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Coastal Engineering Technical Note

Submerged Reef Structures for Habitat Enhancement and Shoreline Erosion Abatement

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Purpose: This Coastal Engineering Technical Note (CETN) 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™ artificial reef units along the southern shore of the Dominican Republic near Bayahibe (east of Santo Domingo and LaRomano) during the summer 1998.

Introduction: Approximately 450 Reef Ball™ 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 units and 1.4m high Ultra Ball units, with base diameters of approximately 2 meters. Figure 1 shows an individual Reef Ball™ unit, and Figure 2 shows a photograph of the deployment, using large buoys inside and strapped to the Reef Ball units to float the individual units offshore and set them in place by divers.

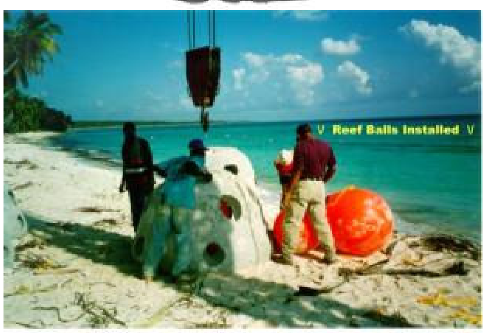

Figure 1. Individual Reef Ball TM Unit. **Figure 2. Reef Ball Deployment.**

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

Table 1. Reef Ball 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
Mini-Bay Ball	2.5 feet (0.76m)	1.75 feet (0.53m)	150-200 lbs (70-90 kg)	less than 4 50 lb bags	8-12
Lo-Pro	2 feet (0.61m)	1.5 feet (0.46m)	70-100 lbs (30-45 kg)	less than 2 50 lb bags	6-10
Oyster	1.5 feet (0.46m)	1 foot (0.31m)	30-45 lbs (14-20 kg)	less than 1 50 lb bag	6-8

The design of the submerged breakwater system consisted of three segmented breakwater sections, using three rows of Reef Ball™ 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 Fiberglas rebar were pre-cast into the Reef Ball units, with number five 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 with rocks to provide additional habitat and weight.

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 of the Reef Balls on 20 November 1998 indicated that none of the Reef Ball units moved from their 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. The shoreline that had been sand prior to the hurricanes consisted of 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 and increase the wave attenuation of the Reef Ball breakwater was also discussed.

Gran Dominicus added a small quantity of sand to the beach, and placed a considerable amount of small rocks seaward, landward, and on top of the submerged Reef Ball breakwater, as shown in Figure 6. This photograph shows that small rocks were used, instead of the larger rocks that would be stable under wave attack. 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, as shown in Figure 7. Due to the use of the smaller rocks that were added to the breakwater, wave action easily displaced the rocks, scattering them landward of the original breakwater. Figures 8 and 9 show two aerial photographs that delineate the original Reef Ball breakwater from the scattered smaller rocks.

Figure 6. Placement of smaller rocks on top of Reef Ball breakwater.

Figure7. Rock placement on top of Reef Ball breakwater and connected to shore.

Figure 8. Deliniation between the orignal Reef Ball breakwater and smaller rocks.
Aerial photograph taken April 28, 2001.

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Aerial photograph taken April 28, 2001.

Project Performance: The smaller rocks placed on top of the Reef Balls were moved landward 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 smaller rocks landward of the breakwater (the smaller rocks were subsequently removed to regain the swimming area).

The comparison photographs in Figures 9 through 11 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. No adverse effects have occurred on adjacent beaches, as the beaches adjacent to the project 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.

Survey data showing the gains in shoreline position and sand volume are presented in the following section.

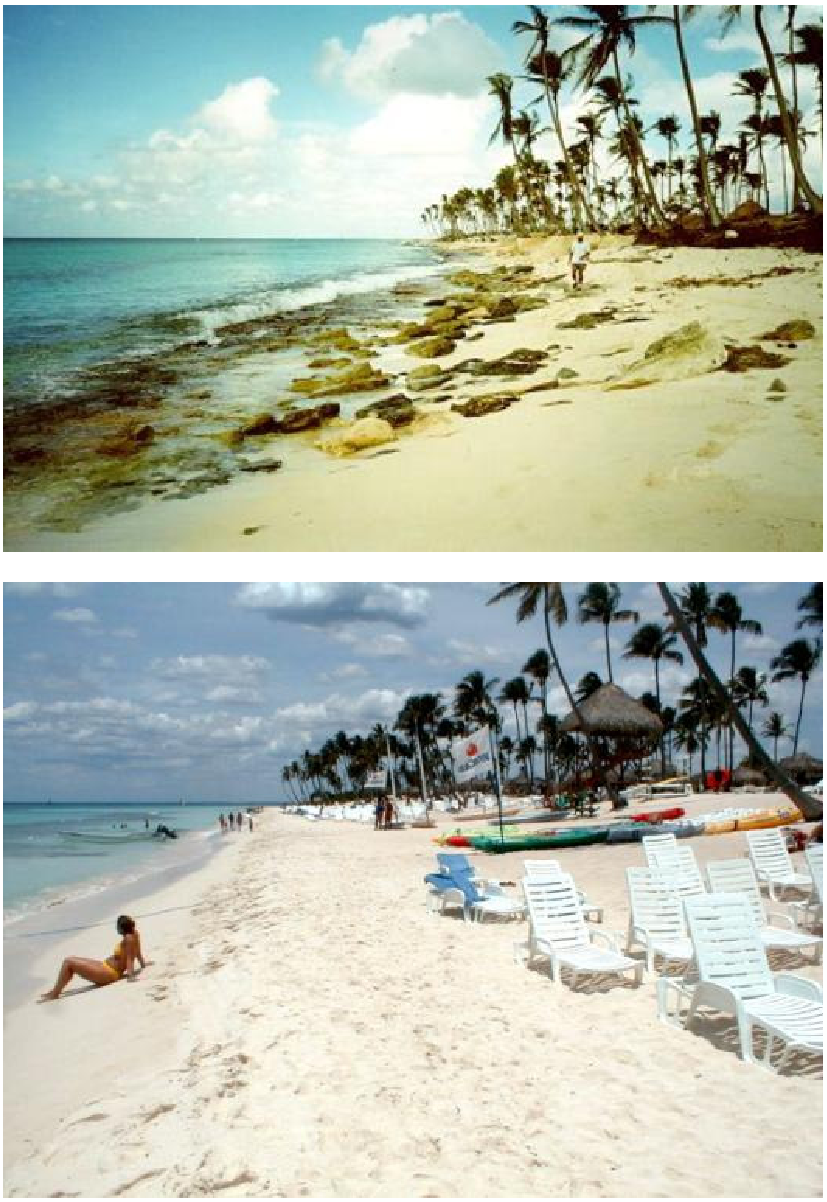

Figure 9. Increased Beach Width at Gran Dominicus - looking west.

November 1998 (top photo) compared with April 2001 (lower photo)

Figure 10. Increased Beach Width at Gran Dominicus - looking east.
Summer 1998 (top photo) compared with April 2001 (lower photo)

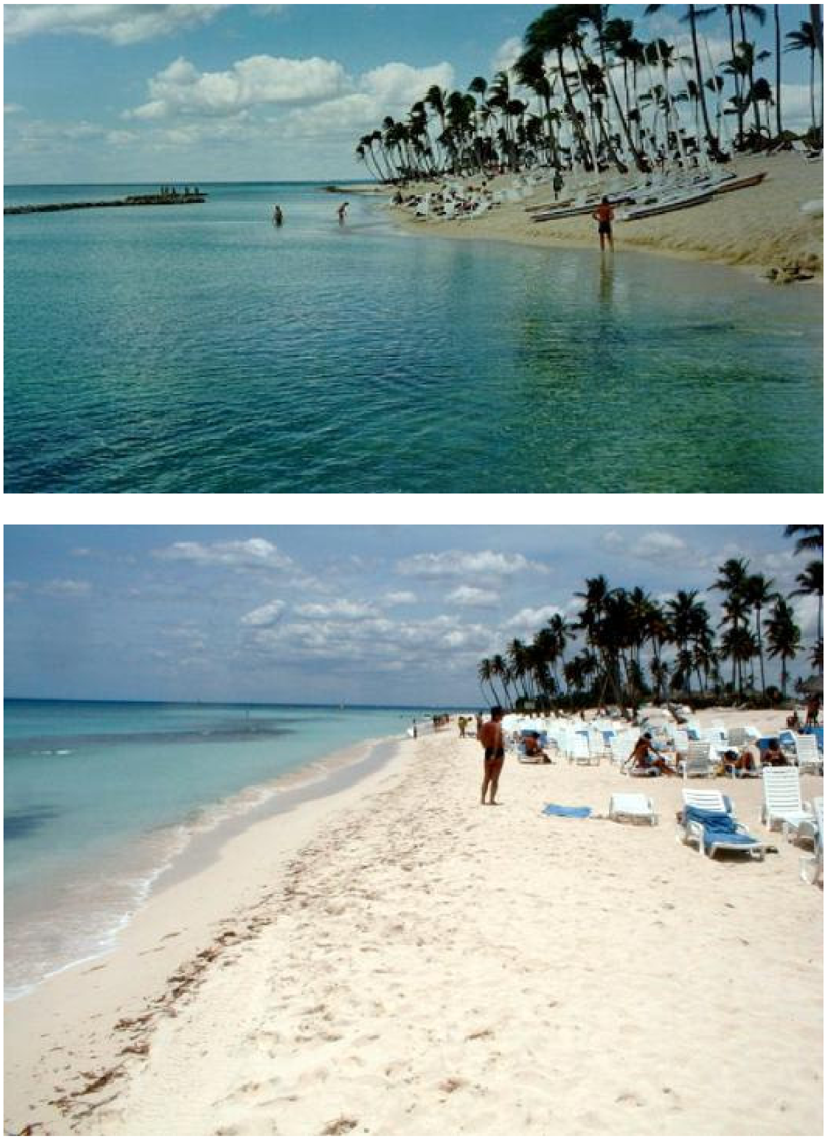

Figure 11. Increased Beach Width at Gran Dominicus.
February 1999 after small rocks added on top of breakwater and sand fill (top photo), compared with April 2001 showing large natural accretion (lower photo).

Beach Profile Survey Data: Post storm surveys of the Reef Ball artificial reef submerged breakwater were performed during February 1999 (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).

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.

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 west end of the project and 13m shoreline advance at the east end of the project. Figure 15 shows the area immediately east of the project, where very little change in the amount of sand occurs. Comparisons between these three graphs in Figures 13 - 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.

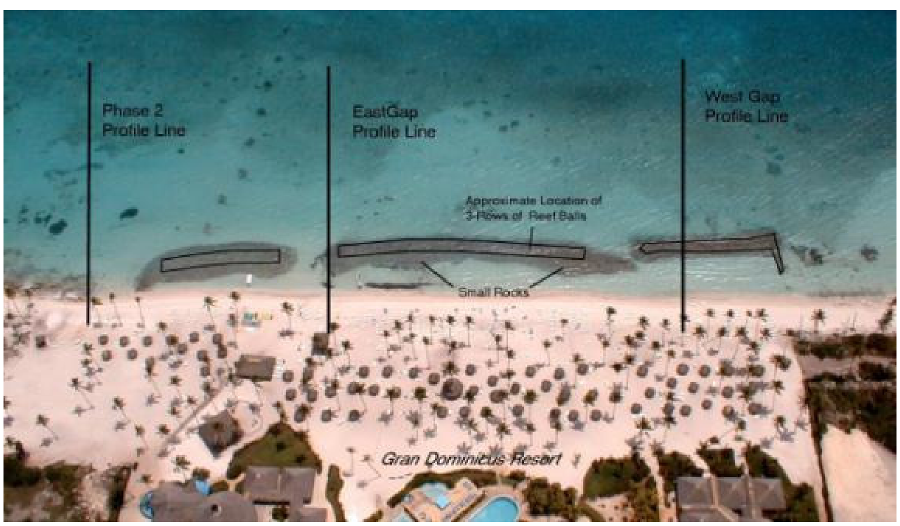

Figure 12. Location of Survey Profile Lines

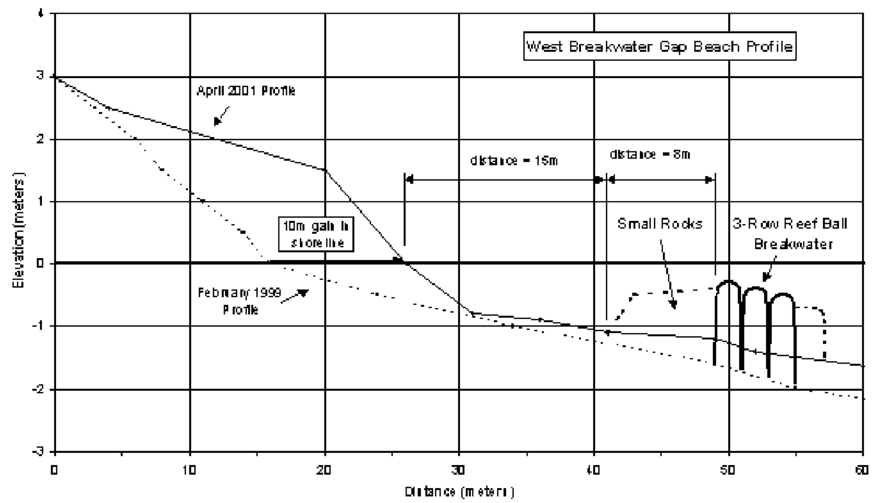

Figure 13. Survey Profile across Breakwater at West Gap.

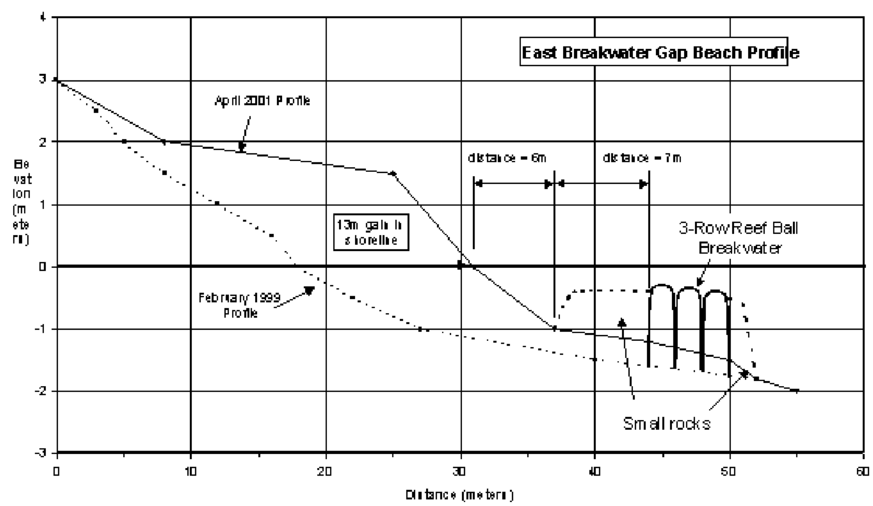

Figure 14. Survey Profile across Breakwater at East Gap.

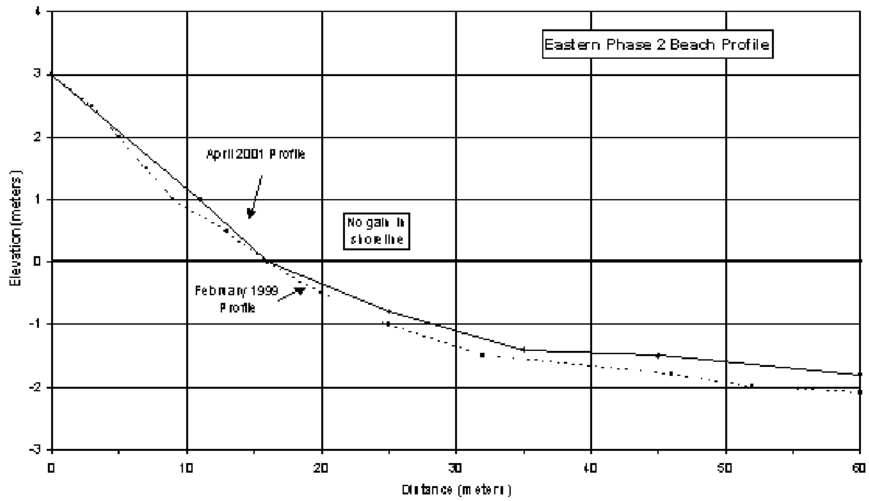

Figure 15. Survey Profile East of Breakwater.

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 parallel 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 long 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 the 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 CETN demonstrates the technology available to provide shoreline stabilization due to wave attenuation at a site with a low tidal range and wave climate. 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.