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Combined Recreational Amenities and Coastal Erosion Protection using Submerged Breakwaters for Shoreline Stabilization

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ABSTRACT

Submerged breakwaters have the potential to assist with shoreline stabilization, mimicking the functionality of natural reefs. Recent submerged breakwater projects incorporate the use of artificial reefs in shallow water to act as submerged breakwaters, while also providing the benefits associated with artificial reefs. These benefits are environmental enhancement, plus recreational benefits including swimming, snorkeling, diving, fishing and surfing.

This paper presents projects that incorporate submerged breakwaters for shoreline stabilization that also provide recreational amenities and environmental enhancement. These projects include those that have been constructed in the U.S. and Caribbean, as well as those currently being designed and soon to be deployed as part of the U.S. Army Corps of Engineers Section 227 National Shoreline Erosion Control Development and Demonstration Program (see: http://limpet.wes.army.mil/sec227/). The designs and performance of these systems are presented.

INTRODUCTION

Although beach nourishment often is used as the most effective methodology for shoreline stabilization, it is not economically or environmentally suitable for some sites. Even successful beach nourishment projects such as Miami Beach, Florida have required coastal structures to assist in stabilizing the beach at "hot spots" that erode at higher rates than adjacent areas.

The projects included in this paper include submerged breakwaters designed to assist with shoreline stabilization. Coastal engineering applications include nearshore sills for perched beaches, offshore breakwaters for wave refraction and attenuation, and other coastal structures associated with stabilizing shorelines and beach nourishment projects. These structures may be constructed of rock, concrete, steel and other traditional "hard" materials; or "soft" materials such as geosynthetics used as filter cloth foundations and/or sand-filled container systems. Submerged sand-filled container systems have been referred to as artificial reefs, but also could be referred to as artificial sandbars.

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SHORELINE STABILIZATION BY SUBMERGED BREAKWATERS

There are many examples in nature where natural reefs act as submerged offshore breakwaters, contributing to the stability of the beaches in their lee. Submerged breakwaters have the potential to assist with shoreline stabilization, while minimizing adverse impacts on adjacent beaches. There are two mechanisms by which submerged breakwaters can assist with stabilizing shorelines: (1) wave attenuation and (2) wave refraction, which are discussed in the following paragraphs.

As the name "breakwater" implies, the submerged breakwater can be designed so that the larger waves are forced to break on the structure, reducing the wave energy that reaches the shore. This wave attenuation is quantified by the wave transmission coefficient, which is the ratio of the transmitted wave height to the incident wave height. Due to the complexities in wave breaking, physical and numerical model tests are performed to determine the wave transmission coefficients.

For submerged breakwaters, the wave attenuation generally increases with increasing wave height. During periods of smaller waves, little or no wave attenuation occurs, with the waves passing unaffected over the submerged structure. This allows the normal coastal processes to occur in the lee of the reef without disruption, thereby minimizing any adverse effects on adjacent beaches. During periods of larger waves, the submerged breakwater forces the waves to break, reducing the wave energy reaching the shore, and reducing the erosion of the beaches.

Even if the waves do not break on the submerged breakwaters, they can still assist with shoreline stabilization due to wave refraction. When waves break at an angle to the shoreline, a longshore current is generated that can transport sand down the coast. The greater the angle of the waves to the shoreline, the greater the magnitude of the longshore current and littoral transport of sand. As waves enter shallower water, they refract and bend to become more nearly parallel to the shoreline. For waves traveling across sufficiently wide and shallow submerged breakwaters, this wave refraction or "wave rotation" can reduce the magnitude of the longshore current and sand transport, hence reducing sand losses from an area (Mead and Black, 2002).

ENVIRONMENTAL AND RECREATIONAL ENHANCEMENTS

Depending on the materials used to construct submerged breakwaters, they may act as artificial reefs, providing habitat for benthic and pelagic flora and fauna. Some of the same materials used for artificial reefs in deeper water, such as limestone boulders and custom designed concrete reef units, can be used to construct submerged breakwaters by deploying the units in shallow water. Artificial reefs are also used for mitigation of damages caused by burial and sedimentation on natural reefs due to beach nourishment projects.

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REEF BALL™ ARTIFICIAL REEF BREAKWATERS

One of the artificial reef units that has been used to construct submerged breakwaters is the Reef Ball™ artificial reef unit, shown in Figure 1. Originally designed as an artificial reef unit for habitat enhancement, these units have advantages over traditional breakwater materials, including: (1)easy and economical on-site fabrication using a patented mold system, (2)easy and economical deployment of the units by floating them using lift bags (not requiring barges and cranes), and (3)units can be custom designed as habitat for selected benthic and pelagic species, including transplanting and propagation of corals. Physical model tests have been performed to evaluate the stability of the individual units, and to test the wave attenuation of row of units deployed as submerged breakwaters.

The first project constructed using Reef Ball™ artificial reef units for a submerged breakwater was along the southern Caribbean shore of the Dominican Republic during the summer 1998. Approximately 450 Reef Ball™ artificial reef units were installed 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 1.3m high Ultra Ball units, with base diameters of 1.5 and 1.6 meters, respectively, and masses of 1600 to 2000 kilograms. The breakwater was installed in water depths of 1.6m to 2.0m, so that the units were 0.3m to 0.8m below the mean water level (the tide range in the project area is approximately 0.4m). Figure 2 shows the three-row Reef Ball submerged breakwater. In the fall of 1998 shortly after the installation of the breakwater system, a direct hit by Hurricane Georges (Category 3) and large waves from Hurricane Mitch (Category 5) impacted the project area, but not a single Reef Ball™ unit was displaced or damaged.

Figure 1. Reef Ball™ Unit.

Figure 2. 3-Row Submerged Breakwater.

Figure 3 shows the location of three profile lines surveyed to document the performance of the submerged breakwater system. The beach profile shown in Figure 4 shows that the Reef Ball™ breakwater has been very effective in stabilizing the beach, with a significant increase in beach width and elevation along the project shoreline.

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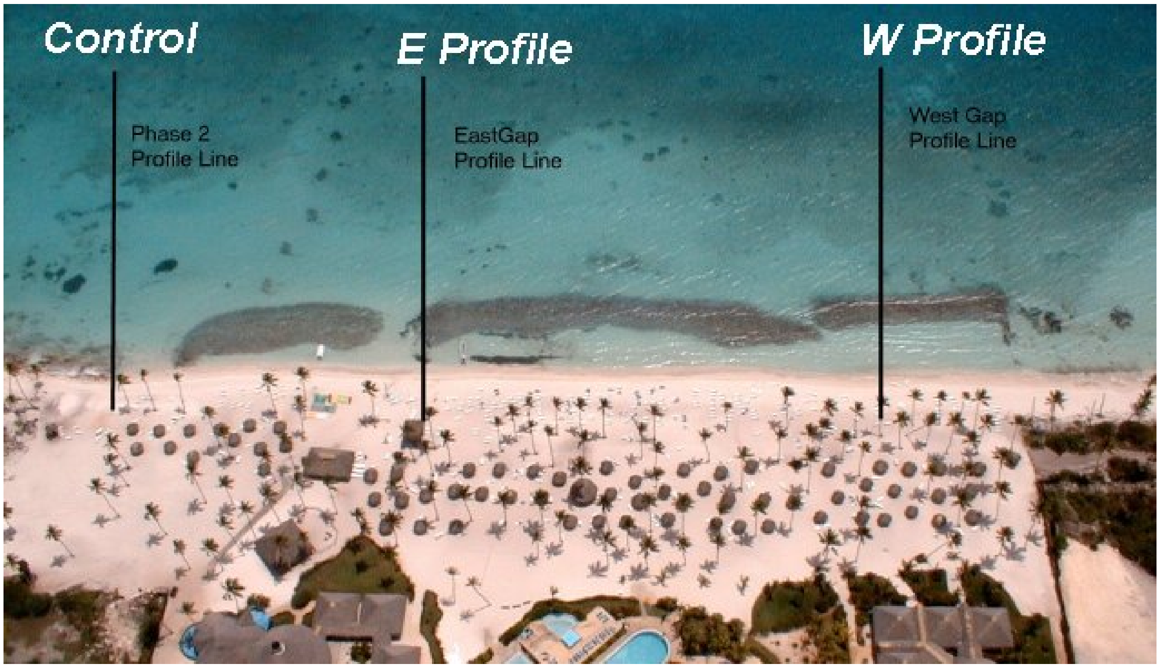

Figure 3. April 2001 Aerial Photograph.

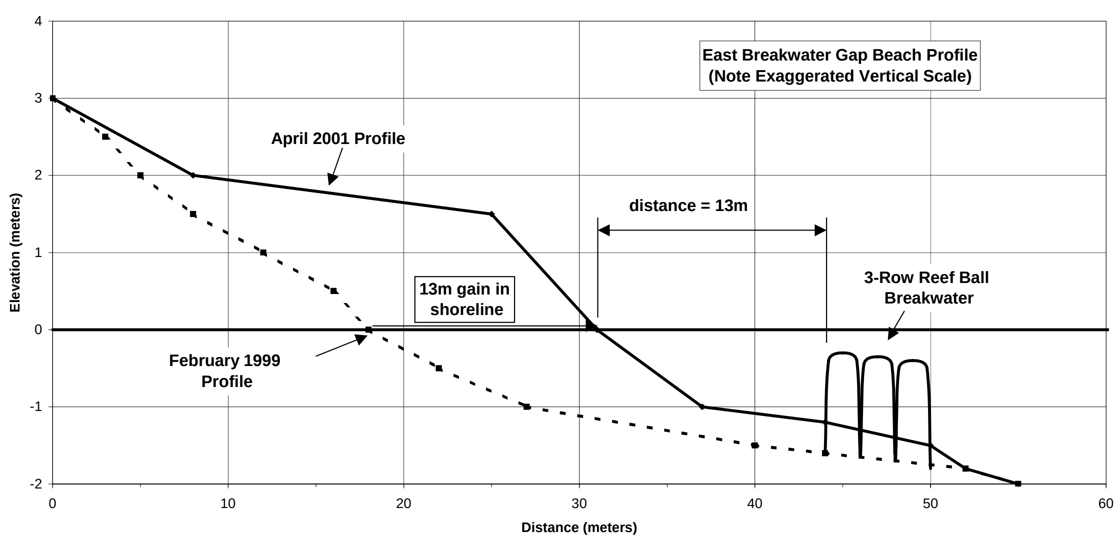

Figure 4. Beach Profile across Breakwater near East Gap

Shoreline and sand volume calculations are shown in Table 1. As shown in Figure 5, the beach and shoreline in the lee of the submerged breakwater system has been stabilized and has accreted sand, and there have been no adverse impacts on adjacent beaches. In addition, the use of artificial reef units for the breakwater provides habitat enhancement for the marine life, which can be enjoyed by divers and snorkelers.

Table 1. Changes in Shoreline and Sand Volume Calculations 1998 to 2001

Profile Line	Shoreline Change (meters)	Sand Volume Change (m^3/m)
West	+10 m	+25.65 m^3/m
East	+13 m	+44.25 m^3/m
Control	0 m	+2.0 m^3/m

Figure 5. Increased Beach Width 1998 to 2001 at Center of Project - looking west.

Other Reef Ball submerged breakwaters have been constructed in other parts of the Caribbean including the Dominican Republic, Mexico, Cayman Islands, and Antigua. Figure 6 shows some photographs of the 5-row submerged breakwater offshore of Seven Mile Beach on Grand Cayman.

Figure 6. Photographs of 5-Row Reef Ball Breakwater offshore Grand Cayman

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In addition to the natural marine growth, hard and soft corals can be transplanted and propagated on artificial reef units. The artificial reef units provide stable bases upon which coral can be attached, as shown in Figure 7. Corals can be moved from areas that have been or will be damaged from ship groundings, storms, dredging or other natural or man-made activities.

Figure 7. Coral Transplants and Propagation

For recreational enhancement, artificial reef units can be designed as snorkel and diving trails. Figure 8 shows a 5-row submerged breakwater being completed in Antigua, which has gaps and special areas designed for use by swimmers, snorkelers and divers.

Figure 8. Aerial Photograph of 5-Row Reef Ball Breakwater in Antigua
(Note that the breakwater also incorporates snorkel trails, swimming and diving areas.)

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REEF STABILITY, SCOUR AND SETTLEMENT

Stability, scour and settlement are much greater design problems for artificial reef units deployed as submerged breakwaters in shallow water, and many experimental projects have undergone substantial settlement due to scour (Stauble, 2003). Submerged breakwaters must be designed to withstand the breaking wave forces, wave induced currents and scour that occurs in the surf zone. For reef units placed on hard bottom, where settlement and scour cannot occur, the concerns are the strength of the units and resistance to movement by sliding or overturning. The weights of the individual units contribute to their resistance to movement, and the units also can be pinned to the bottom for additional stability.

When placed on sand in shallow water, artificial reef units are very susceptible to scour and settlement (Smith, Harris, and Tabar, 1998). Two methods recently developed to increase the stability and resistance to movement, scour and settlement of artificial reef units are (1)rods or pilings driven or jetted through the reef units into the bottom and (2)attaching the reef units to an articulated mat (Figure 9). The pilings and rods go through the reef unit and into the bottom at an angle, so that the reef units will resist movement and settlement.

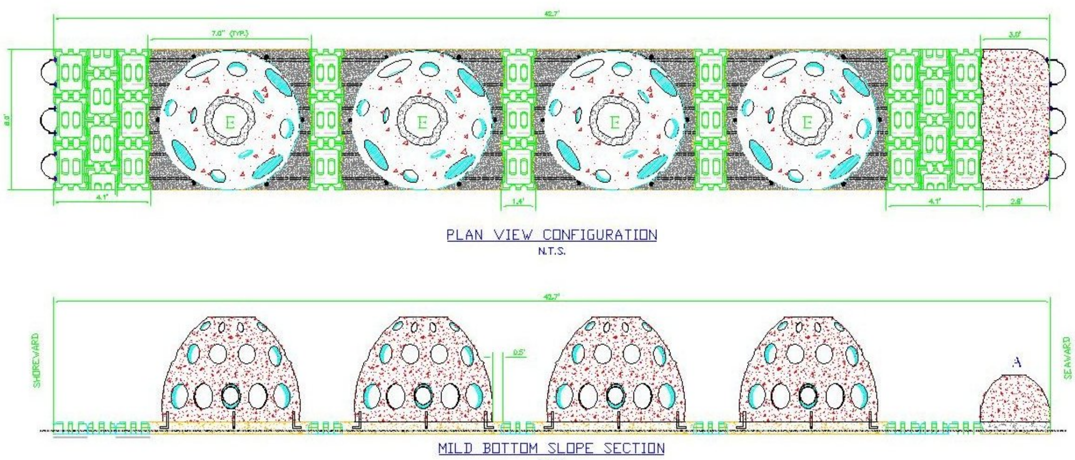

Figure 9. Reef Ball Units on Articulated Mat

CONCLUSIONS

New technologies are being developed for the use of submerged breakwaters for shoreline stabilization. These systems mimic natural reefs and sandbars in reducing the wave energy that reaches the shore. In addition to the coastal erosion protection, environmental and recreational amenities can be provided by these systems, including increased habitat for marine life plus recreational benefits including swimming, snorkeling, diving, fishing and surfing.

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