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Coastal Engineering Technical Note

SEAWALL-BEACH INTERACTION: A Comparison of Monitoring Locations

PURPOSE: Research is under way to examine the influence of coastal armoring on beaches. This research involves literature reviews, ongoing long-term beach profile monitoring, and statistical analyses of collected data to investigate the true impacts of seawalls on beaches. Results of this research will address some of the classic questions associated with seawall and beach interaction, including (but not limited to): Do seawalls accelerate beach erosion?; Does the presence of seawalls alter the nearshore profile system?; Do seawalls impede post-storm beach recovery?

BACKGROUND: Three independent study sites are being monitored: Monterey Bay, CA; Sandbridge Beach at the south end of Virginia Beach, VA; and Duck Lake on the eastern shore of Lake Michigan near Whitehall, MI. Each site is at a different stage of monitoring. Dr. Gary Griggs of the University of California, Santa Cruz, has been collecting beach profiles at the Monterey Bay site since 1986. Dr. David Basco of Old Dominion University has been collecting beach profiles at Sandbridge Beach since 1990. The U.S. Army Engineer District, Detroit, began collection of beach and nearshore profiles at Duck Lake in July 1993.

These three sites were selected to sample three typical seawall-beach interaction categories: (a) a seawall located on an equilibrium beach with seasonal and storm interaction, such as at Monterey Bay; (b) a seawall/bulkhead located on an eroding beach with frequent interaction especially during storms, such as at Sandbridge; and (c) a rock revetment with no fronting beach that is constantly inundated, like Duck Lake. Since 1986, CERC has been sponsoring the collection of defendable and controlled data and rigorous data analysis. These data, now from three different sites, are being used in an attempt to answer the question, "In what way and to what extent do seawalls influence beach changes beyond the historic, seasonal, and storm-induced changes present at adjacent sites with no seawalls present?" Some results will be primarily site-specific due to the varied hydrodynamic conditions at each site. However, some seawall/beach interaction phenomena will be similar at multiple sites. This paper will relate corresponding features of each site and review preliminary observations that may indicate similar responses at each site.

SITE DESCRIPTIONS

Monterey Bay, CA. Monterey Bay is located on the central California coast between Santa Cruz and Monterey and is provided a continuous supply of sand from upcoast streams and bluff erosion. Sand is medium size with 50 percent to 80 percent in the 0.25- to 0.5-mm range. Tides are mixed semidiurnal with a maximum range of 2.75 m. Deepwater wave heights offshore of Monterey Bay during two severe winters (1978 and 1983) reached 6.5 m, and wave heights 1.6 km offshore ranged between 2 and 3 m. A slope array gage installed in 13 m of water off Santa Cruz measured maximum significant wave heights of 1 m approximately 50 percent of the time from December through May in the first year of beach profile monitoring. The original four monitoring sites have now been reduced to one (South Aptos Seascape), which is relatively protected from the predominating northwest swell (Figure 1). Waves emanating from the west or southwest have been primarily responsible for past storm damage. Beach widths on Monterey Bay vary, though the beach at South Aptos Seascape is considered to be in equilibrium, with no net erosion (Griggs and Tait 1988).

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Beach profiles to wading depth were measured at each of the four sites on a biweekly schedule from October 1986 to May 1989. Since 1989, monthly surveys have continued at the South Aptos Seascape location shown in Figure 2. The 300-m-long structure at this site is a curved concrete seawall with riprap toe protection. The top of the structure is at +6.4 m mean lower low water (mllw) with toe protection placed on a 2:1 slope. The structure is approximately 75 m seaward from the base of a cliff and is constructed to protect a development of homes built on the back beach. Five lines were measured in front of the structure at 30-m spacings with a 90-m spacing at the structure end where control beach monitoring is conducted with three lines, again at 30-m intervals. Occasional nearshore surveys to the 9-m depth were also conducted with a boat and recording fathometer (Griggs and Tait 1988).

Sandbridge Beach, Virginia Beach, VA. Sandbridge Beach, a subdivision of Virginia Beach, VA, is the southernmost developed portion of southeastern coastal Virginia lying just north of Back Bay and the North Carolina border. Sandbridge borders on the northern tip of Back Bay, thereby functioning somewhat like a barrier island system (Figure 3). The Sandbridge area has also experienced historic long-term erosion, with recession rates varying between 1.1 m/year at the north end of the study area to 2.9 m/year at the south end of the study area (Basco 1991). The average d_{50} grain size at Sandbridge is 0.23 mm.

Sandbridge is a nodal zone for sediment transport. The net direction of sediment transport is southward south of Sandbridge and northward at Sandbridge. Coupled with (and/or related to) this nodal zone phenomenon is the steep offshore bathymetry in the vicinity of Sandbridge. The contour of the typical closure depth (10 m) in southeastern Virginia is approximately 4,000 m offshore at Virginia Beach, providing a relatively flat nearshore profile. South of Virginia Beach, the 10-m contour moves landward to about 1,200 m offshore at Sandbridge, creating a much steeper nearshore profile before moving back seaward at False Cape. In addition, wave propagation analysis to examine the effect of the differing bathymetry on expected wave conditions revealed that weighted average breaking wave heights for a "typical northeaster" were larger at Sandbridge than at areas north and south (Wright et al. 1987).

To address the continuing erosion problem at Sandbridge, homeowners began to construct individual and/or groups of seawall (bulkhead) sections (Figures 4 and 5). The first seawalls were constructed in 1978, with a proliferation of construction in the mid- to late 1980s. Primary construction consists of steel sheet-pile bulkheads with "dead-man" tiebacks, but wooden and concrete walls have also been constructed in some locations. As of 1992, approximately 60 percent of the 7.7-km reach of coast had been structured (Basco et al. 1992).

Beach monitoring at Sandbridge consists of monthly beach profile surveys which began in August 1990. A total of 28 profile locations have been established with 12 at walls, 10 at dunes, and 6 at or near endwalls. Some nearshore surveys to the 8-m depth have also been taken. Included in this research is an attempt to utilize historic survey data collected by the city, state, and other agencies to document longer-term analysis.

Duck Lake, MI. Duck Lake is located north of Muskegon, MI, on the south-central east coast of Lake Michigan (Figure 6). Near the small, non-navigable inlet to Duck Lake, Scenic Road approaches Lake Michigan and runs along the lake frontage for approximately 0.5 km. In the fall of 1990, the Detroit District of the Corps of Engineers (CENCE), constructed a rubble-mound revetment to protect Scenic Road from erosion, changes in lake water level, and wave attack (Figure 7). This revetment extends from approximately elevation 592 ft IGLD to nearly the low-water datum (577.5 ft IGLD). No fronting beach exists at this revetment. Prior to revetment construction, a mixture of miscellaneous, non-designed shore protection methods had been utilized for stabilization. Starting approximately 0.75 km north of the revetment, and extending for roughly 1.0 km northward, is a series of short wooden groins and a dilapidated steel bulkhead at the base of a vegetated bluff. Between the revetment and the start of these miscellaneous structures is sandy beach backed by high bluffs. Immediately to the south of the Duck Lake revetment is a system of four short "concrete-bag" groins, beyond which is sandy beach again backed by high bluffs.

Profile measurement consisting of beach and nearshore surveys began in July 1993. A total of 12 lines (3 at the structure, 2 at the ends, and 7 north and south of the structure for control) will be measured quarterly. These quarterly surveys will be supplemented by historic Corps of Engineers' surveys. Beach profiles extend from the base of the bluff to wading depth and are continued with a boat-mounted fathometer to the 9-m contour.

QUALITATIVE SITE COMPARISON:

Several criteria were used in selecting the sites, including differing wave and water level climates, differing structure position relative to still-water line, historical database, available unstructured beach reaches for control, and lack of nearby influencing structures. Generally, three of the predominant four types of coastal hydraulic environments found in the United States are represented. The Monterey Bay location, situated on the Pacific coast, experiences the largest and longest waves of the three monitoring sites. Even though the Sandbridge site is located where the offshore slope is steeper than surrounding areas, the wide continental shelf tends to limit wave heights. Both the Monterey Bay and Sandbridge sites experience periodic tidal inundation. The Duck Lake site, situated on Lake Michigan, has a reduced fetch and experiences comparatively smaller waves with smaller periods than the west coast, though at times the wave climate can be similar to the Atlantic coast. Although Lake Michigan does not have significant astronomical tides, water level changes resulting from storms, spring rains, snow melt, and water level controls on the Great Lakes system are common and contribute significantly to the coastal processes affecting the Duck Lake site.

Weggel (1988) suggested a classification of seawall types based on the seawall's position on the beach and the water depth at the toe of the structure. Weggel's classification is summarized in Table 1.

Table 1
Weggel's Seawall Classification

Type	Location of Seawall
I	Landward of maximum level of runup during storms
II	Above swl of max storm surge and below the level of max runup
III	Above normal high water and below swl of storm surge
IV	Within the normal tide range; base is submerged at high water
V	Seaward of mlw; base is always submerged; subjected to breaking and broken waves
VI	So far seaward that incident waves do not break on or seaward

Weggel also conducted a dimensional analysis for each type showing the important factors and processes associated with each type. Weggel's classification in the context of this paper provides for an organized qualitative comparison of the three monitoring sites.

The South Aptos Seascape site at Monterey Bay could be classified as a Type I to Type III seawall depending on the season and storm condition. In the summer, the seawall is always landward of the berm crest (Type I) and, thus has no interaction with water level and wave runup. During the winter the seawall is in contact with the runup swash at most high tides (Type II), and during winter storms, the structure can be inundated by storm surge (Type III).

Sandbridge can be classified as being both Type III and Type IV, depending on the season and location. During the summer months, Sandbridge has a relatively narrow beach width where the walls remain above the mean waterline except during periods of high water. During the winter months, some southern sections of the seawall are within the normal tide range.

The Duck Lake structure is Type V because the structure toe is always submerged, and it is subjected to wave breaking during periods of storms. The Duck Lake revetment does not, however, project farther seaward than the adjacent sand beaches, thereby preventing classification as a Type VI.

Both the Sandbridge and Duck Lake sites have a history of existing beach and nearshore profile surveys that were available to extend any data collection efforts. Sandbridge has been surveyed by various investigators from Virginia Institute of Marine Sciences, University of Virginia, and the City of Virginia Beach as early as 1980. Researchers from the University of Michigan have conducted periodic surveys at Duck Lake, and there are Corps of Engineers' surveys for the area dating back to the mid-1970s.

All three monitoring locations have structure-free beaches in the vicinity that are monitored as control. At Monterey, surveys are extended both up- and downcoast of the structures to avoid the influence of the seawall. At Sandbridge, control is located between structured portions of the beach and at up- and downcoast locations. Duck Lake has extensive control beaches with detailed historical records both up- and downcoast of the revetment.

PRELIMINARY COMPARATIVE RESULTS:

After 7 years of monitoring at the South Aptos Seascape site on Monterey Bay, Griggs, Tait, and Corona (1993) presented general conclusions on the impact of this structure on the beach. During the transition from a summer to a winter beach profile, the beach berm recedes faster in front of the seawall than on the adjacent control beach. Once the berm retreats beyond the seawall location, the profile is indistinguishable from the nearby unarmored beach. Scour is also observed during the winter at the downcoast end resulting from wave reflection from the end section. Transition from a winter to a summer beach profile shows no preference to the presence of a seawall. Recovery begins as the berm at the unarmored sections advances to the seaward edge of the seawall. At this point, berm growth progresses uniformly along the entire reach of shoreline. No long-term effects of the seawall have been observed during the 7-year monitoring period.

Basco et al. (1994) present preliminary results after 3 years of monitoring at Sandbridge, VA. Four beach profile parameters are utilized in analysis of the beach profile data at seawall and non-seawall locations. These parameters, defined here, are shown in Figure 8:

P = shoreline position from survey baseline to MHW

E_B = elevation of beach berm at seawall locations or partition line for non-seawall locations

V_L = volume of material landward of seawall/partition

V_S = volume of material seaward of seawall/partition

A fifth parameter, total volume V_T can be used by summing the seaward and landward profile volumes. Weighted averaging is performed by assigning profiles a length of "coverage" and summing similar types (seawall or non-seawall), then dividing by the total length of each type. Each of the four parameters is averaged according to this method, and time series plots of each parameter are generated for both seawall and non-seawall profile types. For each parameter at both seawall and non-seawall profiles, the 3-year trend is a negative sloping average indicating a net volume loss, lowering of berm elevation, and retreat of shoreline. Comparisons of seawall and non-seawall averages show that the subaerial volume loss rate seaward of the seawall/partition V_s was statistically the same for both seawall and non-seawall reaches. In other words, the 3-year volume loss trend is the same for both types of profiles.

For the first 2 years of data, shoreline position P and berm elevation E_B change rates were larger for the seawall reaches than for the non-seawall reaches. Because the volume change rates were similar, Basco initially attributed this difference to a general "flattening" of the beach face. Figure 8 shows that P is measured to mhw, whereas V_S is measured to mlw. For the volume change rates to remain similar but P and E_B to reduce, the beach face must flatten. In the third year of monitoring, beach scraping activity by property owners further affected P and E_B. Recently, some property owners have also begun isolated beachfill operations. These factors have resulted in relying on volume measurements as the most appropriate parameter for studying beach changes at Sandbridge. Beach scraping moves material only on the beach face itself, so the total volume V_T of material should be unchanged. Examination of the beachfill permits should allow tracking of the volume of material placed to be incorporated into the volume calculations[1].

Preliminary seasonal trend analysis conducted by Basco et al. (1994) shows that Sandbridge seawall and non-seawall beaches responded similarly to post-winter profile recovery. Though general recovery was similar for seawall and non-seawall sections, specific differences were observed. In the spring of 1991 seawall beaches recovered before non-seawall beaches; in 1992 non-seawall beaches recovered before seawall beaches; and in 1993 both types recovered at the same time. These differences may be attributed to mild winter seasons and favorable accretionary summer seasons. A full seasonal analysis will be conducted for the entire 5-year data set in 1995.

Because data collection at the Duck Lake site has only recently begun, no quantitative analyses or comparisons have been made at this time.

CONCLUSIONS:

Motivation for a coordinated, systematic approach to seawall and beach interaction research was identified by Weggel (1988), who stated, "Actually, the effects of seawalls on coastal processes have not been researched sufficiently to either indict or exonerate them. The seawall/beach interaction must be examined on a case-by-case basis. This paper (Weggel 1988) is a plea to initiate such seawall research." The research effort described in this paper was started in 1986 at Monterey, but was expanded to cover three sites. The research approach included development of selection criteria, long-term data collection, and spatial representation within the continental United States. Site selection was based on: (a) broad representation of wave and water level climates and coastal process regimes (a stable Pacific coast site, an eroding Atlantic coast site, and a non-tidal Great Lakes site); (b) structure position on the beach face as described by Weggel (1988); (c) pre-monitoring, historical database to extend data set; (d) available nearby unstructured beaches that could be used for control; and (e) lack of nearby influencing structures.

[1] Personal Communication. (1994). D.R. Basco, ____________________________, ____________________________.

By the end of the study, 9 years of monitoring will have been conducted at the stable Monterey Bay site. So far, preliminary results indicate that at this seawall (Type I to Type III according to Weggel [1988)) changes are seasonal and no long-term net losses *occur.* Both seawall and non-seawall beaches recover in the same manner when transitioning from a winter to summer profile, and at the fully developed winter and summer profiles no discernable difference exists between the structured and unstructured sections of beach. The only differences identified by Griggs, Tait, and Corona (1993) are (a) earlier berm deflation in front of the seawall during transition from a *summer* to a winter profile (the seawall causes the berm to deflate sooner than adjacent unstructured beaches), and (b) local scour occurring at the downcoast end of the seawall due to wave reflection and groin effect.

The Sandbridge site is located on a narrow retreating shoreline and varies between a Type III and Type IV seawall as described by Weggel (1988). Five years of monitoring will be completed by study conclusion. Basco's (1994) preliminary statistical analysis of 3 years of monitoring indicates that there is no difference in the volume loss rate in front of seawall profiles versus nonseawall profiles. Differences have been observed, however, in shoreline recession and beach berm elevation between the two profile types. Beach scraping and beachfill have recently become a factor, thereby influencing P and E_B, but not the V_T/

Interestingly, the preliminary results of Griggs, Tait, and Corona (1993) and Basco et al. (1994) show similar results for seasonal trends. Griggs has shown that essentially no difference exists in berm growth towards a summer profile in front of a seawall or non-seawall beach at the Monterey Bay site. Basco observed that during a 3-year period at Sandbridge, 1 year saw seawall profile recovery before the non-seawall profile and 1 year saw identical recovery. Although the seawalls at these two sites are at different positions on the shoreline, and wave and water level conditions and long-term shoreline trends are different, recovery patterns at the two sites are similar. This may hint that post-winter recovery of beaches near seawalls is independent of hydraulic and geologic conditions. Final conclusions must await complete analysis of seasonal trends at Sandbridge for the entire 5-year monitoring period.

Finally, although post-winter recovery appears at this time to be non-site-specific, other seawall/beach responses may behave differently. Because all three monitoring sites are in different coastal regimes, some site-specific responses may be expected. Because each site is in a different stage of monitoring, final comprehensive results will not be available until data collection and analysis are completed in 1996.

ADDITIONAL INFORMATION: For additional information, contact Ms. Cheryl E. Pollock (601) 634-4029, Cheryl.E.Pollock@erdc.usace.army.mil, Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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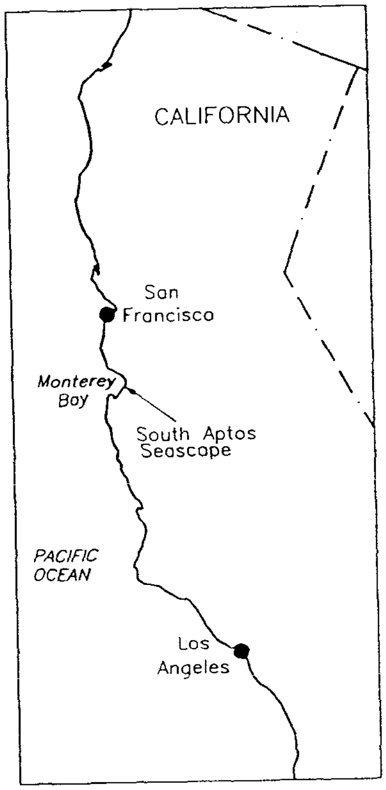

Figure 1. Location of South Aptos Seascape Seawall at Monterey Bay

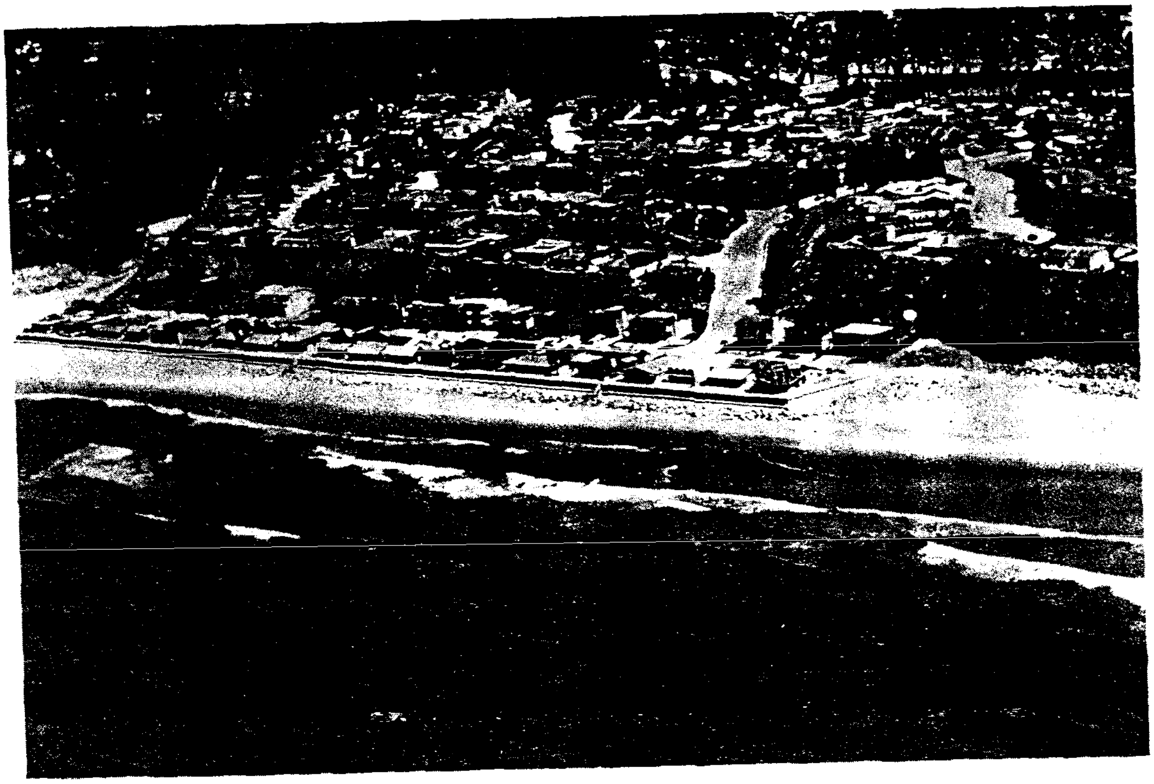

Figure 2. South Aptos Seascape Seawall (Griggs and Tait 1988)

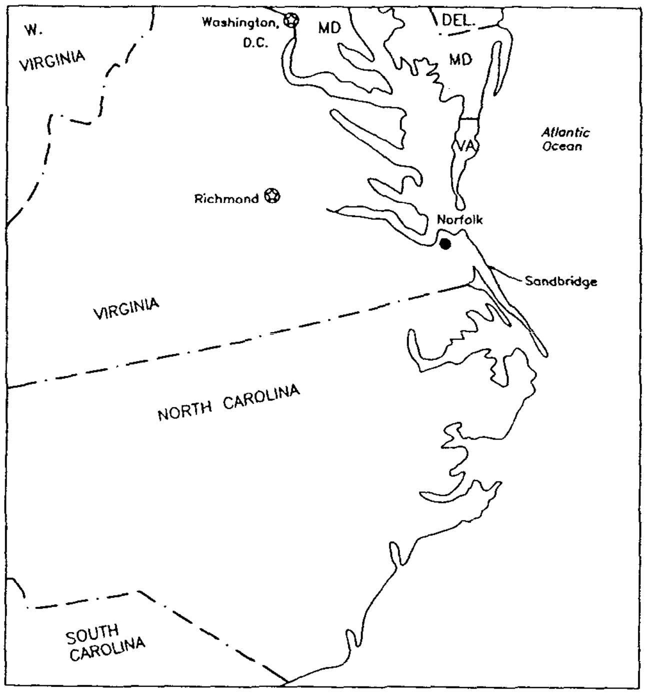

Figure 3. Location of Sandbridge Beach at Virginia Beach, VA

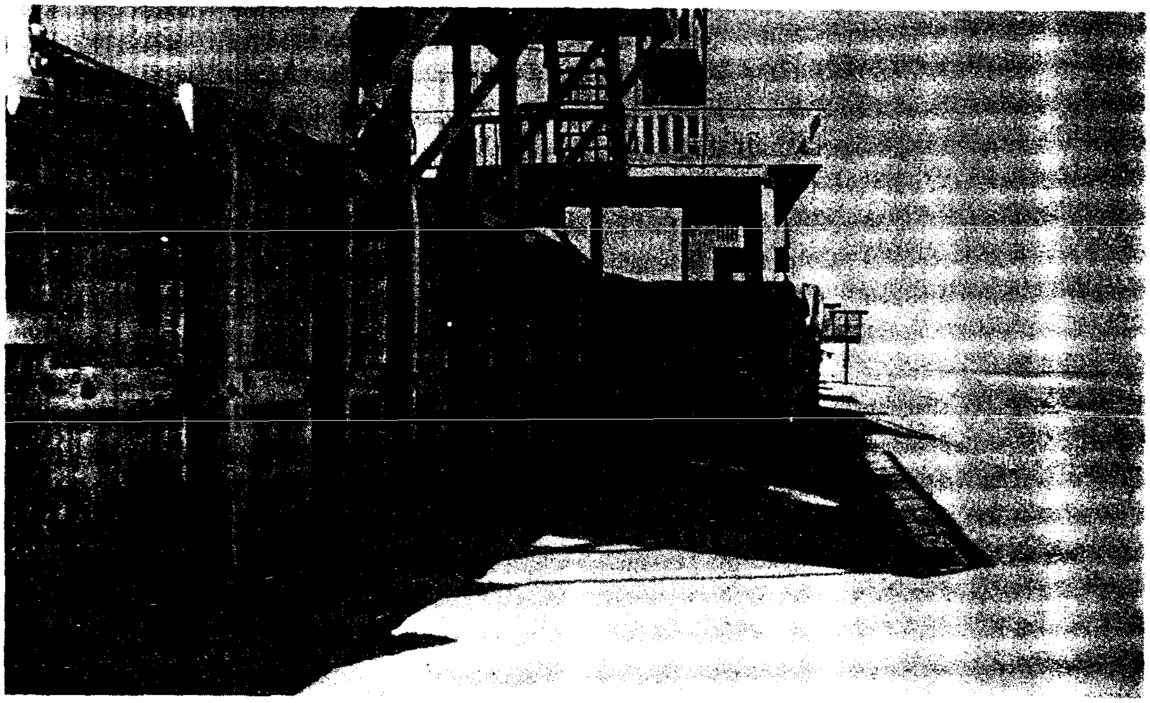

Figure 4. Wooden seawall at Sandbridge

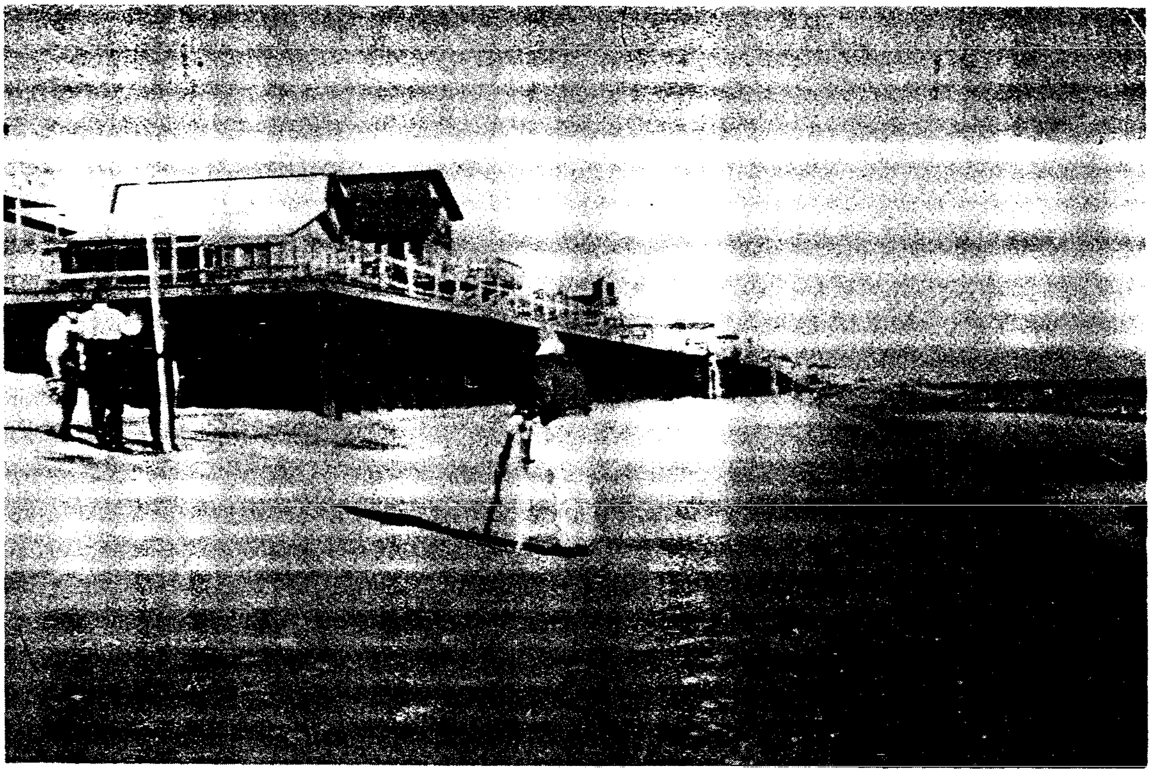

Figure 5. Steel sheet-pile seawall at Sandbridge

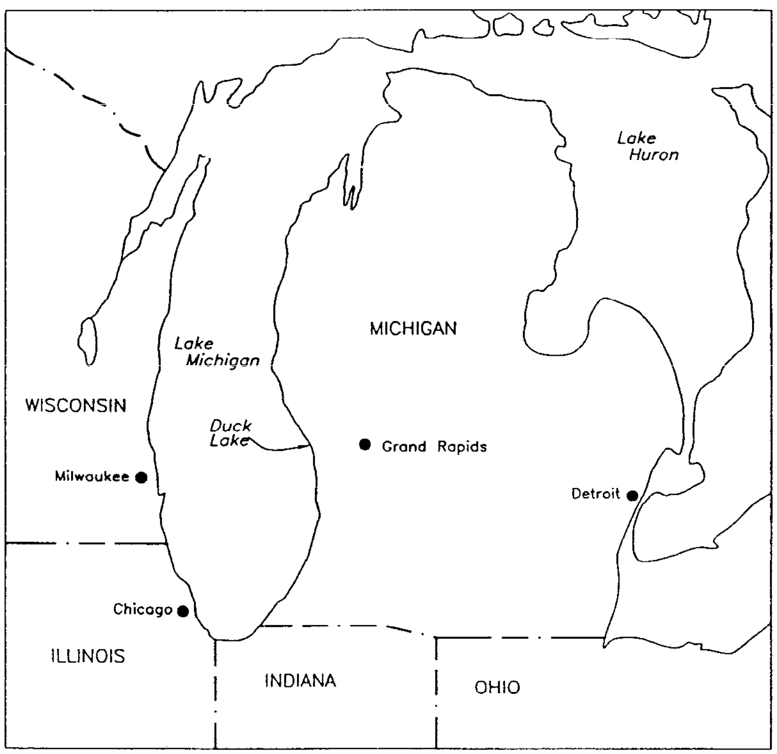

Figure 6. Location of Duck Lake revetment site on eastern shore of Lake Michigan

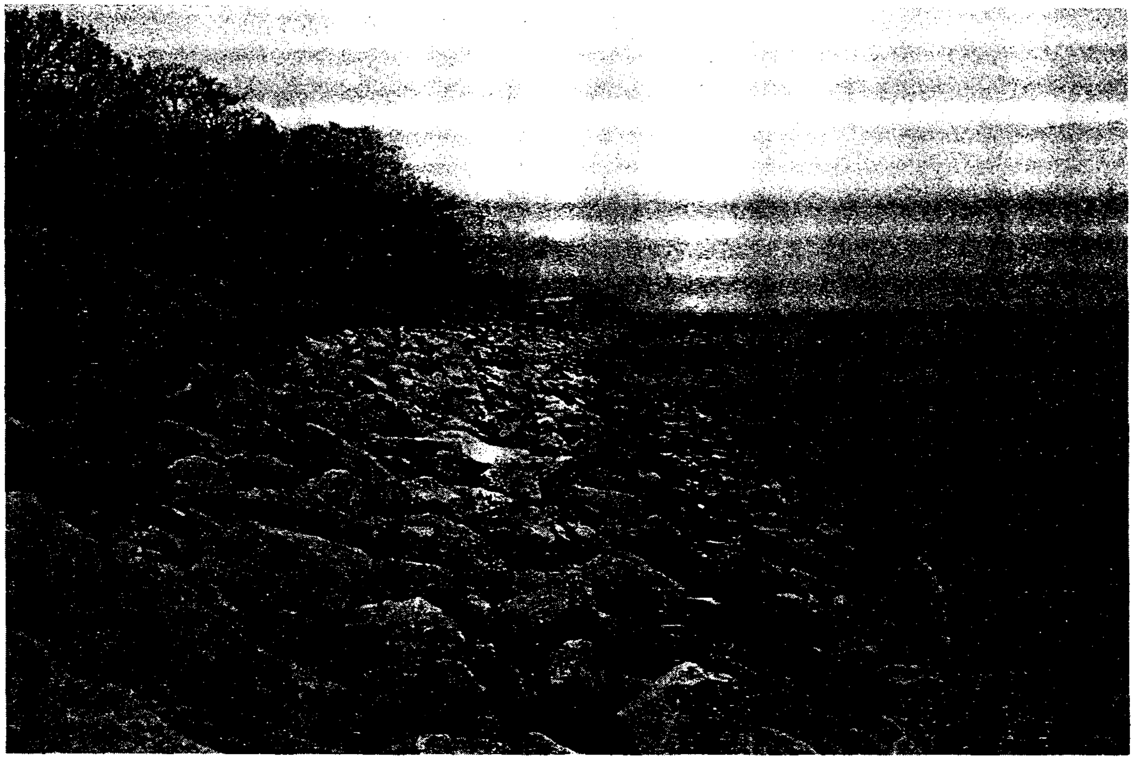

Figure 7. Duck Lake revetment

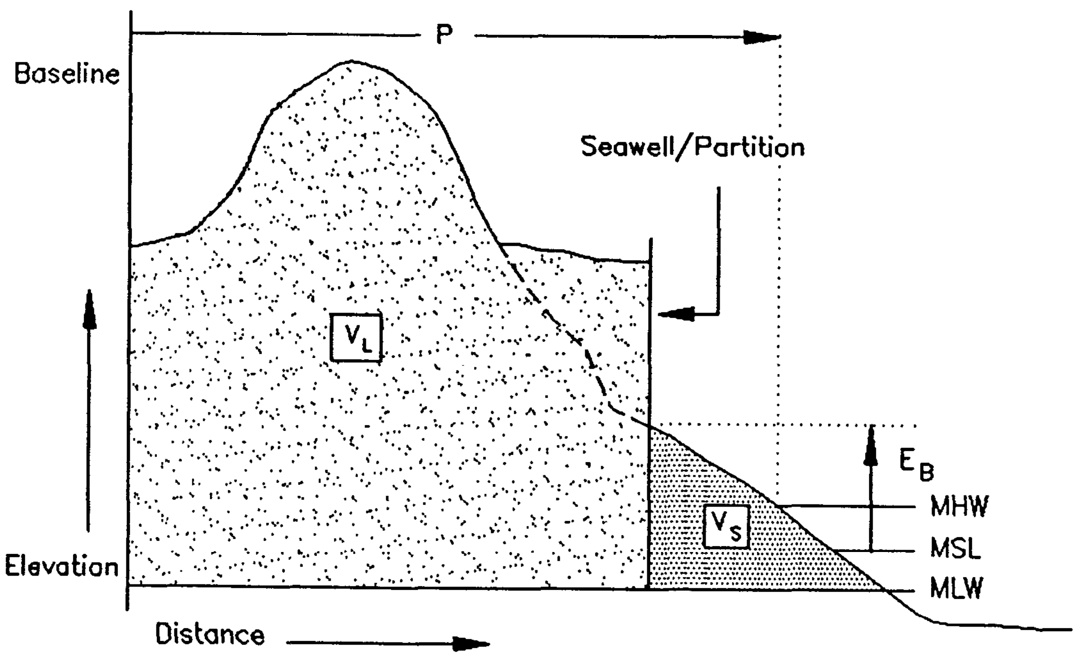

Figure 8. Definition sketch for the four beach profile parameters analyzed for Sandbridge, VA (Basco et al. 1994)