PART V

Coastal Processes and Sediment Transport

CHAPTER 153

The Effect of a Shore-Parallel Offshore Breakwater on the Beaches at Ocean City, NJ

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Abstract

The design, construction and performance of a shore-parallel nearshore breakwater at Ocean City, NJ (USA) are described. The breakwater, which is connected to a long, high, impermeable groin at 9th Street, was constructed from armor stone removed from the groin when the groin cross-section was lowered. Constructed over a two month period in late 1987 and early 1988, the breakwater caused accretion immediately behind it and erosion along downdrift beaches. A beach fill of 40,000 cu yd of sand was recommended as a part of the original project; however, the beachfill was not placed until the spring of 1990, more than two years after the breakwater/spur was constructed. The project, in the absence of the recommended beach fill, is performing as would be expected. The sand within the groin compartment has been redistributed with a net gain behind the breakwater just downdrift of the 9th Street groin and a loss updrift of the groin at 11th Street.

Introduction

In 1987 the City of Ocean City, New Jersey, commissioned the design of a shore-parallel nearshore breakwater to provide a "sitting beach" in the vicinity of 9th Street in Ocean City. See Figure 1. The design was to be in conformance with an earlier study (Weggel, Douglass & Sorensen, 1988) which recommended that several of the existing rubble-mound groins in Ocean City be lowered so

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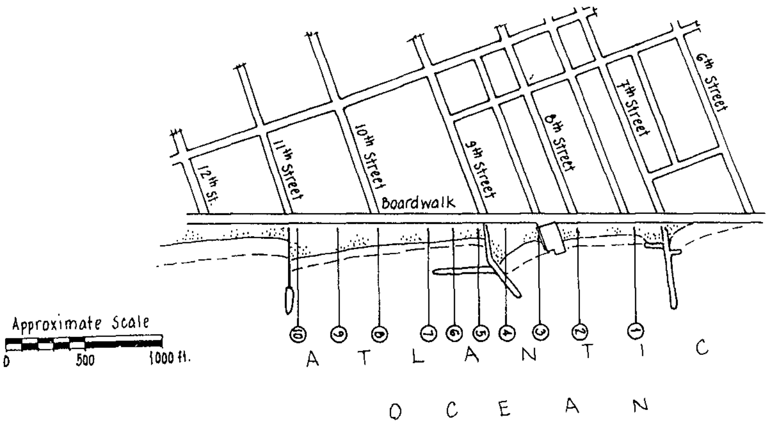

Figure 1 Location Plan, Breakwater/Spur Structure, Ocean City, NJ (USA)

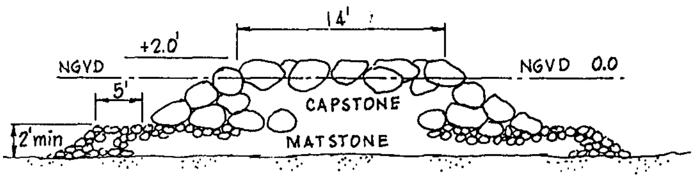

Figure 2 Typical Breakwater/Spur Structure Cross-Section

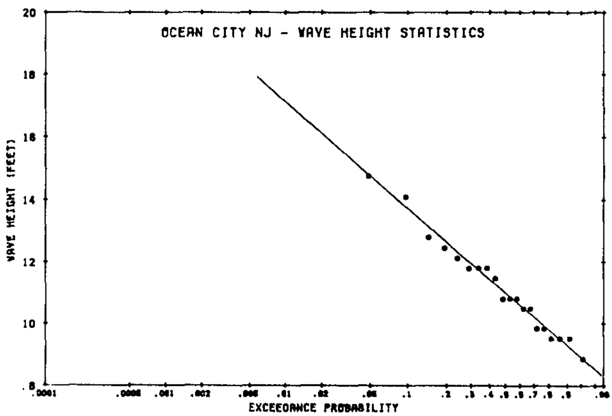

Figure 3 Wave Environment at Ocean City, NJ from WIS Hindcasts (Jensen, 1983)

that sand would be transported over and through them during storms. The resulting breakwater design made use of stone that would become available by lowering the existing groin at 9th Street and by removing a shore-parallel groin stub on the beach face between 9th and 10th Streets. The quantity of stone that would become available by lowering the groin was incorporated into six alternative breakwater designs located in three different water depths with crest elevations of +4 feet (+1.22 m) MLW and +6 feet (1.83 m) MLW. A typical breakwater cross-section is shown in Figure 2. The alternative designs were all connected to the existing 9th Street groin to facilitate construction by land-based equipment. The structure thus formed a shore-parallel groin stub/breakwater rather than a truly detached offshore breakwater. Beach fill was recommended as an integral part of the project. Each alternative was evaluated to estimate its effect on the shoreline.

Design Analyses

The wave environment at Ocean City was determined from the Wave Information Study (WIS) hindcasts of the U.S. Army Corps of Engineers (Jensen, 1983). The 100-year significant wave height at Ocean City is about 17 ft (5.18 m). See Figure 3. Potential net longshore sand transport at the site is generally southward as evidenced by the accumulation of sand along the northerly sides of groins in the area. (About 10 blocks further north the potential net transport is northward because of the proximity of Great Egg Harbor Inlet, the sheltering of the beaches by the inlet's ebb tidal shoal, and a change in shoreline orientation.) Most southward transport takes place during the winter months because of "northeasters" - storms in the North Atlantic that generate winds and waves that approach Ocean City from the northeast. During the summer months, transport is often northward causing some reorientation of the shoreline within groin compartments. Because of the presence of the groins, however, the potential longshore transport is probably never realized. The existing groins are high, long and impermeable and the compartments formed by them are, for the most part, independent cells.

Diffraction analyses for the area behind the breakwater were used to determine if a tombolo would form and the projected shoreline configuration was used to determine how much beach fill was needed. The criterion used to estimate whether a tombolo would form was the location of the $K' = 0.3$ diffraction coefficient line for the range of directions of wave approach at the site. (The breakwater was assumed to be detached with waves propagating around each end and diffraction coefficients were determined from diffraction diagrams for a semi-infinite breakwater. However, the interaction of the two wave systems coming around each end of the breakwater was not accounted for. Clearly, these assumptions were not met because of the presence of the 9th Street groin at the northerly end of the breakwater.) Incident wave directions at the nearshore site were assumed to range from 15° on either side of a line perpendicular to shore. The breakwater was positioned far enough offshore so that the intersection of the resulting K'= 0.3 lines was seaward of the original shoreline location. The post-construction shoreline configuration was estimated from the diffraction analysis. It was judged that the end of the shoreline salient would extend seaward a maximum distance of about 150 ft (45.7 m) from the pre-construction shoreline. The increase in beach area brought about by the breakwater/spur was expected to be about 1,400 sq ft (130 sq m) and, if no sand was to be lost from adjacent beaches, the required volume of fill behind the breakwater was estimated at 40,000 cu yd (30,600 cu m).

The stability of the rubble-mound breakwater/stub was evaluated using the preliminary laboratory test results obtained by Ahrens (1985) for reef-type breakwaters. Ahrens's analysis is for dumped-stone, nearshore breakwaters. He gives the crest height reduction for various levels of wave attack by the equation,

$$\frac{h_c}{h_c'} = \exp(c_o N_s^{*\,c_1}) \tag{1}$$

in which, h_c = the height of the breakwater crest after it has been subjected to wave action, h_c' = the height of the breakwater crest before it has been subjected to wave action, c_o = a coefficient equal to -0.0000969, and c_1 = a coefficient equal to 3.106. N_s^* = the stability number given by,

$$N_s^* = \frac{\{(Hmo)^2\ L\}^{1/3}}{(W/\tau_r)^{1/3}(\tau_r/\tau_f - 1)} \tag{2}$$

in which, Hmo ≈ the root-mean-square (rms) wave height at the breakwater, L = the wave length in the water depth at the breakwater, W = the weight of the armor stone, τ_r = the unit weight of the armor stone, and τ_f = the unit weight of the water.

The design significant wave height for the present analysis was 13.6 ft (4.15 m) or an rms height of 9.6 ft (2.9 m). The period was 10 sec. These conditions are expected to be equalled or exceeded once in 10 years. See Figure 3. The median stone weight available in the existing structure - the material from which the new breakwater was to be built - was about 6 tons (5.45 tonnes). A nearshore breakwater built of 6 ton stone in water 5 feet (1.52 m) deep with a crest elevation of +4 feet (1.22 m) MLW would be reduced in height by no more than 2% by the design wave at the worst stage of the tide (low tide). (Waves at the breakwater were depth limited for many of the design conditions investigated.)

For the above conditions, wave transmission by overtopping can be significant. Ahrens gives the following equation for the wave transmission coefficient.

$$K_T = 1/[1 - (A_T/D_{50}^2)^{0.545} \exp(-6.726 + 3.36\ h_c/d_s)] \qquad (3)$$

in which, A_T= the area of the breakwater cross-section, d_s = the water depth at the breakwater, and D_{50}= the diameter of the sphere having the same volume as the median stone diameter. For the Ocean City breakwater, K_T = 0.31 at low tide. At high tide K_T increases to 0.86. However, some wave transmission by overtopping was deemed necessary to preclude tombolo formation. Based on the design analyses, the alternative selected was a breakwater/spur about 360 feet (109.7 m) long in water about 5 feet (1.52 m) deep, located about 150 feet (45.7 m) seaward of the existing MHW shoreline with a crest elevation 4 feet (1.22 m) above MLW (approximately at MHW). The criteria for selecting this alternative included its ease of construction, the best use of the available stone, the stability of the resulting structure in the selected water depth, and the estimated shoreline location and increased beach area. The estimated volume of beach fill needed for the selected alternative was 40,000 cubic yards (30,600 cubic meters).

Construction

Construction of the breakwater/spur began in October of 1987 and was completed by the end of January 1988. In October and November work was limited to mobilization, site work and lowering the crest elevation of the existing 9th Street groin to obtain stone to construct the breakwater/spur. There was a nine day delay in construction in early December caused by the failure to secure a required permit. Construction of the breakwater/spur itself was completed in December and January. Construction was done using land-based equipment from the tops of the groin and breakwater/spur. The total project cost was $375,000 of which about $350,000 was for breakwater construction including boardwalk removal, lowering the 9th Street groin and breakwater construction. The 9-day construction delay added about $28,000 to the cost. Beach fill was not placed until spring 1990, more than two years after completion of the breakwater/spur construction. Nourishment sand from the originally proposed source could not be obtained because of pending litigation to determine its ownership. Subsequently, another source was selected. Sand dredged from the navigation channel of Great Egg Harbor Inlet in the fall of 1989 was stockpiled at the north end of Ocean City on the inlet beaches. About 28,000 cu yd (21,400 cu m) of this sand was later trucked to the 9th Street beach and stockpiled north of the groin. In the spring of 1990 some of this sand was moved to the area behind the breakwater/spur. Only about 10,000 cu yd (7,600 cu m) could be placed behind the breakwater because of losses from the stockpile during the preceding winter. Based on a volume of 28,000 cu yd, the cost of obtaining sand for the project was $7.26/cu yd. About $2.68 of this cost is associated with trucking the sand from Ocean City's inlet shoreline to the 9th Street area. The rest of the cost ($4.58/cu yd) is the difference in cost between pumping the sand to Ocean City's inlet beaches and using a hopper dredge with offshore disposal.

Beach Response

The response of beaches in the vicinity of the breakwater/spur was monitored for about 1 1/2 years. Ten profile lines were established; the most northerly profile extends seaward just south of a rubble-mound groin at 7th Street; the most southerly profile extends seaward just north of the groin at 11th Street. See Figure 1. There is also a short timber groin just south of the Music Pier located between 8th and 9th Streets. Thus beaches in the project area are affected by several groins as well as by the breakwater/spur. The lowered portion of the 9th Street groin serves as a control on the amount of sand that enters the compartment between 9th Street and 11th Street. Sand is transported over the groin only during storms and there were only one or two storms during the 1 1/2 year monitoring period during which sand transport over the groin was reported. The compartment between 9th Street and 11th Street is thus practically a closed system, at least for the period of the present analysis. A "pre-construction" survey of the profiles was obtained in November 1987. The first post-construction survey was obtained in January 1988 shortly after construction was completed. Subsequent surveys were obtained monthly during 1988 (except for October) and in January, March and May of 1989. Changes at selected profile lines occurring between November 1987 and January 1988 and February 1988 are shown in Figures 4 through 7. Significant accretion occurred behind the breakwater/spur between November 1987 and February 1988 (Figures 4 & 5). There was little change north of the project while erosion occurred south of the project (Figures 6 & 7). Erosion was greatest adjacent to the 11th Street groin (Profile 10) during this period while intermediate profiles (Profiles 8 and 9) show less erosion. While some erosion at these profiles can be attributed to the normal seasonal profile changes, it appears that the initial accretion behind the breakwater/spur has been at the expense of beaches to the south. A scour hole developed at the southern terminus of the breakwater/spur. The scour hole is shown at Profile 7 in Figure 6. Between March 1988 and August 1988 the profiles north of the site showed some accretion - possibly the normal summer profile recovery after the preceding winter. The profiles through the breakwater showed little change because of sheltering by the breakwater. Following the initial period of accretion, the beach behind the breakwater exhibited little seasonal variation. The scour hole at the terminus of the breakwater filled between March and August 1988 and the profiles south of the project showed accretion - again probably due to the normal summer recovery.

Those beach profiles between the 9th Street and 11th Street groins (Profiles 5 through 10) were subject to detailed analysis to determine how the location of the MSL shoreline and the volume of sand associated with each profile varied with time. (Refer to Figure 1 for the location of the profiles. Also note that the present analysis is for the time period preceding placement of the beach fill in the spring of 1990.) Figures 8 through 11 show the location of the MSL shoreline as a function of time at Profiles 5, 6, 7 and 10, respectively. Profiles 5 and 6 are behind the breakwater; Profile 7 is just south of the southern end of the breakwater and Profile 10 is just north of the 11th Street groin - the most southerly profile within the 9th Street to 11th Street groin compartment. The shoreline at Profile 5 (Figure 8) built out to the breakwater in less than 100 days following the start of breakwater construction. It subsequently receded for a short time but then built out to the breakwater again. The shoreline at Profile 6 (Figure 9) shows similar behavior although it took longer for the shoreline to build. The shoreline at Profile 7 (Figure 10) built out and then receded to about its pre-construction location. Profile 10 (Figure 11) shows significant initial erosion with subsequent recovery and then erosion again. Since this profile is adjacent to the 11th Street groin it shows seasonal accretion and erosion in response to seasonal changes in the direction

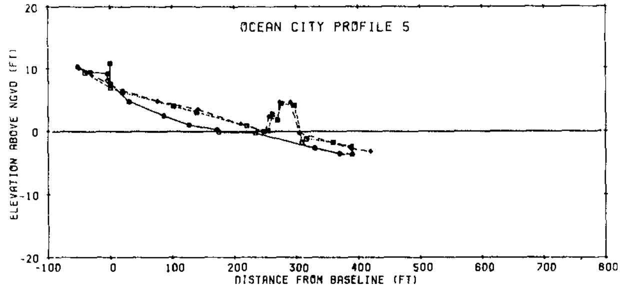

Figure 4 Profile 5 Behind Breakwater/Spur Structure (Solid line = 19 Nov 1987, Long dashes = 22 Jan 1988, Short dashes = 19 Feb 1988)

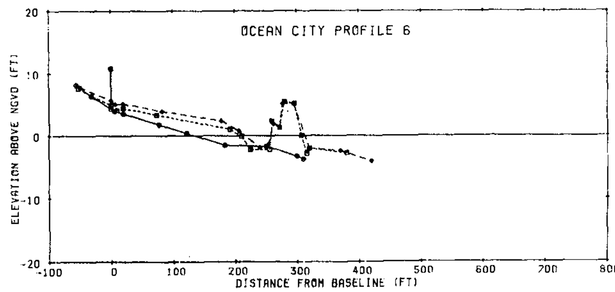

Figure 5 Profile 6 Behind Breakwater/Spur Structure (Solid line = 19 Nov 1987, Long dashes = 22 Jan 1988, Short dashes = 19 Feb 1988)

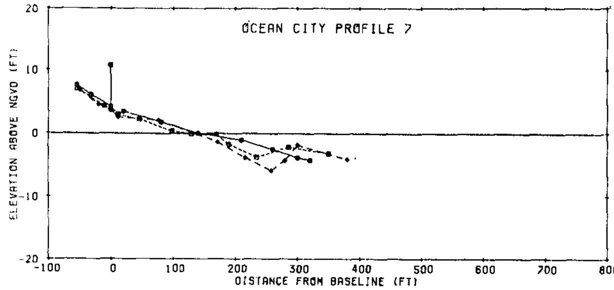

Figure 6 Profile 7, Just South of Breakwater/Spur Structure (Solid line = 19 Nov 1987, Long dashes = 22 Jan 1988, Short dashes = 19 Feb 1988)

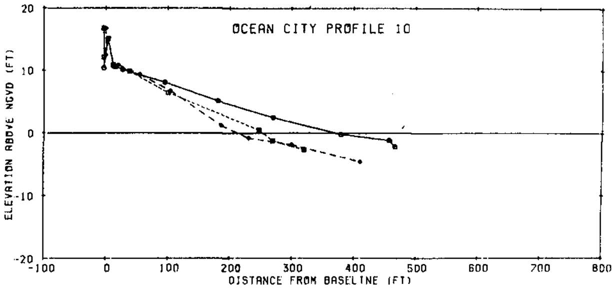

Figure 7 Profile 10 Near 11th Street Groin (Solid line = 19 Nov 1987, Long dashes = 22 Jan 1988, Short dashes = 19 Feb 1988).

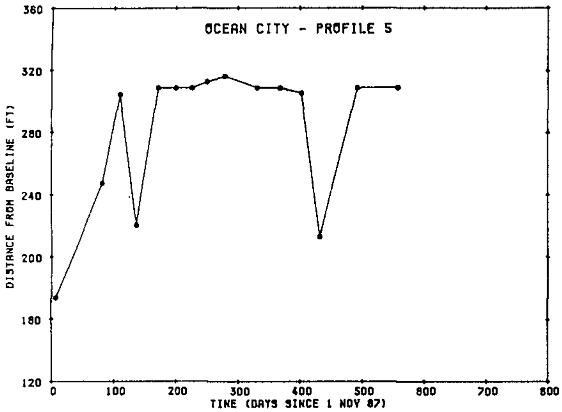

Figure 8 MSL Shoreline Movement at Profile 5

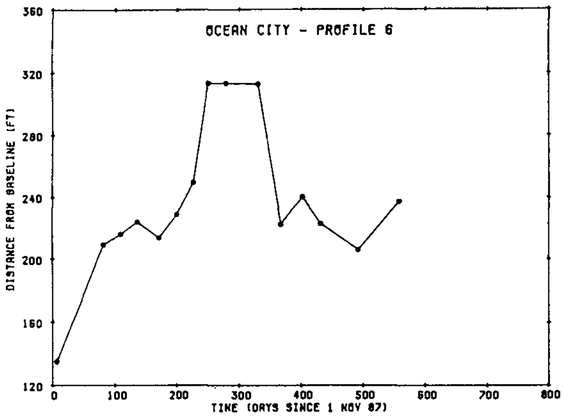

Figure 9 MSL Shoreline Movement at Profile 6

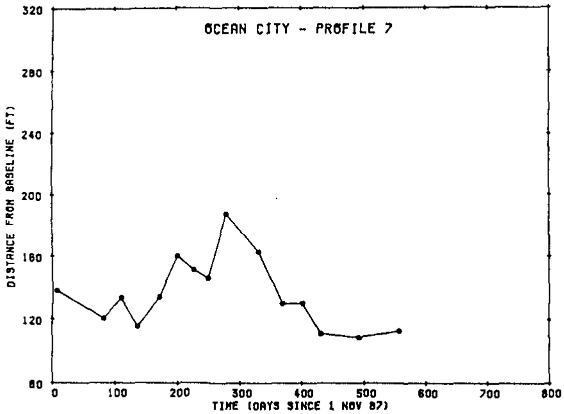

Figure 10 MSL Shoreline Movement at Profile 7

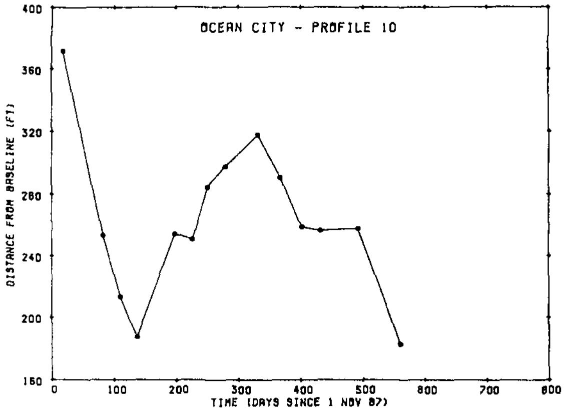

Figure 11 MSL Shoreline Movement at Profile 10

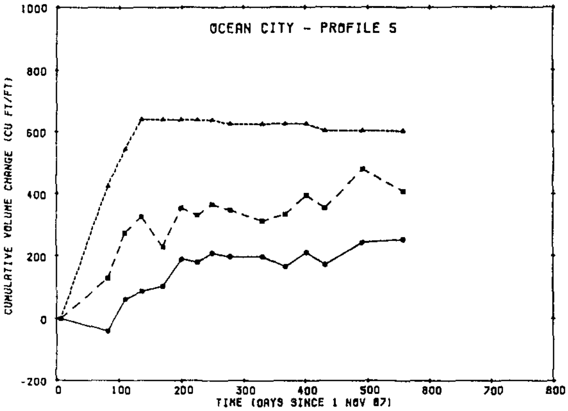

Figure 12 Volume Changes Below Given Contour at Profil 5 (Solid line = MSL, Long dashes = +2 ft Short dashes = +4 ft)

of wave approach. Similar behavior, although less pronounced, was observed at Profiles 8 and 9.

Figures 12 through 15 for profiles 5, 6, 7 and 10 show the cumulative change in volume below the given contour line. The solid lines with circles represents changes occuring below the +4 ft NGVD (National Geodetic Vertical Datum, or mean sea level of 1929) contour line. The long dashes with squares give changes occuring below the +2 ft contour line and the short dashes with triangles are the 0 ft contour (MSL). A positive slope represents accretion while a negative slope represents erosion. A horizontal line indicates no change in the volume of sand below the given contour. Figure 12 indicates that after the initial accretion behind the breakwater at Profile 5 little seasonal change in the volume of sand on the beach occurred. Profile 6 (Figure 13) shows a similar, but more dramatic, initial accretion with little subsequent change. Profile 7 (Figure 14) shows a small seasonal fluctuation with the profiles returning to approximately their initial condition. Profile 10 (Figure 15), however, shows rapid initial loss of sand with a subsequent reduction in the rate of loss followed by another rapid loss. Similar, but less dramatic, losses were recorded at Profiles 8 and 9.

The volume changes at Profile 5 through 10 suggest that the sand accumulation behind the breakwater is at the expense of the beaches to the south. Figure 16 is a sediment budget analysis for the beach cell between the 9th Street and 11th Street groins for the period between 7 November 1987 and 18 February 1988. Figure 16 is a mass curve showing the accretion (positive slope) and erosion (negative slope) as one moves southward along the beach from 9th Street to 11th Street. The figure shows the accretion behind the breakwater between about 0 and 300 ft (91.4 m) along the beach and the erosion along beaches farther to the south. Most of the lines on the curve return to a zero cumulative volume change at 11th Street (1,200 ft or 366 m along the beach) indicating that the volume of sand in the cell was conserved for the period of the analysis. Figure 17 summarizes the sediment budget analysis for the 7 November 1987 to 18 February 1988 time period and shows the location of accretion and erosion areas. The numbers on the figure represent the volume of sand accumulated between the given contour intervals and along the various profiles. (The vertical lines on the figure are at the midpoint between two adjacent profile lines, i.e., the first vertical line parallel with the 9th Street groin is midway between Profiles 5 and 6.)

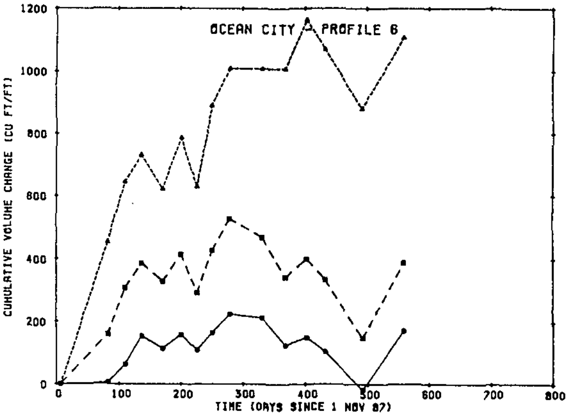

Figure 13 Volume Changes Below Given Contour at Profile 6

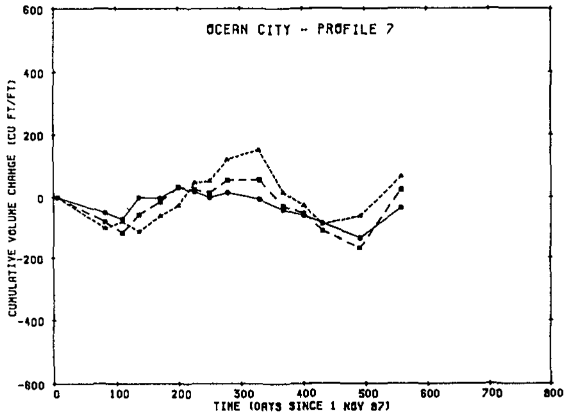

Figure 14 Volume Changes Below Given Contour at Profile 7

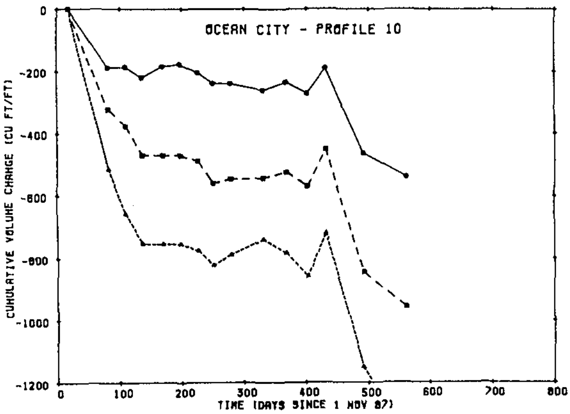

Figure 15 Volume Changes Below Given Contour at Profile 10

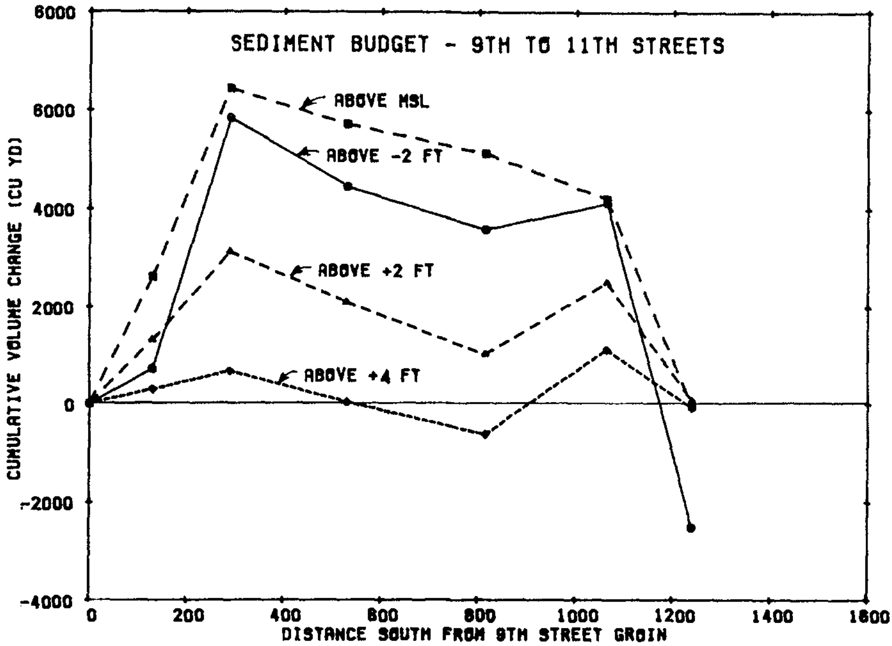

Figure 16 Cumulative Sand Volume Change Along Between 9th Street and 11th Street.

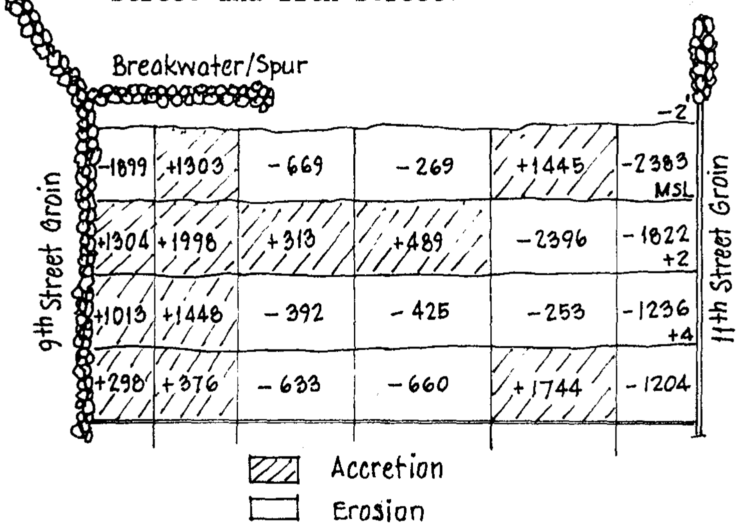

Figure 17 Summary of Sediment Budget Analysis for Area Between 9th Street and 11th Street Groins Showing Spatial Distribution of Accretion and Erosion Areas (Shaded Areasndicate Accretion, Numbers in Blocks Indicate Volume of Sand Lost [-] or Gained [+])

Conclusions

The breakwater/spur at 9th Street in Ocean City has functioned as expected in the absence of the 40,000 cu yd of beach fill recommended in the original project design. Sand which has accumulated behind the breakwater has been at the expense of beaches farther to the south within the same groin cell. During the period of observation, the beach cell formed by the two long, high, impermeable groins at 9th Street and 11th Street fuctioned as a closed system. Little sand appears to have entered from the north and little appears to have been lost to the south. The net sand gain or loss in the cell was zero; thus, accretion observed behind the breakwater/spur was balanced by erosion along beaches farther south near 11th Street. Seasonal fluctuations in beach width and volume changes are smaller for the beach behind the breakwater than for adjacent unprotected beaches exposed to direct wave action.

Appendix - References

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