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Inner-Bank Erosion Processes and Solutions at Coastal Inlets

by William C. Seabergh

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein provides information on erosion which occurs on the banks (or shoulders) of tidal inlets stabilized with jetties. The causes for initiation of this erosion area are discussed, and potential solutions for reducing/preventing the erosion are presented.

BACKGROUND: Jetties at inlets often terminate in the alluvial soil of the barrier island or mainland of the entrance that they stabilize. The termination area, exposed to waves and currents, is frequently observed to erode (Figure 1). If erosion is permitted to proceed unabated, a crenulate-shaped shoreline region will develop from the terminus of the jetty, extending both bayward and laterally into the adjacent beach. The expansion of erosion leads to loss of property and difficulties in reclamation if a shallow-water environment develops. The eroded sediment may move into the channel, contributing to shoaling.

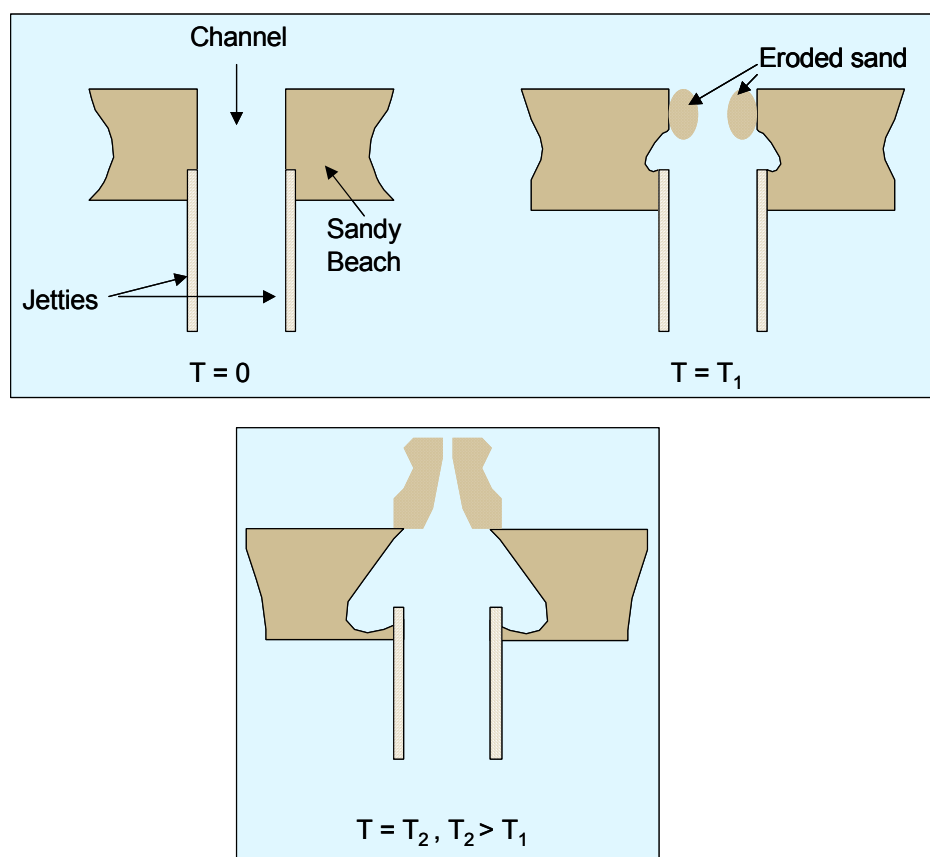


Figure 1. Sequence of inner-bank erosion over time, from time $T = 0$ to time $T = T_2$

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The eroded region may flank the jetty, leaving it isolated from the shore. Figure 2 shows an example before and after breaching. This breaching at Moriches Inlet, NY, has been described by Sorensen and Schmelz (1982). Isolation of the jetty may lead to potential problems of tidal current scour near the structure, opening the already eroded embayment to increased wave activity and additional erosion, and permitting increased wave attack on the jetty itself. As part of the Coastal Inlets Research Program (CIRP) being conducted at the U.S. Army Engineer Research Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), erosion at the bay side of jetties was studied in a movable bed physical model of an inlet. After the governing processes were understood, preventive techniques were investigated.

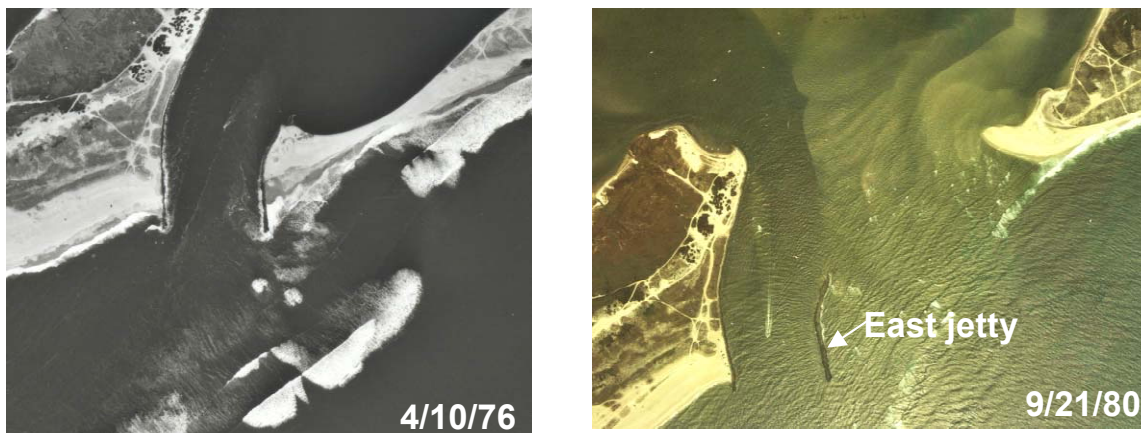


Figure 2. Left panel shows Moriches Inlet, NY, before it breached on 15 January 1980. East jetty was flanked, after it breached, as shown in the right panel

COASTAL SEDIMENT PROCESSES DETERMINING INNER BANK EROSION, EXAMPLES: In this section, examples are given to illustrate the response of the inlet shoulder to construction of jetties. If maps and aerial photos of inlets are examined, one will find many appearances of eroded inner banks. This examination reveals a characteristic curved eroded shoreline on the inner bank, or channel side of a jetty where it terminates in a sandy shore. At many inlets, that region of lateral expansion shoreward of the jetty terminus has been revetted or protected in some way with rock, bulkheads, or sheet-pile structures.

Erosion occurred at St. George Inlet, located on the Gulf Coast in the eastern part of the Florida panhandle. Figure 3 shows the inlet in its natural state (left panel), and the right panel shows the inlet 12 years after parallel jetties were constructed. An erosive force created the curved shorelines at the base of the jetties. Figure 4 shows the entrance channel at Panama City Harbor, FL, created by cutting through an elongated spit in 1933. The construction included jetties extending to the -3.7-m-mllw (mean lower low water) contour. The inner 90 m of the jetties flared outward and were anchored in sand. Between 1935 and 1956, landward extensions of the jetties were made to prevent continued erosion of the inner-bank shoreline. Flanking of the jetties was a major concern.

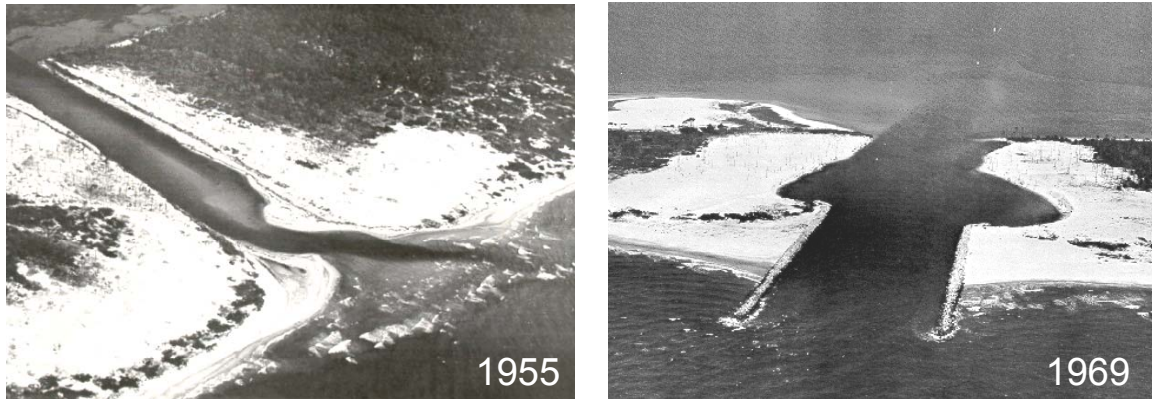


Figure 3. Before and after jetty construction at St. George Inlet, FL, on Gulf Coast

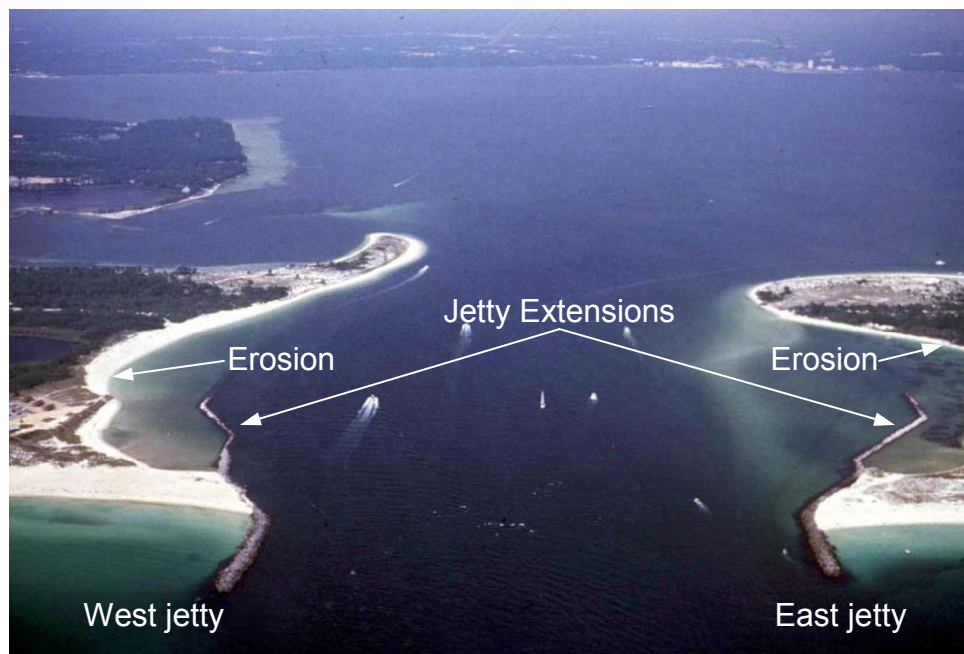


Figure 4. St. Andrews Bay Inlet (Panama City, FL) 1992. Jetty extensions added to prevent flanking

Figure 5 shows flanking of the south jetty at Grays Harbor, WA. The region behind the shoreline is called Half Moon Bay. This “bay” was created after the south jetty was raised from +3.65 m mllw to +6.10 m mllw. With the jetty at the +3.65-m elevation there was continual sand transport from the ocean shoreline to the region inside the inlet, probably due to the strong wave climate of the region pushing sediment over the landward intersection of jetty and beach. After the jetty was raised, the sediment supply was cut off and creation of Half Moon Bay began. The jetty was raised in 1936, and by 1993 the distance between the beach and Half Moon Bay was short enough that a winter storm caused a breach or flanking of the inlet (Seabergh 1999b).



Figure 5. Jetty flanking at Half Moon Bay, Grays Harbor, WA

This commonly occurring recession of the inner bank of an inlet is found at jetties on all United States coasts, including the Great Lakes (Figure 6). The basic condition necessary for this erosion to occur is the termination of a jetty in a sandy area that is not receiving any sediment into the local region of the jetty termination. The forcing mechanisms are discussed next.

INITIAL HYPOTHESIS FOR EROSION: The manner in which inner-bank erosion is initiated and evolves can be assumed to be related to the attack on the shoreline by currents (due to tide or river flows), short-period wave action, or a combination of both. For this study, it was initially hypothesized that this erosion process develops over time similar to that of a logarithmic spiral plan-view shape of headland-bay beaches (LeBlond 1979) or a crenulate bay (Silvester 1970). Dean and Maurmeyer (1977) examined an erosion spot inside Shinnecock Inlet, NY, and concluded waves, not currents, were the causative agent. Walton (1977) produced an analytic method using wave-height energy distribution to predict a stable sheltered shoreline. Moreno and Kraus (1999) developed a hyperbolic-tangent function to fit these shoreline shapes.

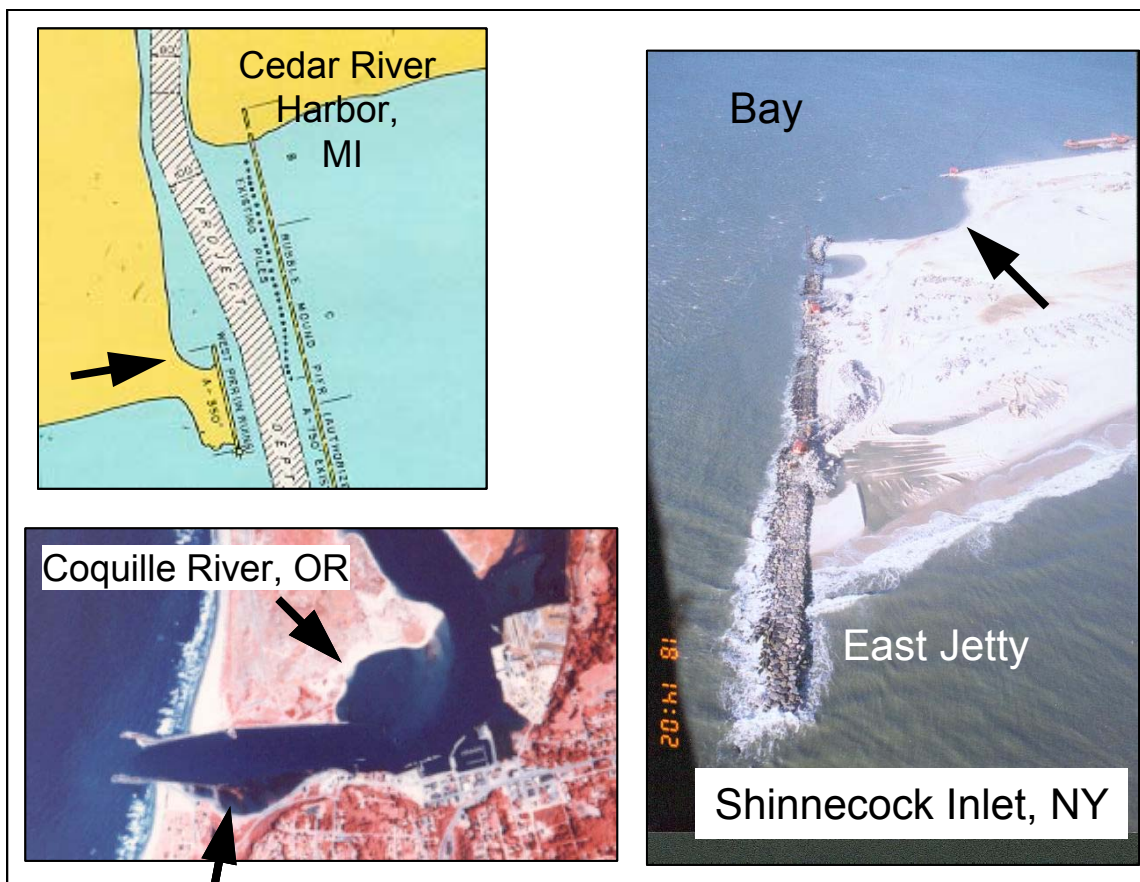


Figure 6. Examples of inner-bank erosion at coastal inlets on Atlantic, Pacific, and Great Lakes coasts

PHYSICAL MODEL OF INNER-BANK EROSION: Inner-bank erosion was examined in the Idealized Inlet Model (Seabergh 1999a) installed at CHL. This physical model supports basic and applied research through CIRP. The concrete basin (46 m wide, 99 m long, 0.6 m deep) contains an ocean and bay separated by an inlet. A movable wave generator on the ocean side creates waves of fixed direction and variable height and period. Tidal cycle water level variation can be simulated or steady-state ebb/flood flows can be produced for a given water level with a combination of pumps, storage tanks, valves, and sump. For this study a fully movable bed was placed along the entrance channel, from a region just inside the jetties bayward.

Modeled Conditions. The approach was to construct a pair of parallel jetties that terminated in a sandy beach. The initial experiments were run with a wave-only condition, followed by other experiments with waves and a steady-state-flood current, and then waves with a tide (all modeling was governed by a 1:50 scale). The wave generator was oriented perpendicular to the channel center line. Initially, the rock jetties were permeable, but were made impermeable with thin aluminum sheeting placed vertically along the length of the jetty center line. This eliminated sand from the beaches passing through the permeable structure, reaching the channel and changing channel bathymetry. For the wave-only and wave-plus-steady-state current runs, the water level was +1.5 m relative to mean low water (mlw). The semidiurnal tide level varied between 0.0 and +1.5 m, mlw, with a period of 105.4 min (Froude time scale = 1:7.07 model to prototype). The initial condition for

the movable-bed portion of the bathymetry was composed of two different side slopes for the inner bank on each side of the channel.

Inner-Bank Erosion Experiments. The first wave condition was 2.7-m height, 10-sec period (scaled to prototype), and no currents were reproduced. The model was run until equilibrium plan view and vertical profile shapes were reached for the given wave and water level, and the bathymetry was measured. For this wave-only condition, the erosion at the jetty terminus was initiated by the lateral runup produced by the water level variation as wave crests, then troughs, moved past the terminal end of the structure. The runup and rundown motion at the landward terminus of the jetty created a notch in the sand, which gradually deepened, then widened, permitting increasing wave diffraction to carve out the embayment.

The erosion region developed from a straight bank line into the crenulate shaped embayments as seen in Figure 7. It reached an equilibrium shape after about 20 hr model time. Raising the water level with the same incident wave conditions produced a greater erosion area (right side of Figure 7). The addition of currents with the waves increased the size of the embayment, but the initiating process was observed to be the same as the no-current experiment. Sediment eroded from the embayment moved along the edge of the inlet channel. With the no-current condition, sediment built out into the center of the entrance channel and reduced the rate of removal from the eroded region. The flood current increased the angle of wave attack and movement of sediment out of the embayment. With a tide-plus-waves condition, a similar shape embayment formed as for previous conditions, larger than the no-current condition, but smaller than the wave-plus-steady-state flood current. The variation in tidal elevation permitted a deeper cut in the embayment. With currents (steady-state or tidal) present, the eroded volumes increased in the range of 8 to 45 percent.



Figure 7. Physical model experiments showing inner-bank erosion development

Inner-Bank Erosion Prevention Methods. Follow-up experiments examined potential solutions to minimize erosion by placing hard points to create smaller embayments or altering jetty structure slope and lateral extension into the channel. A diamond shape (in plan view) was built on the end of the right jetty and functioned to reduce wave energy at the end of the jetty. Because of its extension into the beach, it also prevented flanking, as shown in Figure 8, right side. On the left side of the middle photograph, Figure 8, a channel-side structure is placed seaward from the jetty terminus, and flanking of the jetty occurred because there was no tie-in to the beach. The headland concept was adopted by adding a hard point (a rock mound) on a line bayward of the jetty, to create a smaller embayment region than was created without the additional structure (Figure 8, left panel). These are compared to the nonstructure experiment in Figure 7 for wave and tidal current conditions. Volumes eroded and surface area removed were reduced for the prevention methods. The diamond structure reduced erosion and prevented flanking of the structure, reducing volume loss 58 and 47 percent on the right (initially steep slope) and left (initially relatively flat slope) inner-bank regions, respectively.

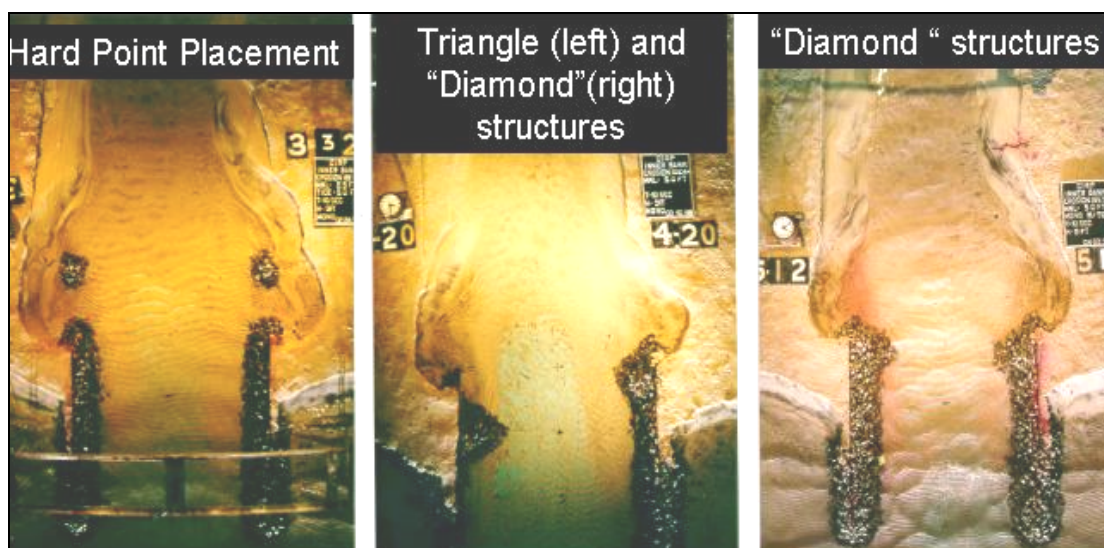


Figure 8. Inner-bank erosion prevention experiments

FIELD APPLICATION: Referring to Figure 5, Grays Harbor, facing the Pacific Ocean of Washington, has a large entrance channel. South jetty construction commenced in 1898, and north jetty construction was completed in 1913. By 1929, the inlet entrance was as shown in the top map of Figure 9. Focusing attention on the shore end of the south jetty, which had a crest elevation of +2.4 m, mllw, there was a continuous shoreline from ocean side to bay side at the south jetty junction with the shore. Apparently, in this region of severe wave climate (average significant wave height of 2 m, with storm waves of 5 m not unusual) and large tide range (diurnal tide range of 2.7 m), sediment can move over and through the jetty at the shoreline during high water and storm conditions. Earlier maps of the inlet, after the jetties were built, showed this continuous shoreline through the south jetty also.

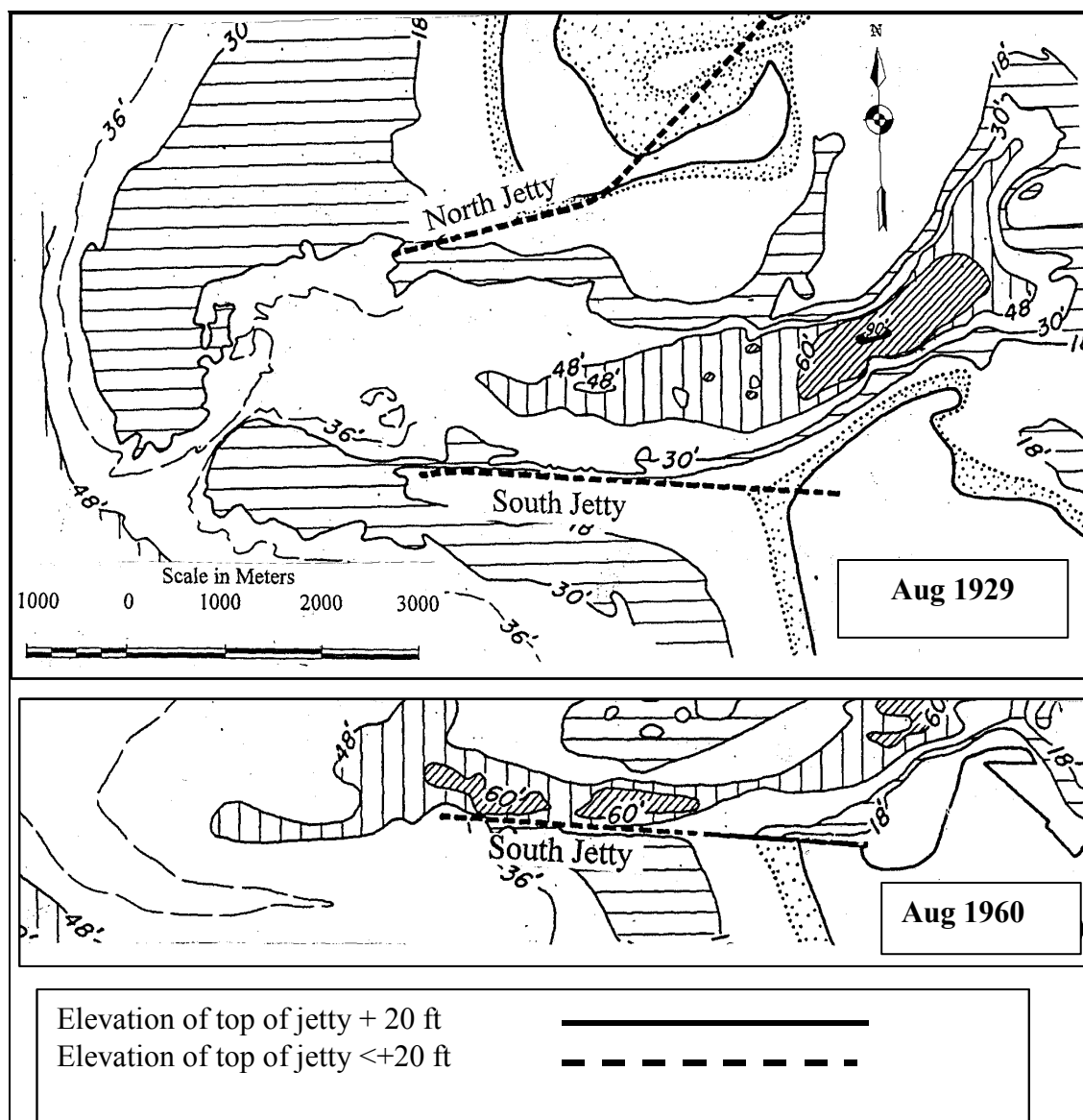


Figure 9. Grays Harbor, WA, entrance channel and adjacent shorelines. August 1929, before south jetty shoreward portion raised, and August 1960, about 24 years after south jetty raised to +6.1 m, mllw. Note inception of inner-bank erosion at landward end of south jetty

In the 1936-1939 time frame, the south jetty crest elevation was increased to +6.1 m, mllw. This addition in elevation was sufficient to reduce or cut off the sediment supply from the beaches to the inner-bank shoreline. As seen in Figure 9, initially the inner bank was receding eastward, and by 1946 the jetty terminus was exposed. An eroded region evolved at the south jetty terminus, as seen in the 1960 time frame. In 1960, the curved notch extended approximately 640 m landward from the jetty terminus, and was recessed 200 m laterally into the inner bank. By 1993, the eroded region had increased to dimensions of 730 m long by 275 m wide. From 1946 to 1960, it expanded at a rate of about 46 m/year in length and 14 m/year in width. From 1960 to 1993, the rate of increase decreased significantly.

In late 1993, the region just south of the south jetty was breached during a storm (Figure 5), and emergency measures had to be taken to repair the breach. The navigation channel was in close proximity, located on the inner edge of the south jetty, and tidal flow could potentially enlarge the breach and cause additional erosion to the region. Increased exposure to wave action was also a possibility for the city of Westport, located east of the eroded area. The ocean-side beach had also been receding, so the combination of inner-bank erosion and beach recession had greatly increased the potential for breaching. The gap was filled with dredged material in this emergency. As part of a plan to reduce likelihood of future breaches, the U.S. Army Engineer District, Seattle, designed a mound structure based on the conceptual model experiments of CIRP as previously described. A model study was conducted to replicate the shoreward region of the south jetty and some of the navigation channel in the laboratory facility. This work validated the design. Figure 10 shows the initial condition as shown in the model and the plan selected for construction. The wave angle sweeping along the shoreline is modified by the mound, directing it more perpendicular to the inner bank shoreline. Also, wave heights were significantly reduced in this region. Figure 11 shows the structure shortly after construction in August 2000.

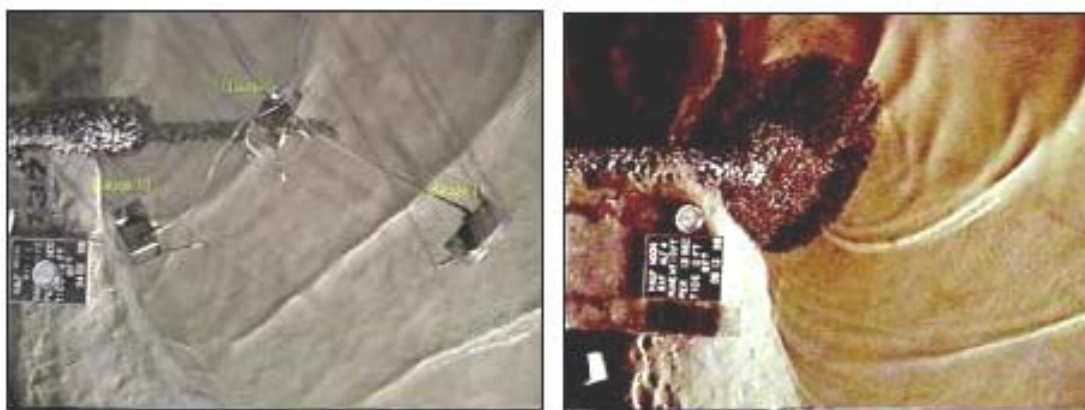


Figure 10. Model study photographs: left picture shows the prediffraction structure condition and right picture shows the mound structure diffracting waves

ANALYTICAL EVALUATION: Analytical expressions for the shape of an equilibrium inner-bank eroded region can be adapted from work developed for shapes of headland-bay beaches. Originally log-spiral curves were developed to fit the beach shape, but more recent work indicates parabolic or quadratic equations can represent the equilibrium form well (Silvester and Hsu 1993). Charts are also available (Silvester and Hsu 1993) which relate the indentation, to elongation ratio of an embayment to the dominant wave angle β , which, once equilibrium is reached, is the angle that the downcoast portion of the shoreline makes with the original shoreline. Figure 12 shows β for the case of inner-bank erosion. These analytical methods were developed for the open coast, but it appears reasonable to use, with caution, these techniques for inner-bank erosion. As was noted in the physical model tests discussed earlier, the effect of currents (especially flood current) and increased water level, can increase the size of the equilibrium eroded area. The dominant wave angle β can be fairly small for a large inlet, high-wave-energy system, such as Grays Harbor. Dominant wave angles compare with those for open coast angles for such large inlet systems. For smaller, narrow inlets, the wave angle will be larger, and less confidence should be placed in these analytic techniques.



Figure 11. Mound diffraction structure as constructed at Grays Harbor, WA (2000)

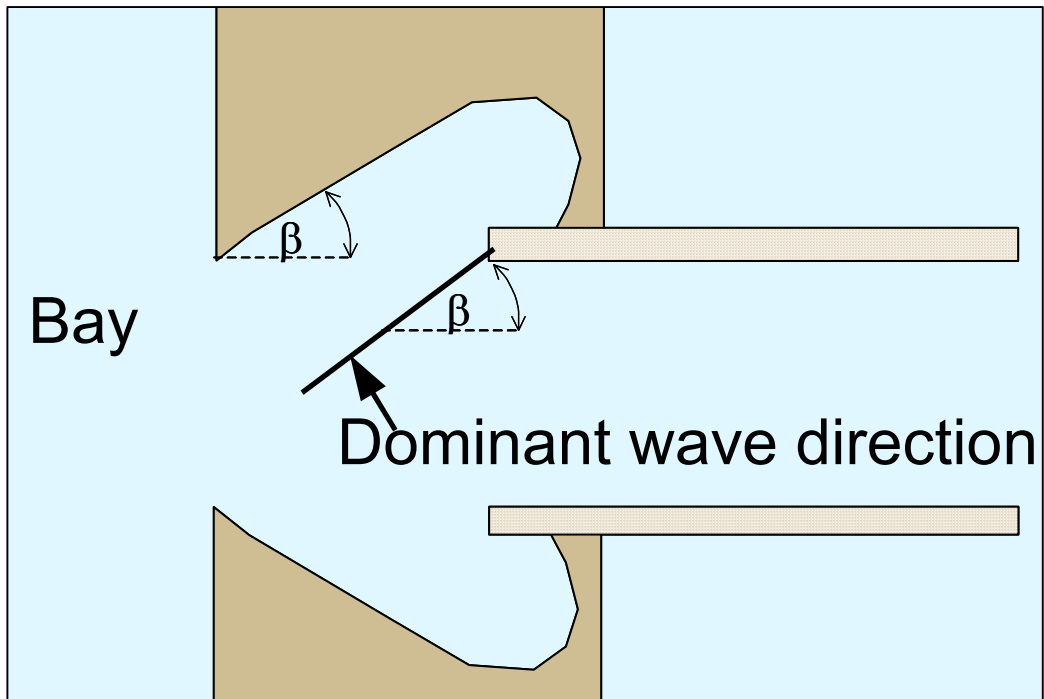


Figure 12. Equilibrium inner-bank erosion showing dominant wave angle and shoreline orientation angle, β

CONCLUSIONS: Inner-bank erosion, which occurs at the shoreward termination of a jetty structure on the channel side of an inlet in a sandy beach, occurs on all United States coasts. An unabated eroded area takes the shape of a crenulate or log-spiral beach, similar to that which occurs on the open coast downdrift of headland features. Investigations in a movable-bed physical model basin have shown that the erosion is a consequence primarily of wave action, which initially cuts a trough at the jetty structure-sandy shoreline intersection then gradually widens, allowing diffracted wave energy to widen the trough, both behind the structure and bayward. Waves refracting up the side of the channel slope then continue to elongate the eroded region. An equilibrium shape is reached similar to that for an open-coast crenulate bay. If a flood-flow current is added to the wave environment, the wave angle becomes steeper, and sand at the landward end of the embayment is pushed further inland along the channel's edges. The waves-plus-current produces a larger equilibrium embayment than for waves-only. For a tide-plus-waves condition, the erosion area is greater than the waves-only condition, but less than the waves plus steady flood current condition.

Physical model experiments were performed to examine solutions for reducing the erosion other than the traditional revetment of the shoreline with armor stone. A hard point stone mound placed some distance bayward of the jetty termination created a shoreline response similar to that of headland beaches, creating smaller embayments rather than one large deep-cutting embayment. A diamond-shaped rock mound on the jetty termination location functioned best, especially because of its projection into the beach side of the jetty. The diamond-shaped mound prevented flanking of the terminal tip of the jetty. Its projection into the channel reduced wave height at the structure-sand interface. The experiments were conceptual in nature and conducted for limited conditions. However, physical modeling can provide a means to aid in the design of optimal termination structures for site-specific wave, current, and jetty conditions.

ADDITIONAL INFORMATION: Questions about this CHETN can be addressed to Mr. William C. Seabergh (601-634-3788; e-mail: William.C.Seabergh@erdc.usace.army.mil). For information about the Coastal Inlets Research Program, contact the Program Manager, Dr. Nicholas C. Kraus at Nicholas.C.Kraus@erdc.usace.army.mil. This Technical Note should be cited as follows:

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