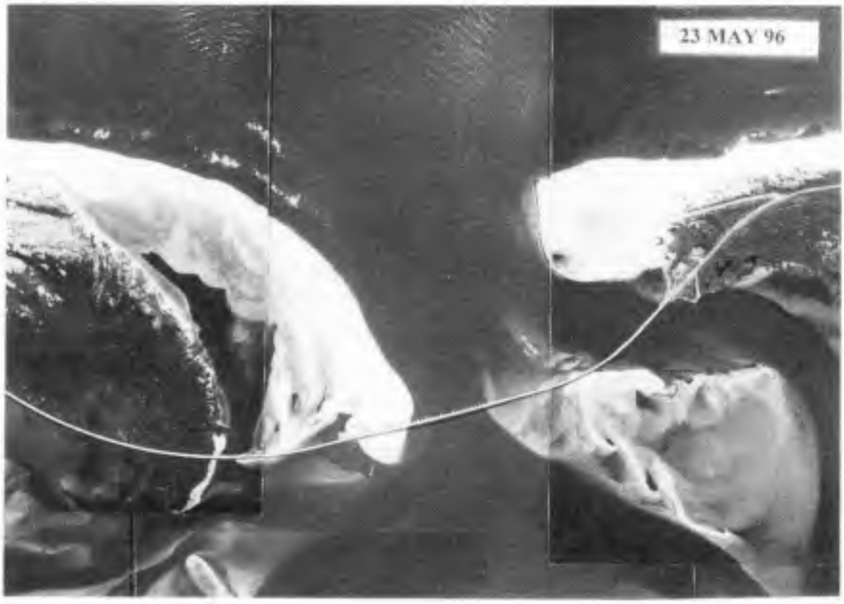

Fig. 13. Aerial photography of OI taken on 23 May, 1996. Development of shoal under bridge has resulted in 15 m of scour in navigation channel.

However, the scour in the navigation channel under the bridge suggests the inlet may be more narrow there. The "effective width" of the inlet might be considered the width measured at the bridge. Considering the shoal, that width is 720 m at this time. As the material continues to enter the inlet and the spit continues to migrate toward the south, it is possible that the main flow channel will shift to "Davis" slough. Should that occur, the spit and island under the bridge would tend to coalesce making it very difficult to maintain the navigation channel at the narrow navigation span of the existing bridge. Also, as the channel moves up against the terminal groin, the scour could increase, possibly, putting the structure in danger. The terminal groin was designed, however, anticipating the channel moving toward the structure by adding a 12 m wide scour apron along the inlet toe.

OI has always been an effective sink for sediment as evidenced by the extensive shoals west of the bridge. The inlet's stability and downdrift beach erosion rates are highly dependant on the natural bypassing of material past the inlet. Unfortunately, with or without the terminal groin, natural bypassing is not efficient at OI. Dredging, in the past used primarily for maintaining the navigation channel, may become an almost mandatory bypassing supplement. This may not be satisfactory since dredging is also not efficient. It requires dredging quantities approaching the annual gross transport of material, which is more than three times the net. An alternative would be to stabilize the inlet with jetties that would prevent the material from entering the inlet and mechanically bypassing the net transport as needed on the downdrift beaches.

Conclusions

A terminal groin was constructed at OI to prevent the important only highway route to popular beaches from being severed from the bridge. The construction was intended to establish a fillet in its lee that would return the shoreline to the pre-1986 position. The structure has been well tested by many large storms and has been very successful.

A long term measurement program, including semi-annual sled surveys, has documented the response of the coast to the construction. Measurements made over the past 6 years captured the unique response of the inlet to an unusual wave climate reversal. During the reversal, erosion was measured on both the up drift and downdrift sides. Since the processes have returned to more normal conditions, there has been recovery on the up drift side and the ebb-shoal is accreting on the downdrift side. However, erosion on both sides indicates that natural bypassing continues to be insufficient at OI.

Apparently, the eroded material is ending up in the inlet. The inlet has adjusted by the growth of the spit toward the south and the rapid development of a shoal under the bridge. The "effective width" of the inlet is now 720 m, near the minimum in half a century, which has caused 15 m of scour in the main channel under the bridge.

The monitoring program at OI has been successful documenting the adjustment of the inlet and adjacent coastal region to construction of the terminal groin. Future efforts will include quantifying the volume changes within the inlet particularly on the shoals. Continued monitoring, as the Bodie Island Spit moves further south, will provide valuable data for future engineering activities that seem inevitable at OI.

References

Birkemeier, W. (1991). "A User's Guide to ISRP: The Interactive Survey Reduction Program." Tech. Rpt. CERC-IR-84-1, Coast. Engrg. Res. Ctr., US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

Birkemeier, W., Miller, H., Wilhelm, S., DeWall, A., and Gorbics, C. (1985). "A User's Guide to the Coast. Engrg Res. Ctr's (CERC's) Field Research Facility." Tech. Rep. CERC-85-1, US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

Dennis, W. and Miller, H. (1993). "Shoreline Response Oregon Inlet Terminal Groin Construction." Proc. The Hilton Head Is. S. Carolina USA Int. Coast. Symp. Jour. or Coast. Res., Royal Palm Beach, FL

Inman, D. and Dolan, R. (1989). "The Outer Banks of North Carolina: Budget of Sediment and Inlet Dynamics Along a Migrating Barrier System." Journal of Coastal Research. Vol. 5, No. 2, pp193-237.

Jarrett, J. (1978). "Coastal Processes at Oregon Inlet, North Carolina." Proc. of the 16th Conf. on Coast. Eng., American Society of Civil Engineers.

Leffler, M., Baron, C., Scarborough, B., Hathaway, K., Hodges, P., and Townsend, C. (1996). "Annual Data Sum. for 1994 CERC Field Research Facility." 2 Vols, Tech. Rep. CERC-96-6, Coast. Engrg. Res. Ctr., US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

Long, C. and Oltman-Shay, J. (1991). "Directional Characteristics of Waves In Shallow Water." Tech. Rep. CERC-91-1, Coast. Engrg. Res. Ctr., US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

McCafferty, H. (1996) "A Comparative Analysis of The Effects of Storms Upon A Tidal Inlet: Pre- and Post Inlet Stabilization Effects Oregon Inlet, North Carolina." Masters Thesis, Dept. of Env. Sci., Univ. of Virginia.

Miller, H. (1991). "A Topographic Survey System For The Surf and Nearshore." Proc. US Army Corps of Eng. Survey Conf. US Army Eng. Topo. Lab., Ft. Belvoir, VA

Miller, H. and Dennis, W. (in prep). "Predicting Longshore Trans. From Near and Far." National Oceanic and Atmospheric Administration. (1996). "Tide Tables 1992 East Coast of North and South America." US Dept. of Commerce, National Ocean Service, Silver Spring, Maryland

Shore Protection Manual. (1984). 4th Edition, 2 Vols, US Army Eng. Waterways Exp. Station, Coast. Engrg Res. Ctr., US Government Printing Office, Wash., DC.

Thompson, E. (1971). "Wave Climate at Selected Locations Along U.S. Coasts." Tech. Rep. CERC-77-1, Coast. Engrg. Res. Ctr., US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

US Army Eng. Dist. Wilmington. (1977). "Manteo (Shallowbag) Bay North Carolina General Design Memorandum Phase 1 Plan Formation."

US Army Eng. Dist. Wilmington. (1995). "Manteo (Shallowbag) Bay North Carolina Feature Design Memorandum Sand Bypassing (Management)."

Wave Information Studies of US Coastlines. (1993). "Hindcast Wave Information For the US Atlantic Coast." WIS Rep. 30. Coast. Engrg. Res. Ctr., US Army Eng. Waterways Exp. Stn., Vicksburg, Miss.

Approvals

The authors would like to acknowledge the late, Robert Williams, Chairman of the Oregon Inlet and Waterways Commission, for his support for the monitoring program, efforts to fund the study, and open mind concerning the findings...he will be missed. Permission to publish this paper was granted by the Chief of Engineers.