Submerged Reef Structures for Habitat Enhancement and Shoreline Erosion Abatement

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Purpose: This Coastal and Hydraulic Engineering Technical Note (CHETN) presents the use of submerged artificial reef structures as submerged breakwaters, providing both wave attenuation for shoreline erosion abatement, as well as artificial reef structures for habitat enhancement. An example of this technology is presented for a project constructed using Reef Ball^{TM} artificial reef units (shown in Figure 1) along the southern shore of the Dominican Republic near Bayahibe (east of Santo Domingo and LaRomano, as shown in Figure 2) during the summer 1998.

Introduction: Approximately 450 Reef Ball^{TM} artificial reef units were installed offshore of the Gran Dominicus Resort during the summer 1998 to form a submerged breakwater for shoreline stabilization, environmental enhancement and eco-tourism. The individual units used for the breakwater were 1.2m high Reef Ball^{TM} units and 1.4m high Ultra Ball units, with base diameters of 1.8 meters. Figure 1 shows an individual Reef Ball^{TM} unit, which is fabricated to provide void spaces and surface areas for habitat and biological growth. These artificial reef units were deployed by using large buoys inside and strapped to the Reef Ball^{TM} units to float the individual units offshore and set them in place by divers.

Figure 1. Individual Reef Ball^{TM} Unit.

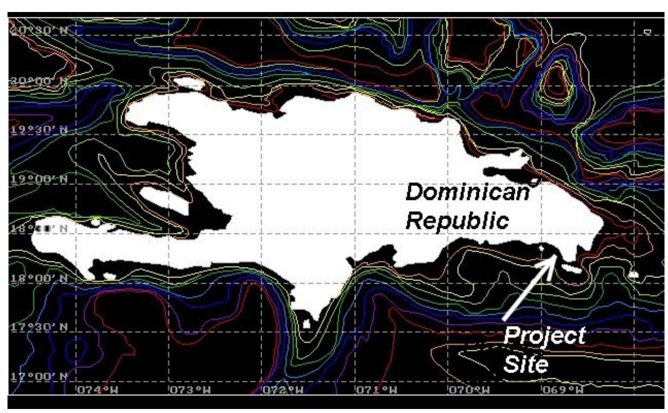

Figure 2. Project Site.

Project Design: Various sizes and weights of Reef Ball^{TM} artificial reef units are available, as presented in Table 1. To obtain the highest individual unit weights possible, the Reef Balls^{TM} were fabricated with the maximum volume of concrete for the molds, resulting in each individual Reef Ball^{TM} unit weighing approximately 6,000 pounds (2700 kg). Microsilica and other additives were used in the concrete to increase the strength and workability plus decrease the pH of the concrete to that of marine environment.

Table 1. Reef Ball^{TM} Sizes, Weights, Volume & Number of Holes

Style	Width	Height	Weight	Concrete Volume	No. of Holes
Ultra Ball	6 feet (1.83m)	4.5 feet (1.37m)	4000-6000 lbs (1814-2722 kg)	1 yard 0.76m^3	29-34
Reef Ball	6 feet (1.83m)	4 feet (1.22m)	3000-6000 lbs (1360-2722 kg)	0.75 yard 0.57m^3	29-34
Pallet Ball	4 feet (1.22m)	3 feet (0.91m)	1500-2200 lbs (680-998 kg)	0.33 yard 0.25m^3	17-24
Bay Ball	3 feet (0.91m)	2 feet (0.61m)	375-750 lbs (170-340 kg)	0.10 yard 0.08m^3	10-16

The design of the submerged breakwater system consisted of three segmented breakwater sections, using three rows of Reef Ball^{TM} units for each segment (Figure 3 and 4). The breakwater was installed in water depths of 1.6m to 2.0m, so that the units were 0.2m to 0.8m below the mean water level (the tide range in the project area is approximately 0.4m).

Figure 3. Three-Row Submerged Breakwater.

Figure 4. April 2001 Aerial Photograph.

The sea bottom where the submerged breakwater was installed consisted of barren limestone rock covered with a light dusting of sand, so that scour and settlement were not a problem. For increased stability of the structure, sleeves for fiberglass rebar were pre-cast into the Reef Ball^{TM} units, with No. 5 fiberglass rebar driven or drilled into the bottom to provide additional resistance to sliding of the units after they were deployed. The central cavities of the units were filled approximately one-third full with small rocks to provide additional habitat.

Hurricane Effects on Reef Ball™ Unit Stability: During the fall of 1998, a direct hit on the project area by Hurricane Georges, a category three hurricane, followed by large swell waves from Hurricane Mitch, a category five hurricane that passed south of the Dominican Republic, greatly tested the stability of the Reef Ball™ artificial reef units shortly after their deployment. The project area experienced large waves, elevated water levels and strong currents associated with the storm surge and hurricane conditions produced by Hurricane Georges in September. In October, large swell waves generated by Hurricane Mitch directly impacted the project area. However, the Reef Ball™ units remained stable, and the originally installed configuration of the submerged breakwater project remained intact following these two severe storm events. Underwater inspection on 20 November 1998 indicated that none of the Reef Ball™ units moved from their originally placed positions.

Shoreline Conditions after Hurricane Impacts: Comparison of photographs taken before and after the installation of the Reef Ball™ artificial reef submerged breakwater show that sand had accreted and the beach was building prior to Hurricane Georges. The storm surge and wave conditions accompanying this category three hurricane greatly exceeded the levels for which the submerged breakwater can provide wave attenuation and shoreline protection, so that significant erosion of the beach and dune occurred, as shown in Figure 5.

Figure 5. Eroded Beach and Shoreline following Hurricane Georges and Mitch.

A submerged breakwater becomes ineffective during severe storm surge conditions accompanying hurricanes. Hurricanes Georges and Mitch produced meteorological and oceanographic conditions that created elevated water levels due to the storm surge and waves. On top of this storm surge, the large waves and strong currents accompanying the hurricanes produced severe erosion of the shoreline, with large volumes of beach sand washed away, leaving a one to two meter high escarpment which undermined several palm trees in the project area and adjacent beaches to the east. As depicted in Figure 5, the shoreline that had been sand prior to the hurricanes became an exposed rock ledge.

Modifications to Breakwater: The Gran Dominicus Beach Resort was scheduled to open in December 1998, so that the sudden loss of beach was catastrophic. A site visit in November 1998 was performed, with a report and recommendations submitted. The report recommended the addition of sand to the beach as the most expedient and direct way of re-establishing the beach, with the natural post-storm beach recovery aided by the submerged breakwater expected over the longer term. The addition of large rocks to widen the structure crest and increase the wave attenuation of the Reef Ball™ breakwater was also discussed.

During the winter of 1999 Gran Dominicus added a small quantity of sand to the beach, and placed a considerable amount of small rocks on top of the submerged Reef Ball™ breakwater, raising the crest elevation above the water level, as shown in Figure 6. These photographs show that contrary to the recommendations of the engineering consultant, small rocks were used instead of larger rocks that would be stable under wave attack, and that in addition to widening and raising the elevation of the breakwater above the water level, rocks were added to connect the eastern end of the breakwater to the shore. The shoreline attachment prevents alongshore sediment transport, which is undesirable. Due to small sizes of the rocks that were added to the breakwater, wave action easily displaced these rocks, scattering them landward of the original breakwater. Figure 7 shows an aerial photograph that delineates the original Reef Ball™ breakwater from the scattered smaller rocks.

Figure 6. Placement of Small Rocks on top of Submerged Reef Ball™ Breakwater.
Photograph taken in February 1999 during construction.

Project Performance: The small rocks placed on top of the Reef Balls™ were moved landward of the breakwater by wave action shortly after they were placed, so that the submerged breakwater system was restored to its original configuration, except for the scattering of the small rocks landward of the breakwater (these small rocks were subsequently removed to regain the swimming area).

The comparison photographs in Figures 8 through 10 show that the Reef Ball™ breakwater has been very effective in assisting with the stabilization of the shoreline, with a significant increase in beach width and elevation along the Gran Dominicus shoreline. With a net littoral drift towards the west, no adverse effects have occurred on adjacent beaches, as these beaches have also accreted sand and recovered after the hurricanes in 1998, but not as much accretion as in the beach and shoreline area protected by the submerged artificial reef breakwater.

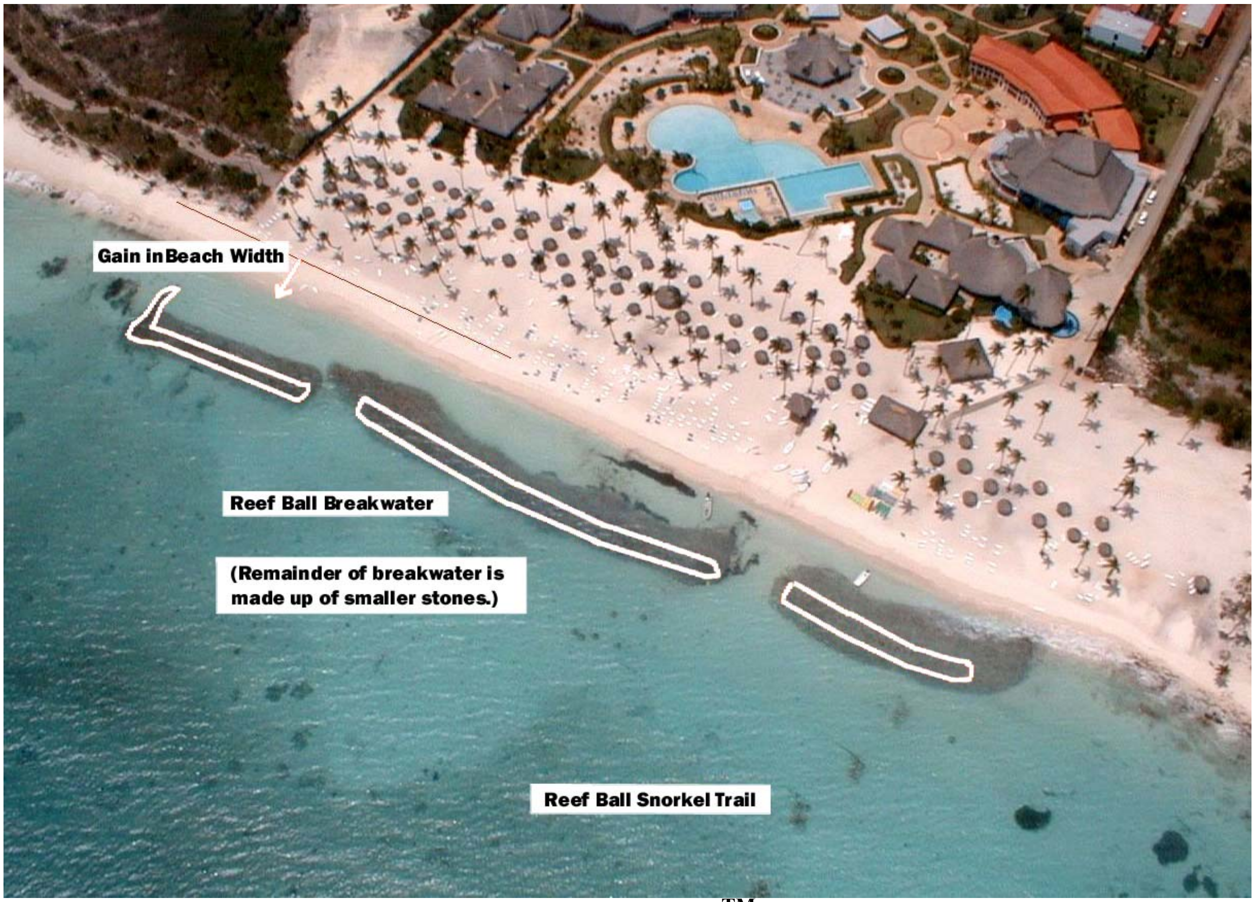

Figure 7. Delineation of the Original Reef Ball™ Breakwater and Small Rocks.
Aerial photograph taken April 28, 2001.

Figure 8. Increased Beach Width at Project Center - looking east.
Summer 1998 (left) compared with April 2001 (right)

Figure 9. Increased Beach Width at Eastern End - looking west.
November 1998 (left) compared with April 2001 (right)

Figure 10. Increased Beach Width at Center Project - looking west..
February 1999 after small rocks added on top of breakwater (left),
compared with April 2001 showing large natural accretion (right).

Beach Profile Survey Data: Survey data are presented herein to quantify the changes in shoreline position and sand volume in the project and adjacent beach areas. Post storm surveys of the Reef Ball™ artificial reef submerged breakwater were performed during February 1999 as shown in Figure 11 (6 months after project construction and 4 months following the direct hit by Hurricane Georges in September and the large swell waves from Hurricane Mitch in October). The latest survey was performed in April 2001 (26 months after the February 1999 survey and 32 months after project construction) and the two sets of survey data were compared.

The aerial photograph in Figure 12 shows the submerged Reef Ball™ breakwater and the locations of the survey profile lines. Figures 13 though 15 show graphs of the survey data comparing the beach profiles in February 1999 and April 2001.

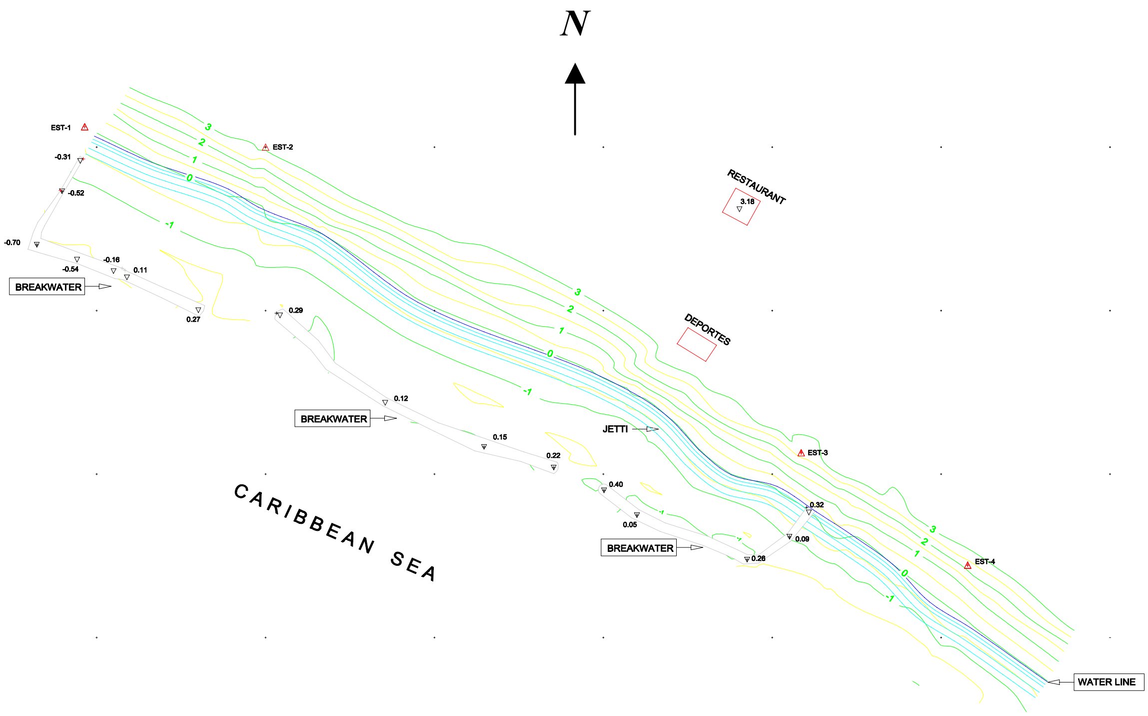

Figure 11. February 1999 Survey of Project

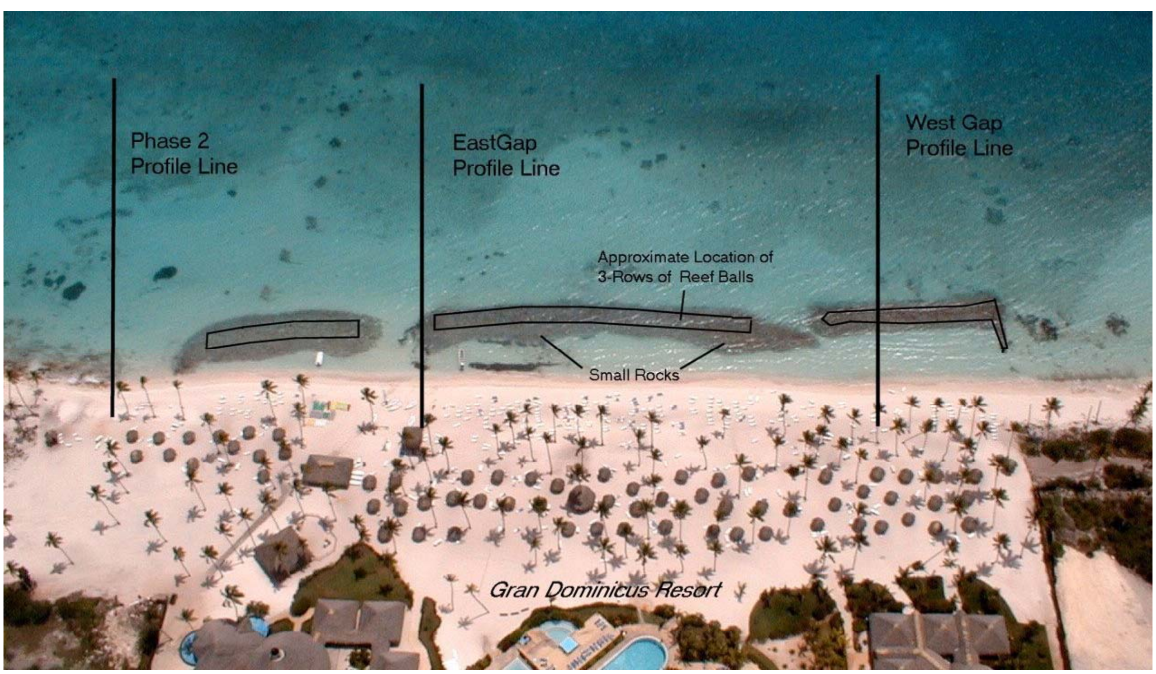

Figure 12. Location of Survey Profile Lines
Aerial photograph taken April 28, 2001.

The two graphs in Figures 13 and 14 clearly show sand accretion landward of the submerged breakwater system, with a 10m shoreline advance at the western profile line and 13m shoreline advance at the eastern profile line. Only a minimal amount of sand fill was added to the beach, with almost all of the sand gain due to natural accretion in the lee of the breakwater system.

Figure 15 shows the area immediately east of the project, where Phase 2 of the Gran Dominicus Resort is planned. Comparisons between these three graphs in Figures 13 to 15 clearly show that the beach has gained a considerable amount of sand and the shoreline has advanced significantly in the project area, but has remained stable to slightly accretionary on the adjacent beaches.

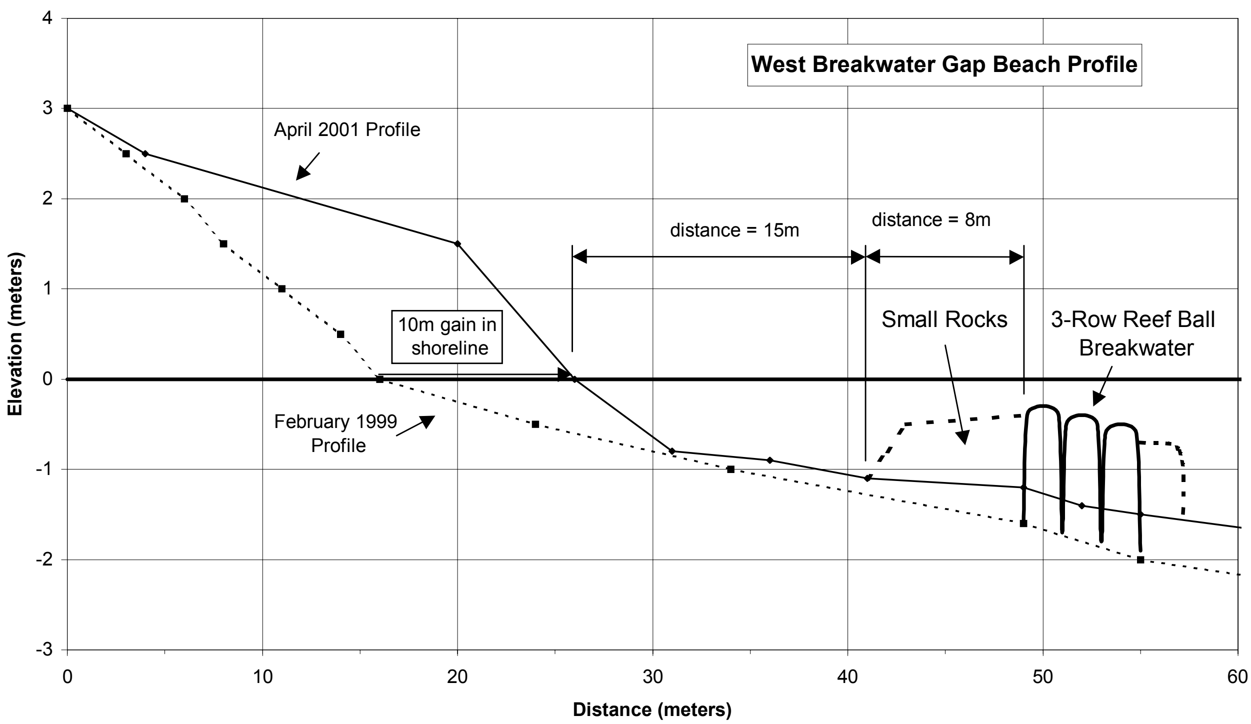

Figure 13. Western Survey Profile across Breakwater near West Gap.

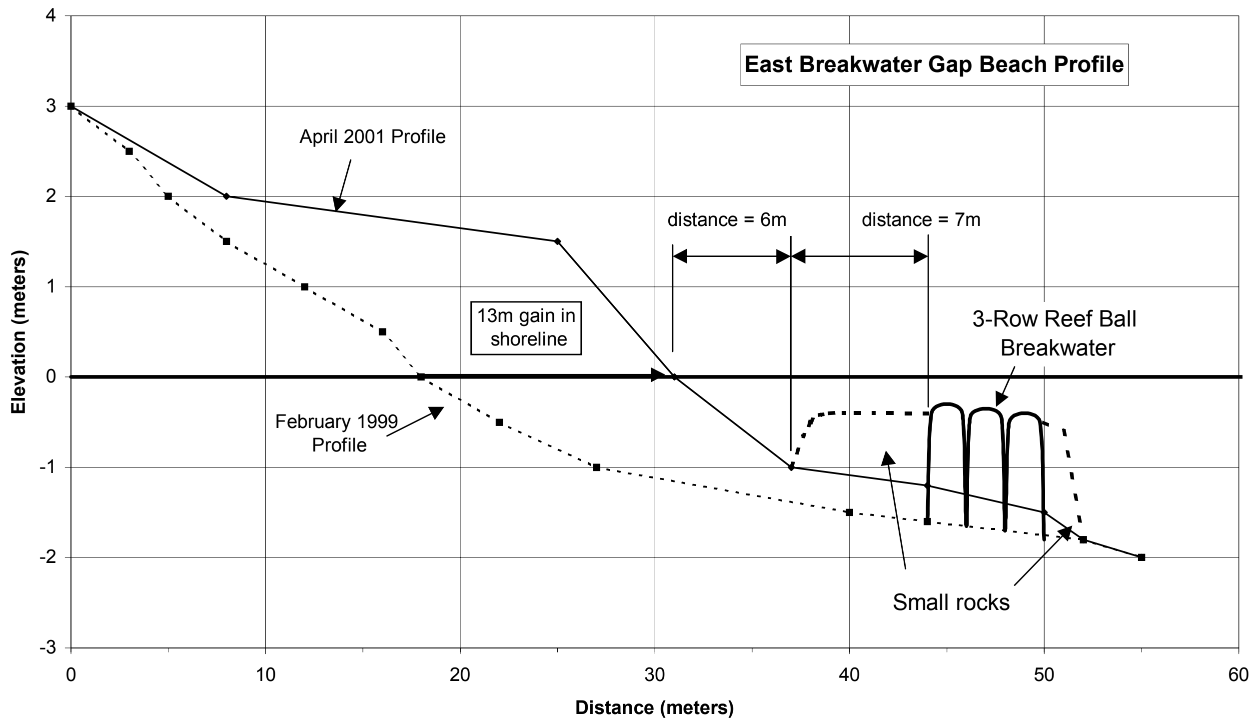

Figure 14. Eastern Survey Profile across Breakwater near East Gap.

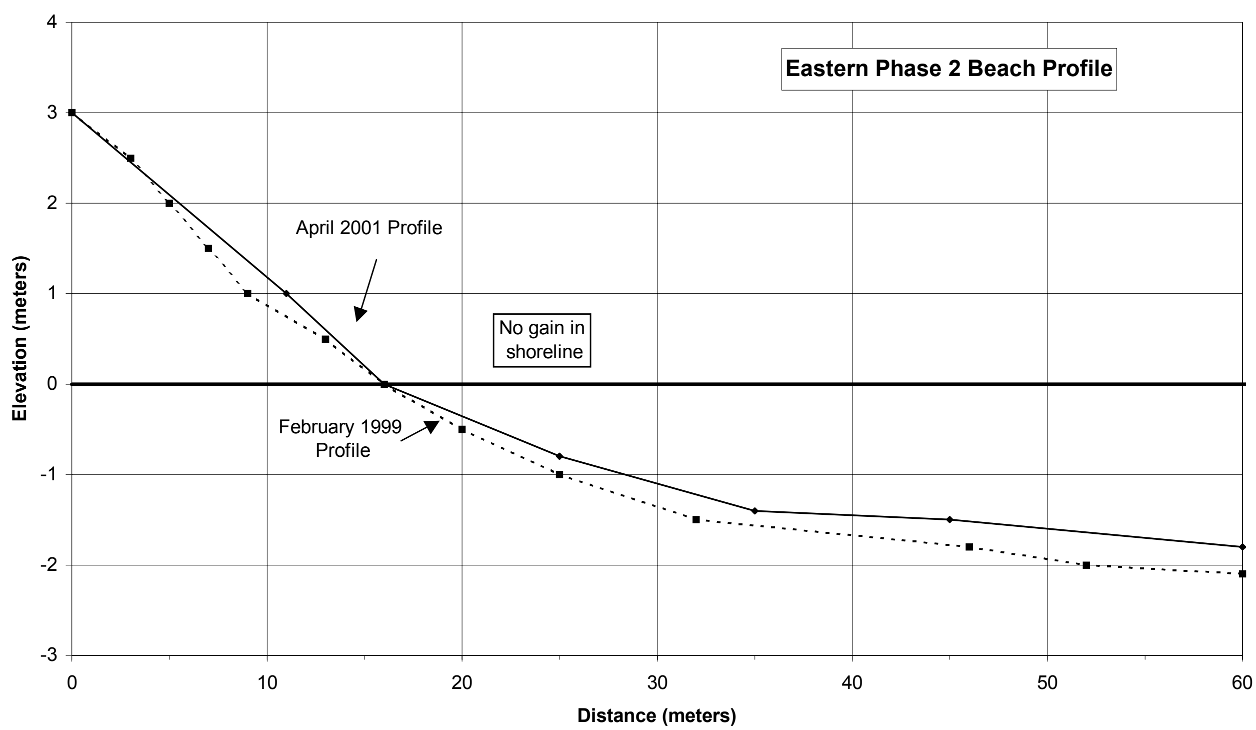

Figure 15. Survey Profile East of Breakwater.

Shoreline and Sand Volume Changes: The survey data from February 1999 and April 2001 were used to compute the shoreline changes and sand volume changes in the project area. The results are shown in Table 2, with the sand volume change per shoreline length computed from the dune seaward to the breakwater (shore perpendicular distance = 49 meters for west breakwater gap and 44 meters for the east breakwater gap).

Table 2. Sand Volume Calculations

Profile Line Designation	Shoreline Change (meters)	Sand Volume Change (cubic meters per linear meter of shoreline)
West Gap Profile Line	+10 m	+25.65 m^3/m
East Gap Profile Line	+13 m	+44.25 m^3/m
Phase 2 Profile Line	0 m	+2.0 m^3/m

The average sand gain in the project area from February 1999 to April 2001 for the two surveyed profile lines in the breakwater area is 34.95 m^3/m. Using that average gain over a shoreline length of 250 meters results in an overall volume gain of 8,740 cubic meters of sand. That is the equivalent of an average gain in beach elevation of 75 centimeters over the 250 meter length by an average of 46.5 meter wide beach area. Using the beach area to the east for comparison, the gain of 2.0 m^3/m over 250 meters of shoreline length results in a gain of 500 cubic meters of sand, which is the equivalent of an average gain in beach elevation of 4.3 centimeters over a 250 meter long by an average of 46.5 meter wide beach area. These data show that the gain in sand volume was almost 20 times greater in the project area than on the adjacent beach.

Conclusions: The submerged breakwater project presented in this CHETN demonstrates the technology available to provide shoreline stabilization due to wave attenuation at a site with a low tidal range and low to moderate wave climate (except during tropical storms and hurricanes). In addition, the use of artificial reef units for the breakwater also provides habitat enhancement for the marine life, which can be enjoyed by divers and snorkelers. Application of this technology to another site must consider its particular site specific conditions.

References:

Harris, Lee E. (April 1999). "Status Report for Gran Dominicus Submerged Reef Ball™ Artificial Reef Breakwater."

Harris, Lee E. (November 1998). "Post-hurricane Site Inspection of the Reef Ball™ Artificial Reef Submerged Breakwater at Gran Dominicus Beach Resort, Dominican Republic."

Additional Information:

For more information on Reef Ball™ units and applications contact:
Reef Ball Development Group, http://www.reefball.com

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http://limpet.wes.army.mil/sec227/