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Shoal-Reduction Strategies for Entrance Channels

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PURPOSE: The Coastal Engineering Technical Note (CETN) described herein presents several methods for reducing sediment shoaling in navigation channels at coastal inlets and entrances.

BACKGROUND: From fiscal year (FY) 1995 through 1998, the US Army Corps of Engineers (USACE) dredged between 200 and 300 million m^3/yr from Federal channels. Maintenance dredging accounted for an average of 89 percent of this volume, and new work and emergency dredging comprised the remainder. Total dredging expenditures increased from approximately $532 to $713 million in FY 1995 through FY 1998, with maintenance dredging accounting for 78 percent of the cost (see U.S. Army Corps of Engineers Navigation Data Center Long-Term Dredging web site at *http://www.wrsc.usace.army.mil/ndc/ddhisbth.htm*). A reduction in maintenance dredging can represent a significant cost and timesaving measure to the operation and maintenance of USACE waterways.

The focus of this CETN is how sediment shoals into open-coast channels. The primary sediment-transport pathways can be referenced to the jetties stabilizing the inlet entrance. Sediment can move around the tip of a jetty, entering directly into the channel; around the tip of the jetty, on to the ebb shoal and into the portion of the channel that transverses the ebb shoal, through a jetty, over a jetty, and around the landward side (see green arrows in Figure 1). Pope (1997) gives a classification system of channel shoaling based on general considerations of geomorphology.

METHODS FOR REDUCING SEDIMENT SHOALING: The following paragraphs give strategies for reducing sediment shoaling at inlet entrance channels.

Anticipate and budget for potential changes in channel shoaling patterns and volumes

Sudden shoaling of navigation channels is often related to storms, antecedent events, and channel bathymetry. Increases in expected dredging quantities and changes in shoaling patterns can occur because of an intense storm season. Storms can increase the rate of material transported alongshore and into the channel, while causing shoreward transport of inlet deltas or the partial breakup of deltas. For rivers feeding inlets, rainfall over the watershed can increase the sediment-laden flow into the inlet. These processes are not fully predictable but can be anticipated to some degree by reviewing long-term (decades to centuries) cycles of climatic and inlet behavior. Whether increased shoaling by storms occurs depends in part on the state of the bottom topography at the time of the storms.

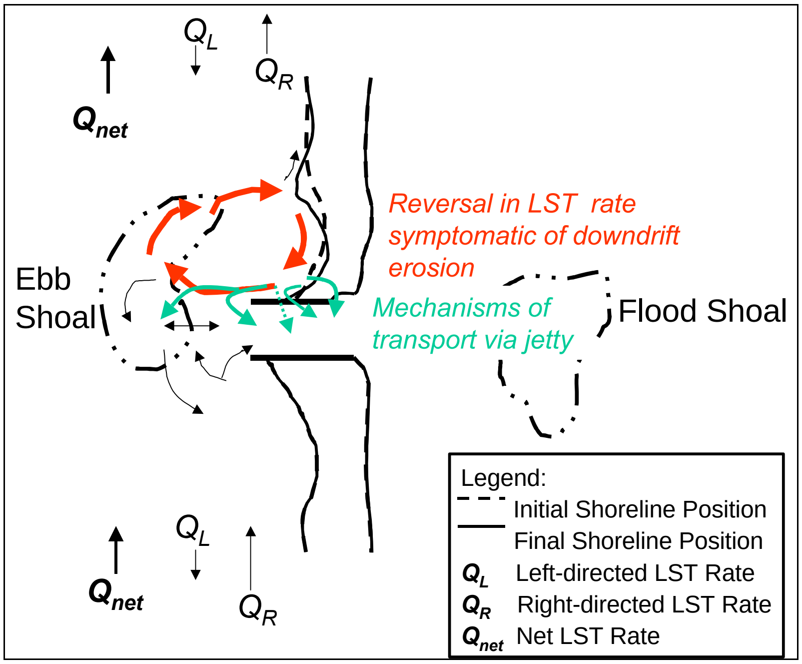

Figure 1. Schematic of longshore sand transport patterns in the vicinity of an inlet, with sediment patterns highlighted (transport via jetty (green); down-drift reversal in the net longshore sand transport (red))

Some situations resulting in increased channel shoaling rates can be anticipated and planned for on engineering time scales (years to decades) through analysis of data (e.g., channel infilling). It is advantageous to plan proactively for the increased shoaling to avoid a time delay in correcting the situation, increased effort in obtaining emergency funding, and hazardous navigation conditions over an extended period. For example, consider two adjacent inlets sharing a common bay. Suppose that Inlet A is dredged deeper than previously and begins to capture more of the bay's tidal prism, thereby causing Inlet B to tend towards shoaling and eventual closure. The increased shoaling of Inlet B can be anticipated and increased dredging planned. An example of this phenomenon is found along the Gulf coast of Texas, where an inlet (Matagorda Ship Channel – Inlet A in the example) was cut in the early 1960s for more reliable navigation. The ship channel has captured more and more of the tidal prism while scouring. Over time, capture of the flow at the ship channel has caused the adjacent natural inlet, Pass Cavallo (Inlet B) to narrow and tend towards closure.

Another example of a foreseeable increase in shoaling is the placement of beach fill updrift of an inlet. Prior to fill placement, the updrift beach may have been eroded with longshore sediment-transport rates less than the potential rate because of adjustment in shoreline orientation to the predominant waves. The beach fill allows the potential longshore sediment-transport rate to be realized, increasing deposition in the channel. After initial cross-shore and end-boundary adjustments of the fill, net longshore transport will move the fill towards the inlet. In the absence of a mechanical sand bypassing plant or sand backpassing, some fraction of the beach fill can be expected to deposit in the inlet channel and tidal delta system. Anticipation of the increased channel shoaling will lay the groundwork for maintaining channel navigability in a timely manner. A prototype example of this situation is Moriches Inlet, New York. From 3.2 to 8.6 km updrift of Moriches Inlet, beach fill totaling 2.9 million m^3 was placed during 1996-1997, and renourishment is planned on 3- to 6-year intervals for 27 years, averaging 288,000 m^3/yr (Figure 2).

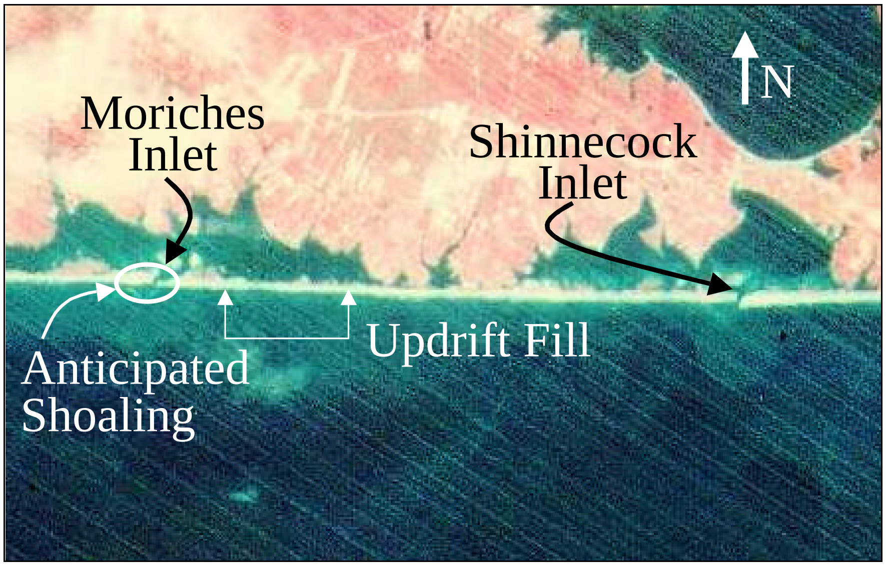

Figure 2. Location of beach fill placed updrift of Moriches Inlet, New York

Considering a regional scale of coastal processes, this beach fill material will be transported towards Moriches Inlet in the net (westerly) direction of longshore sediment transport. As a conservative estimate, it could be assumed that shoaling in the inlet would increase by the renourishment rate, roughly 288,000 m^3/yr. A proactive dredging plan will include budgeting for this possible increase in the out-year Operation and Maintenance schedule, as well as monitoring the shoaling rate and region of deposition, and modifying the plan as appropriate.

Minimize rehandling of adjacent dredged material placement

Inlets located on coasts with a dominant direction of net longshore transport typically exhibit severe and chronic erosion on the adjacent down-drift beach. This eroding region is a logical site for placement of dredged material from the inlet. However, wave refraction over the ebb tidal delta combined with flood tidal current, can create a local reversal in the net longshore sand transport direction along this down-drift beach (see red arrows in Figure 1). Dredged material placed in this region tends to be transported updrift or back towards the inlet, where it can pass over, through, around the tip, and around the backside of the jetty (see green arrows in Figure 1). The result is an increased shoaling rate in the inlet, rehandling of the shoaled sediments, and limited benefits to the downdrift beaches.

Structural alternatives to mitigate for the transport of sand out of an erosive adjacent beach include construction of groins, detached breakwaters, spur jetties, and sand tightening of the jetty (if sand is transported through or over the structure). Non-structural alternatives include placing larger-grained (and therefore more stable) sediment on the beach, perhaps from an upland or offshore borrow site. To improve navigability, the channel can be relocated (perhaps updrift of the ebb shoal).

Construct a deposition basin

Sediments that would otherwise be deposited in navigation channels can be intercepted and temporarily stored through construction of a deposition basin (Seabergh 1983, Bruun 1966). The recommended site for a deposition basin is in a region where the wave and current climate is mild and sand can accumulate at some distance from the channel. Removal of the trapped sediment can be accomplished with minimal interruption to navigation, and sediments will be less likely to be transported outside the basin by more energetic waves and currents. Deposition basins can be constructed interior to (e.g., to the lee of a weir jetty) or exterior to (e.g., to the lee of an updrift weir groin) the inlet.

A dual jetty system was constructed at Murrell's Inlet, South Carolina in 1977, with a 400-m weir section constructed at 0.7-m above mean low water (mlw) on the shoreward portion of the north jetty (Douglass 1987). The weir section was designed to allow southerly moving sand to pass over and into a deposition basin (dredged to –6 m mlw) located within the shelter of the jetty, but outside the navigation channel (dredged to –3 m mlw) (Figure 3). A pre-construction hydraulic model investigation recommended that a third structure, a deflector dike, be included to prevent the main channel from migrating into the deposition basin (Perry, Seabergh, and Lane 1978). This structure was not constructed.

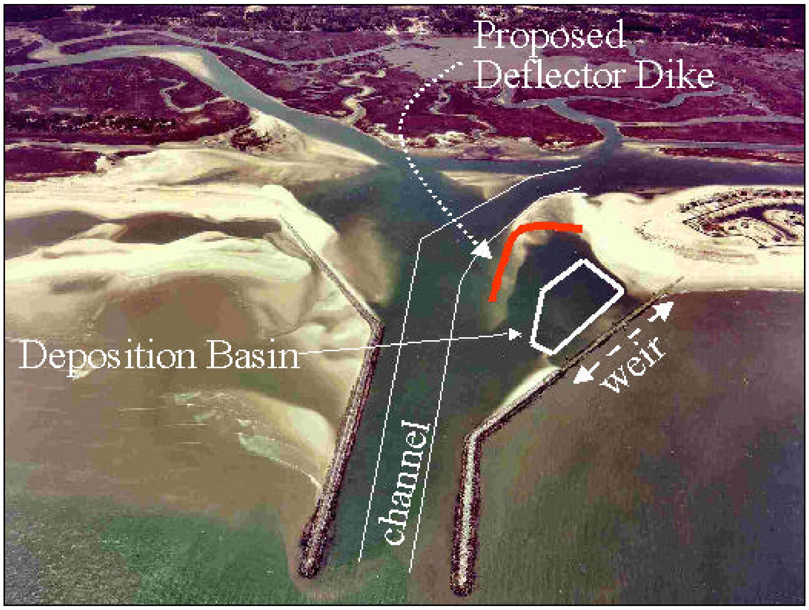

Figure 3. Murrell's Inlet, South Carolina showing weir jetty, deposition basin, and spit formation encroaching channel (photograph dated 7 April 1982)

Results of a 9-year monitoring program indicated that sediment tended to transport over and through the weir jetty, as designed. However, sediment then bypassed the deposition basin, forming a spit that encroached the navigation channel (Douglass 1987, Figure 3). It is likely that the proposed deflector dike would have retained sediment in the deposition basin.

Raise and sand-tighten jetties

Permeable jetties and jetties with elevations that are low relative to the adjacent beach can contribute to erosion of the adjacent beach and shoaling of the inlet channel (Figure 1). Jetty elevation below that of the berm elevation of the adjacent beach allows wave runup to transport sand over the top of a jetty and into the inlet, exacerbated during times of storms and high water level. This sediment-transport pathway is an unnecessary loss of material from the adjacent shoreline, and increases shoaling of the entrance channel. This loss is especially detrimental for down-drift beaches, which tend to lose sand because of a near persistent local transport reversal. As an example of this phenomenon, consider Ocean City Inlet, Maryland (Figures 4a, 4b, and 4c).

Figure 4a shows an aerial photograph of Ocean City Inlet taken in 1952, prior to elevating and sand-tightening of the south jetty. Note the shoal on the northwest corner of the south beach. Superimposed on this photograph are the sediment-transport pathways believed to create the shoal, based on studies by Dean and Perlin (1977).

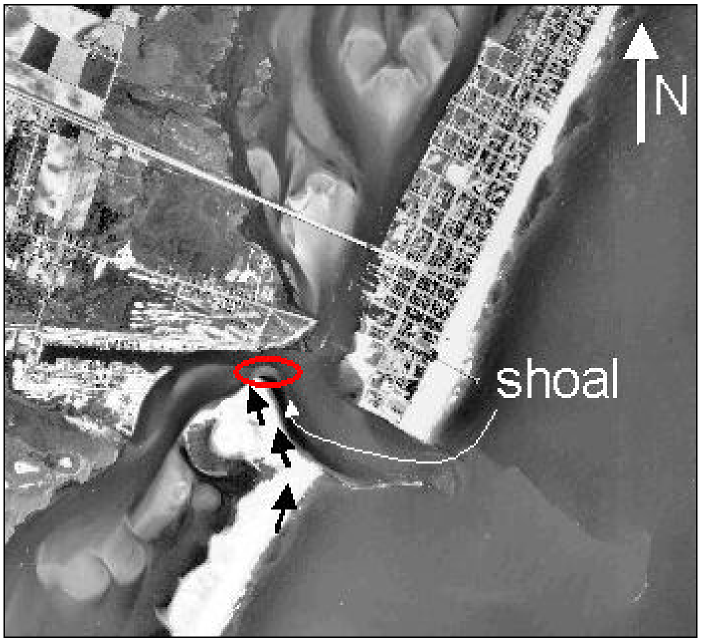

Figure 4a. Ocean City Inlet, Maryland with sediment-transport pathways over and through jetty (based on Dean and Perlin (1977); photograph dated 8 June 1952)

Figure 4b shows the elevation of the berm adjacent to the south jetty, indicating an increase in this elevation with distance from the south jetty. Because the jetty was lower than the adjacent beach berm, a downhill gradient existed from the beach towards the jetty. The downhill gradient in beach elevation allowed the flow of water and sand over and through the south jetty.

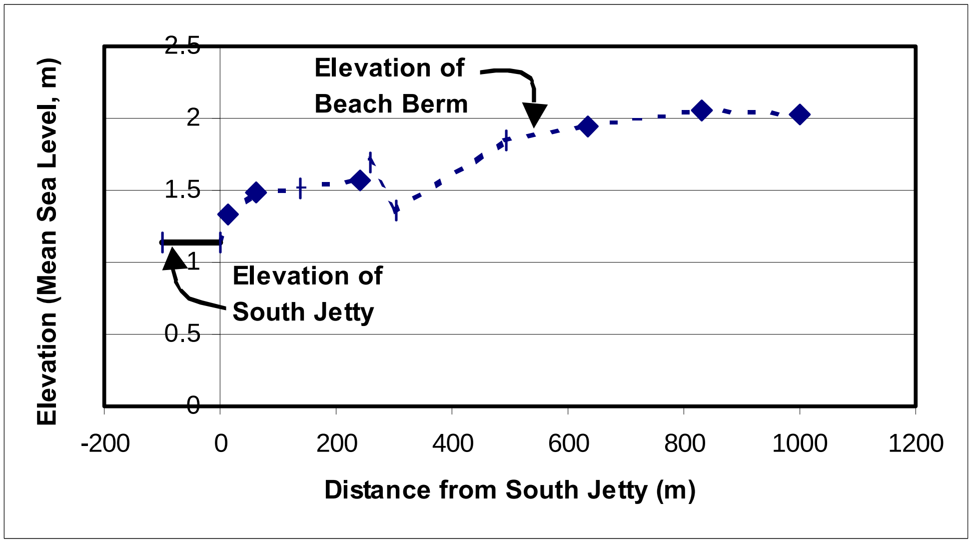

Figure 4b. Increase in beach berm elevation with distance from Ocean City Inlet pre-rehabilitated south jetty (based on March 1976 profile data of Dean, Perlin, and Dally (1978))

In 1985, a new south jetty section was constructed, offset 10 m south of the existing jetty centerline (Bass, Fulford, and Underwood 1994). The new section had a crest elevation 3.3 m relative to mean sea level (msl) (former jetty crest was 1.2 m msl), and was constructed with an impermeable core wall composed of precast concrete units. In addition, three headland breakwaters were constructed on the southern bank of the inner inlet shoreline. It was anticipated that this shoreline would erode because of elimination of the sand supply to this region. Scour at the foundation of the south jetty was also repaired. Figure 4c shows the rehabilitated construction.

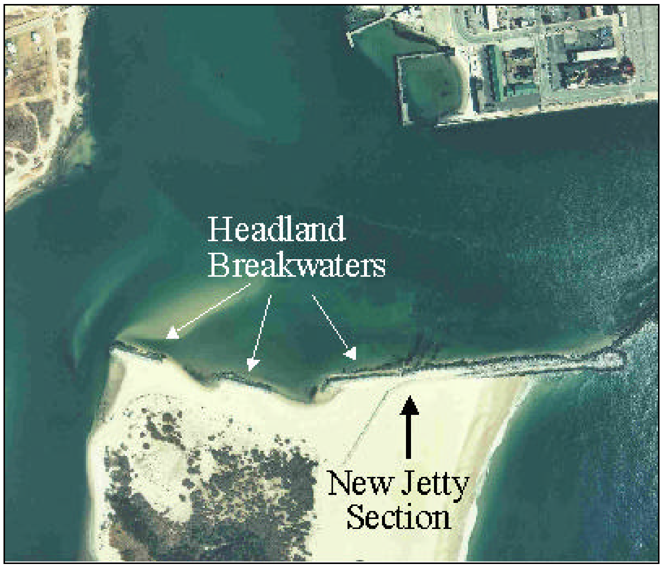

Figure 4c. Ocean City Inlet, Maryland post-project (21 Feb 1990)

Improvements to Ocean City Inlet were monitored over 27 months from October 1986 through January 1989. The monitoring program consisted of beach and offshore profile surveys, aerial and ground photography, hydrographic surveys, wave gaging, and side-scan sonar surveys of the scour protection area. Results of the monitoring program indicated that the rehabilitation effort successfully met its goal of eliminating the sand source to the finger shoal, resulting in an accretionary fillet on the downdrift shoreline.

Prevent transport by wind-blown sand

Sand shoals often appear inside of jetties adjacent to the beach berm or dry beach. These shoals can be created by sand transported over the jetties during times of high water relative to the elevation of the structures and by sand blown over the jetties, which occurs when the wind is blowing with a longshore component and the beach is dry. Seelig and Sorensen (1976) describe an example of shoaling by wind-blown sand transport at Penwater Inlet, located on Lake Michigan, and discuss possible solutions to reduce shoaling (planting vegetation and placing sand fences). For illustration herein, we consider the Mustang Island Fish Pass, Texas.

The Mustang Island Fish Pass was a 3.2-km-long channel dredged and opened in August 1972 by the Texas Parks and Wildlife Department to increase water exchange and fish migration between Corpus Christi Bay and the Gulf of Mexico. It was never a Federal channel and was not maintained once opened. The jetty spacing was 122 m, and the length (measured from the initial shoreline) into the Gulf was 260 m (Behrens and Watson 1977, Kraus and Heilman 1997). By March 1985, the pass had closed, primarily by shoaling near the Gulf entrance. Figure 5 shows areas of shoaling on three dates. Tropical storms tended to open the pass, but the strong and persistent wind blowing on the south Texas coast contributed to formation of the shoals. As described previously, raising of jetties will reduce overtopping by water carrying sand during times of high water. Similarly, higher jetty elevation and amenities such as walkways and railings that increase effective elevation will reduce overtopping by wind-blown sand. At the base of jetties, far from the beach, sand fencing and planting of vegetation can also reduce infiltration by wind-blown sand.

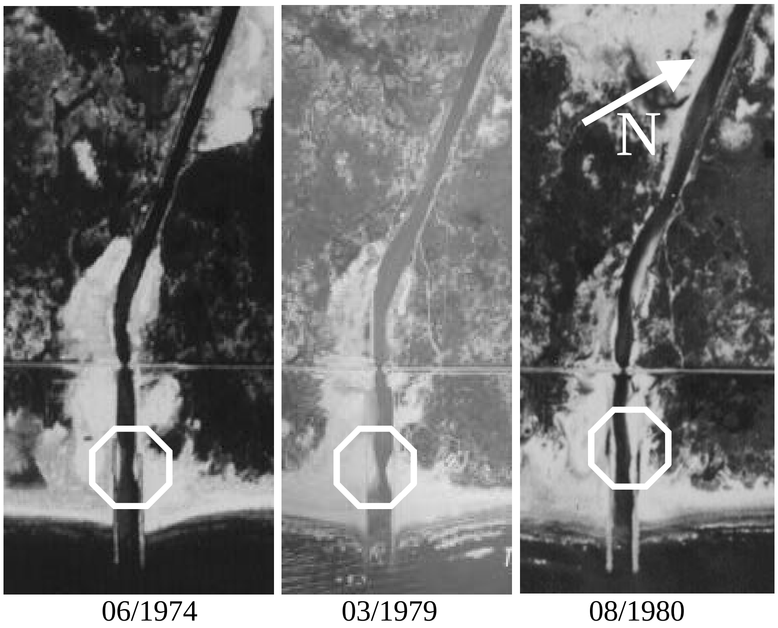

Figure 5. Entrance to Mustang Island Fish Pass, Texas

CONCLUSIONS: The USACE mission to provide safe and navigable waterways requires maintenance dredging of inlet and entrance channels. Maintenance dredging comprises roughly 90 percent of the dredging volume, and approximately 80 percent of the cost. Simple adjustments to existing operations, such as modifying the inlet and entrance infrastructure, dredging location, placement of dredged material, and monitoring of projects can potentially yield cost savings. Several of these methods and "lessons learned" have been described in this CETN by case studies. Readers are encouraged to share successes, failures, and ways that they have modified existing operation and maintenance projects to solve problems at inlets and entrances at the Coastal Inlet Research Program's web page at *http://cirp.wes.army.mil/cirp/cirp.html*.

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