POST HURRICANES EVALUATION OF THE SUBMERGED REEF BALL BREAKWATER AT THE MAYAN PALACE RESORT, QUINTANA ROO, MEXICO

Performed by: Dr. Lee E. Harris, Ph.D., P.E.
Consulting Coastal-Ocean-Civil Engineer and Physical Oceanographer
Associate Professor of Ocean Engineering & Oceanography
Division of Marine & Environmental Systems
Florida Institute of Technology
Melbourne, FL 32901 USA

Performed for: Lic. Mario Chacon Ramos
Marenter, S.A. de C.V.
Cancun, Q. Roo, Mexico

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This letter report presents the results of site visits performed in August 2005 for the submerged artificial reef breakwater at the Mayan Palace Resort. This project is located north of Playa del Carmen in the Mayan Riviera corridor south of Cancun, Mexico. Reference the October 1992 original design recommendations report titled "Recommended Design Layout, Installation and Monitoring for the Submerged Reef Ball Breakwater at the Mayan Palace Resort, Quintana Roo, Mexico." The site visits for this report were performed after the project was impacted by Hurricane Ivan in 2004 and Hurricanes Emily in 2005.

Background Information – Original Design Recommendations

The purpose of the Reef Ball™ submerged breakwater installation offshore of the Mayan Palace shoreline was to reduce the wave energy reaching the beach in this area, thereby stabilizing the sandy beaches landward of the breakwater. For this design, a minimum of 5 rows of Reef Ball units were recommended for the cross-section of the breakwater, with the crest elevation of the breakwater just below the elevation of the lowest normal tide water level. The submerged breakwater was constructed using 4 different Reef Ball units, as presented in the table below:

Reef Ball Sizes for Use in Submerged Breakwaters
Note that maximum sizes and weights are desired, and anchoring of the reef units to the bottom is required.

Unit Type	Base Width (diameter)	Crest Height (above bottom)	Weight (in air)
Super Ball	1.8 meters	1.4 meters	2100 – 2400 kg.
Ultra Ball	1.6 meters	1.3 meters	1600 – 2000 kg.
Reef Ball	1.5 meters	1.2 meters	1600 – 2000 kg.
Pallet Ball	1.2 meters	0.9 meters	700 – 1,000 kg

The recommended layout for the Mayan Palace was to have a minimum of five rows of artificial reef units, using rows of SuperBalls, UltraBalls, ReefBalls, and PalletBalls, depending on the depth variations throughout the project area. This produces an overall structure width of approximately 9 meters, with the units installed tightly together touching each other. Due to their small sizes, the PalletBalls are the innermost (most landward) row. The water depths for the placement of the breakwater should be from the 1.5-meter isobath on the seaward side landward for a width of 5 units, or to a minimum water depth of 1.0 meter where the inner row of PalletBalls are installed, so that the crest of the breakwater is a consistent elevation of -0.1m below the low tide water elevation.

The larger SuperBalls, UltraBalls and ReefBalls should be used for the outer 4 rows, with the variations in heights of the units utilized to allow maximum overall breakwater height, while keeping the tops of the units submerged at low tide. ***The most critical parameter is the height of the overall breakwater cross-section, so that the various reef units must be installed according to the water depths.*** The maximum effectiveness for wave attenuation is for the tops of the reef units to be as high in the water column as possible, but it is often preferred that the tops are just below the water surface at normal low tide water levels. This may expose the tops of the reef units in the troughs of waves or during times of extreme low water levels.

The anchoring of the ReefBall units to the bottom rock substrate should be performed using #5 (5/8-inch diameter) or larger fiberglass rebar driven through the pre-cast slots in the Reef Ball molds. To anchor the units to the rock bottom, drilling into the bottom with a hydraulic or pneumatic drill is required to achieve a minimum penetration of 6 inches into the rock bottom for the fiberglas rebar. The purpose of the fiberglas rebar anchoring system is to prevent the sliding of the units during extreme wave events. The use of 3 or 4 rebar spaced evenly around the outside diameter of the ReefBall units was recommended, especially for the innermost and outermost rows, and at the ends of the breakwaters. 3 or 4 rebar for each ReefBall unit is desired, but for the interior units, a minimum of 2 rebar directly opposing each other is sufficient, due to the direct contact with adjacent ReefBall units on all sides providing additional resistance to sliding.

Recommended Monitoring Plan

A detailed as-built survey of the Reef Ball™ submerged breakwater was required to document the placement and performance of the system. Beach Profile lines at approximately 30 to 50-m spacing should be surveyed from the northern to the southern property line of the Mayan Palace. In addition, at least two more profile lines should be surveyed on the properties to the north and south of the Mayan Palace at 50-m intervals. The profiles need to be run from the upland development seaward approximately perpendicular to the shoreline and extend a distance of at least 30 meters seaward of the Reef Ball™ breakwater (to a depth of 2.5 to 3 meters).

The profile lines need to be surveyed from fixed survey reference markers that are established up on the land, so that the profile lines can be re-surveyed periodically to monitor the performance of the project. Surveys at least every 4 months for the first 2 years and annually thereafter are required, plus additional surveys after major storm or other erosion events.

The aerial photograph shown in Figure 1 shows a monitoring survey layout example for the 6 profile lines surveyed over a 300m shoreline length (approximately 50m spacing) for the Gran Dominicus Reef Ball™ breakwater, and Figure 2 shows the cross-sectional graph of the profile line data for the E Profile line.

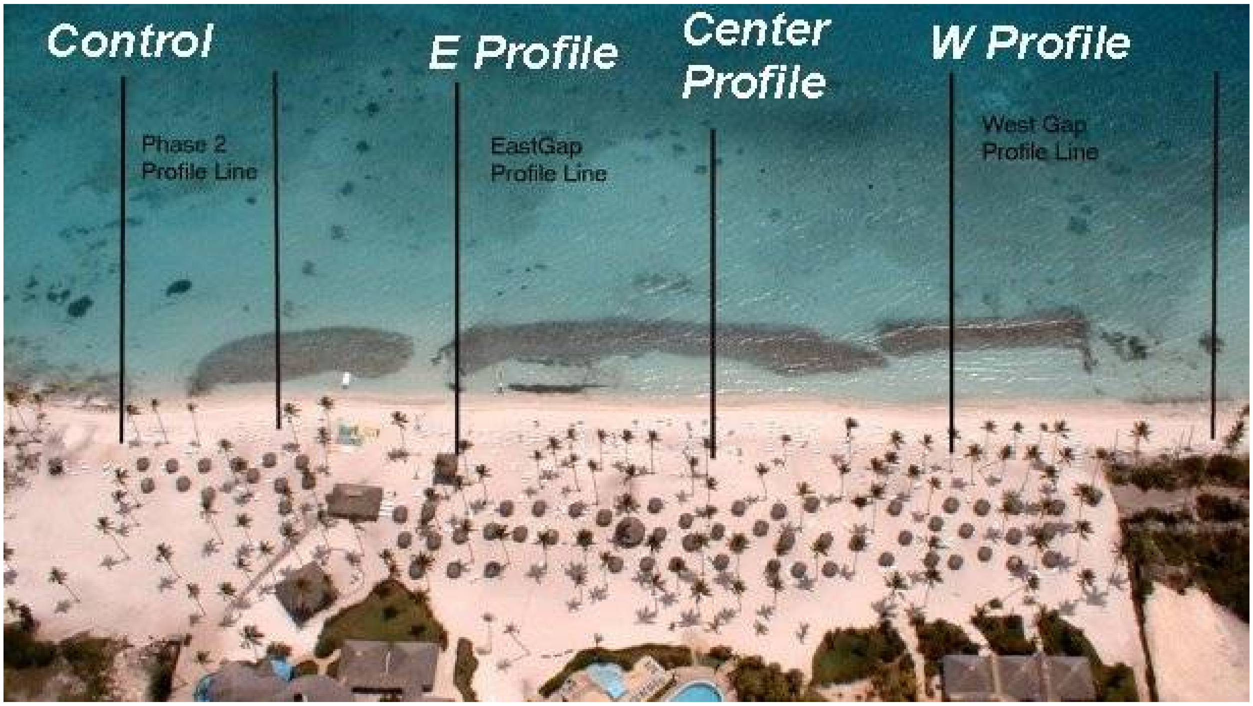

Figure 1. Six Profile Lines Surveyed for the Gran Dominicus Reef Ball™ Submerged Breakwater in the Dominican Republic. Additional profile lines are surveyed further east (to the left) and west (to the right) to determine effects on adjacent beaches.

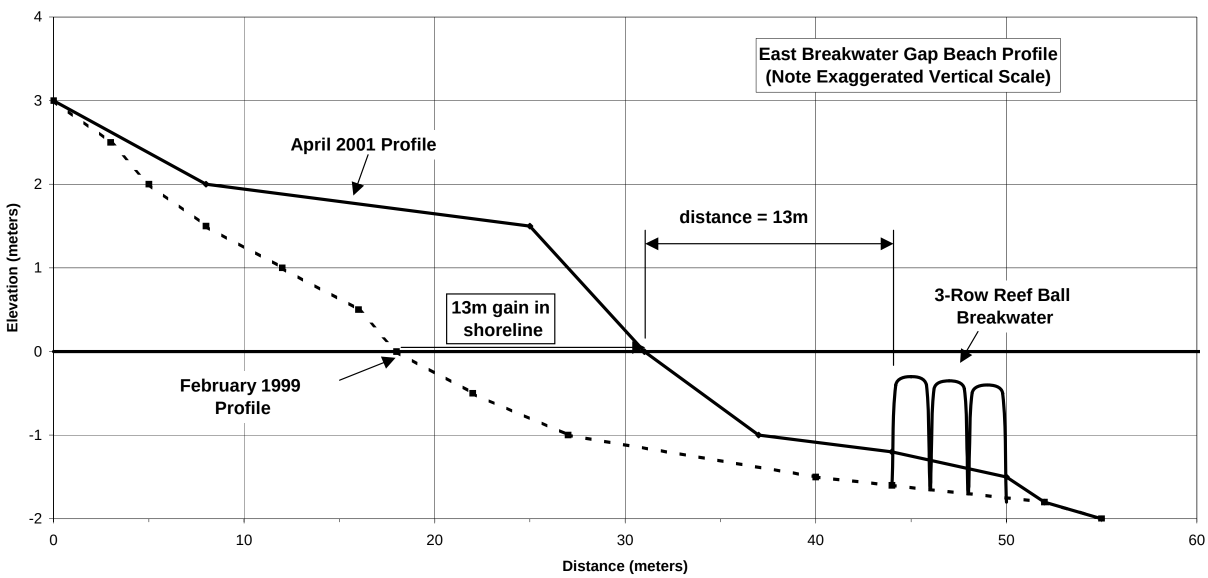

Figure 2. Cross-section of Beach Profile Showing Changes - seaward advance of the shoreline of 13m and gain in sand volume of 44 cubic meters per meter of shoreline.

The monitoring surveys recommended for the breakwater projects are essential in order to determine the effectiveness of the project and any modifications that may be needed to optimize the performance of the system.

Post Hurricanes Assessment

Figures 3 and 4 show the hurricane tracks for 2005 and 2005. Hurricane Ivan in September 2004 produced large waves and water levels that resulted in the breakage and movement of some of the Reef Ball units. However, as presented in this section of the report, the problems were due to improper fabrication of the units, improper anchoring of the units (caused by the improper fabrication), and improper location of units (based on water depths and unit sizes).

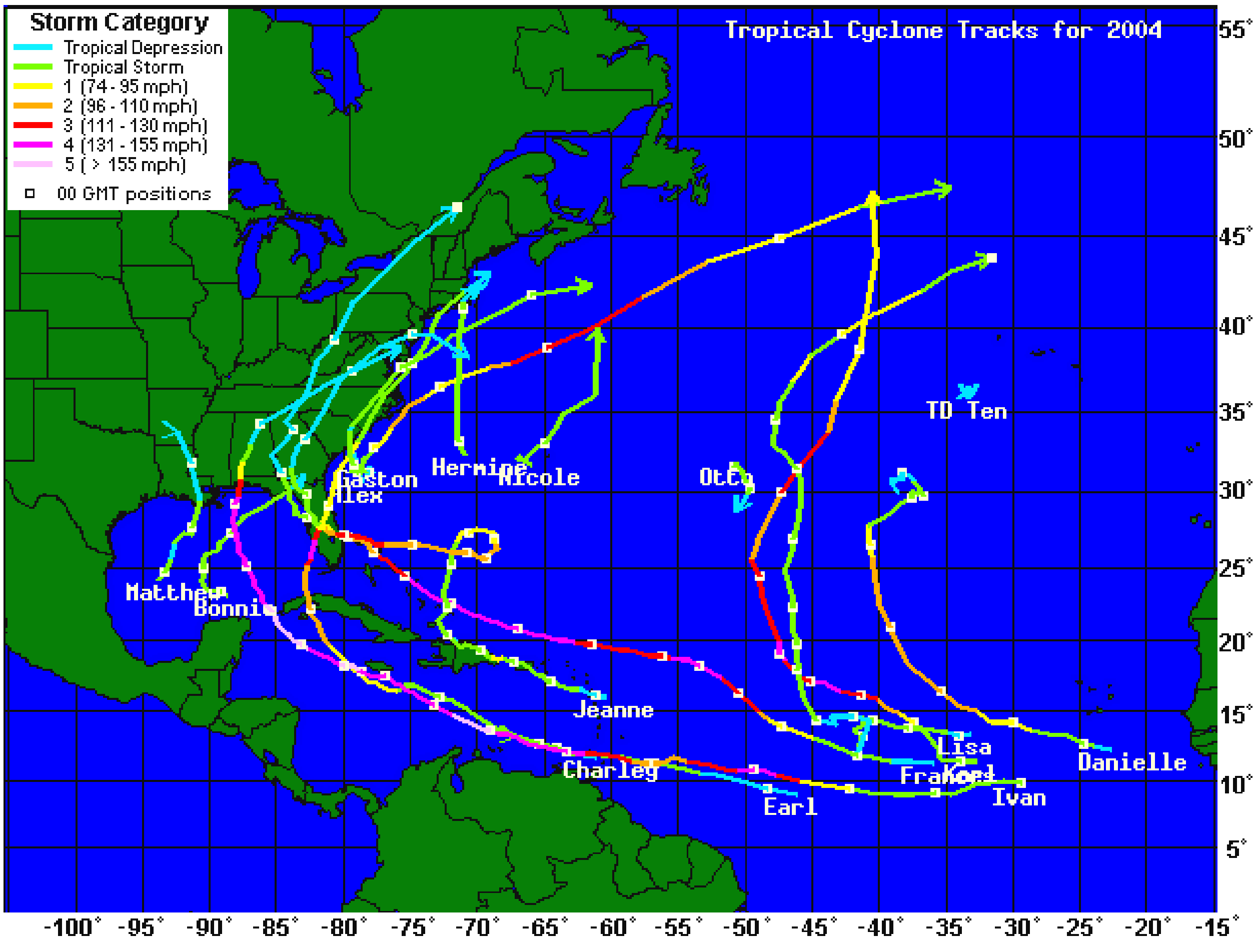

Figure 3. 2005 Hurricane Tracks – Hurricane Ivan affected Mayan Palace project area.

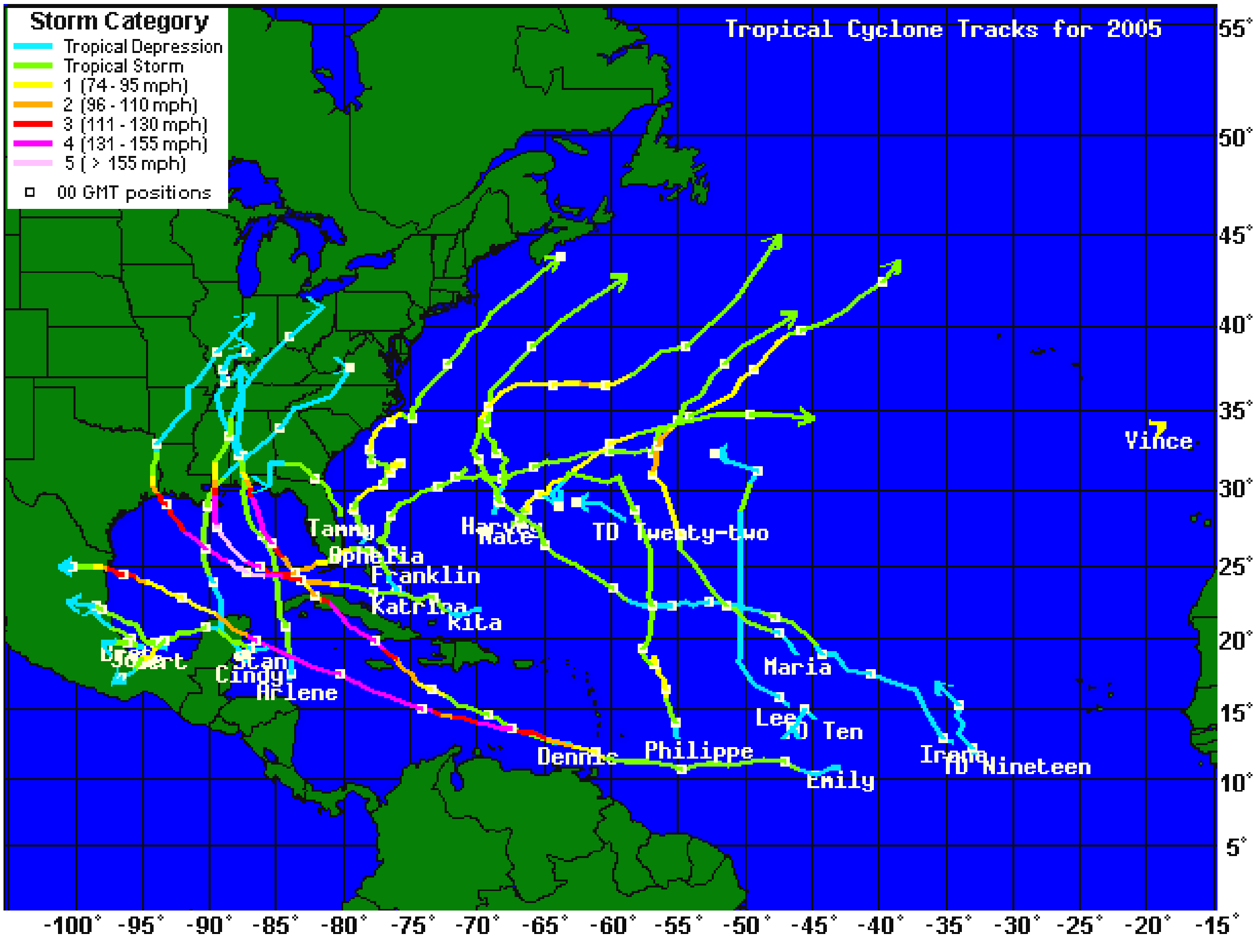

Figure 4. 2005 Hurricane Tracks – Hurricane Emily affected Mayan Palace project area.

Figure 5 shows the post Hurricane Ivan survey performed by Marenter. The different regions of the breakwater are labeled **A** through **F** from south to north as shown in Figure 5 and subsequent Figures, to provide a numbering system to assist with discussions of the performance of different sections of the breakwater system.

Figure 6 shows an aerial photograph taken after construction of the breakwater, and provides a good comparison of the as-built condition compared to the post-Hurricane Ivan condition shown in the survey in Figure 5 (directly above Figure 6 for comparison).

Figure 7 shows an aerial photograph taken after Hurricane Ivan, and provides good comparisons to the as-built photographs and to the post-Hurricane Ivan condition shown in the survey (reproduced as part of Figure 7 for comparison). Figure 8 shows a close-up aerial photograph of all of the breakwater regions after Hurricane Ivan, except for Region F which is further north of the area photographed.

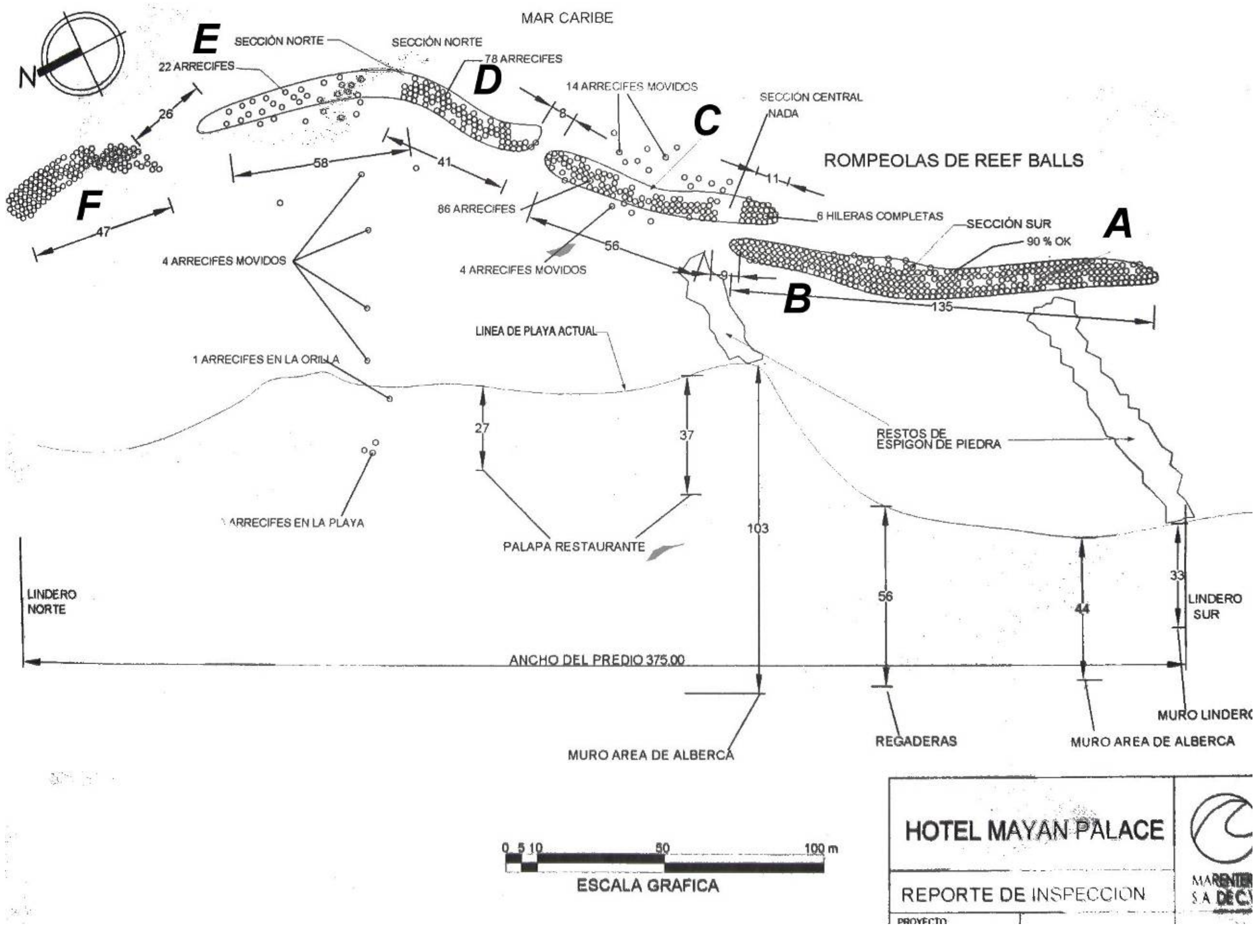

Figure 5. Post Hurricane Ivan Survey Performed by Marenter

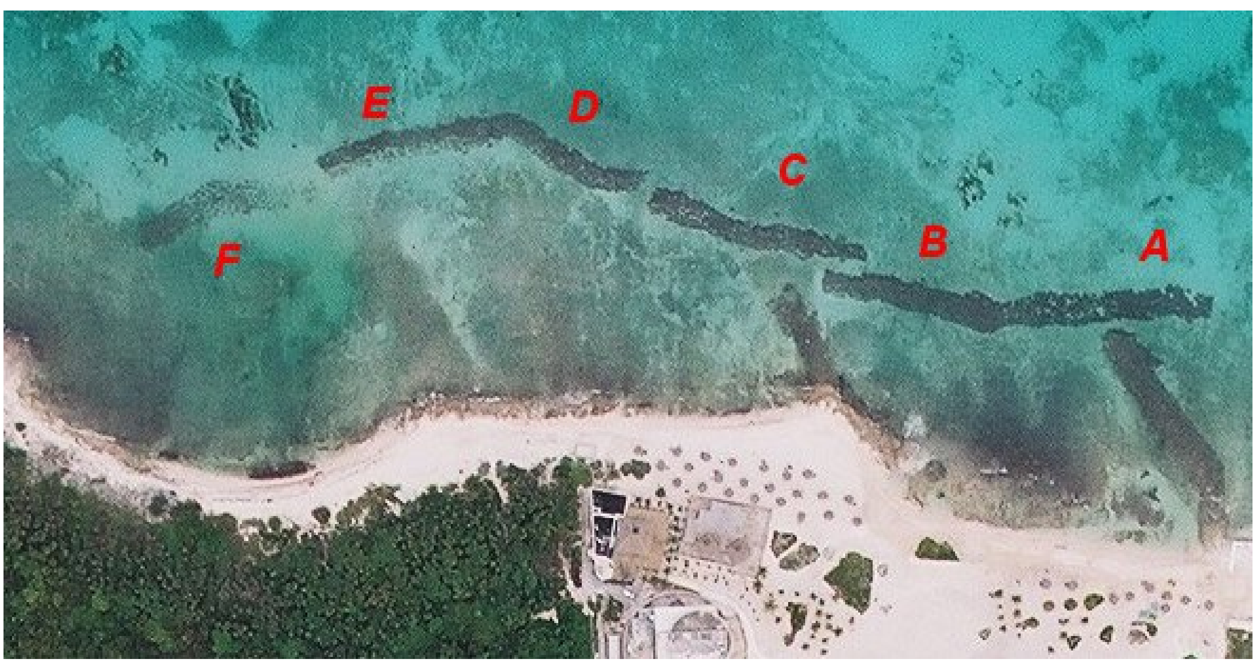

Figure 6. As-built and Pre-Hurricane Ivan Aerial Photograph

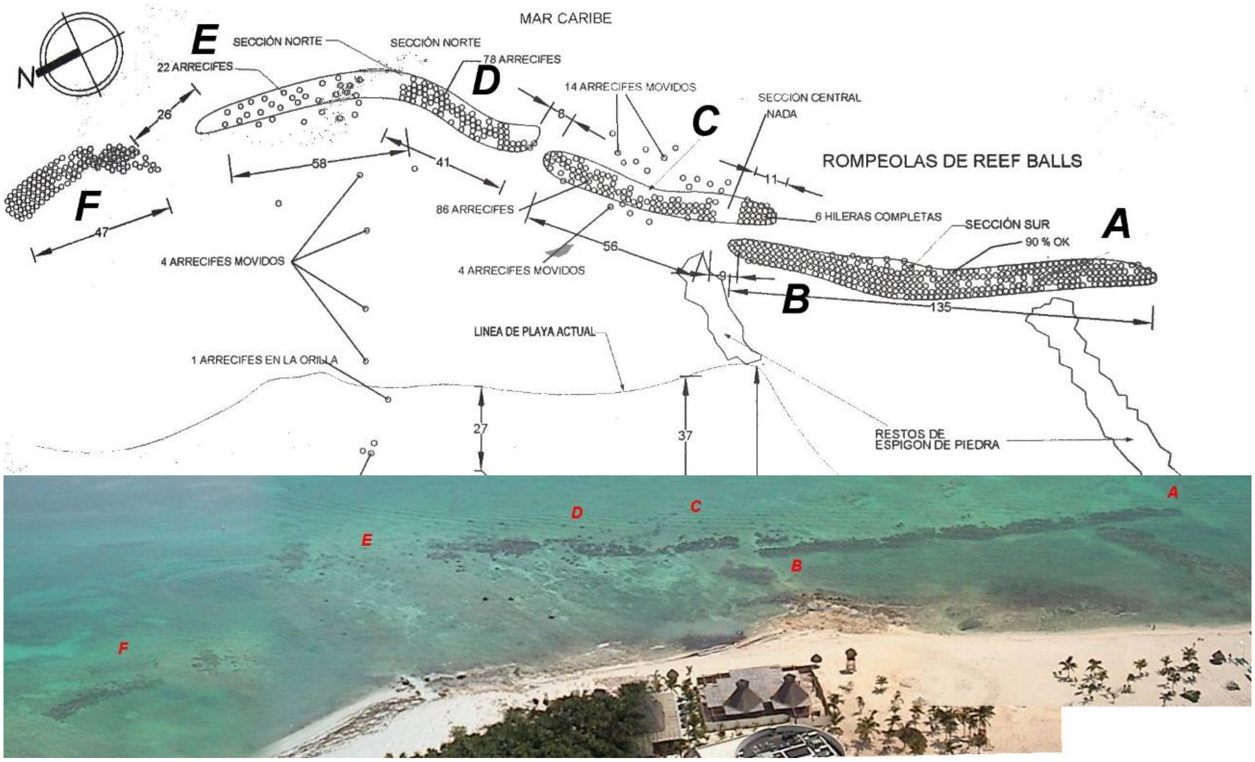

Figure 7. Post-Hurricane Ivan Aerial Photograph

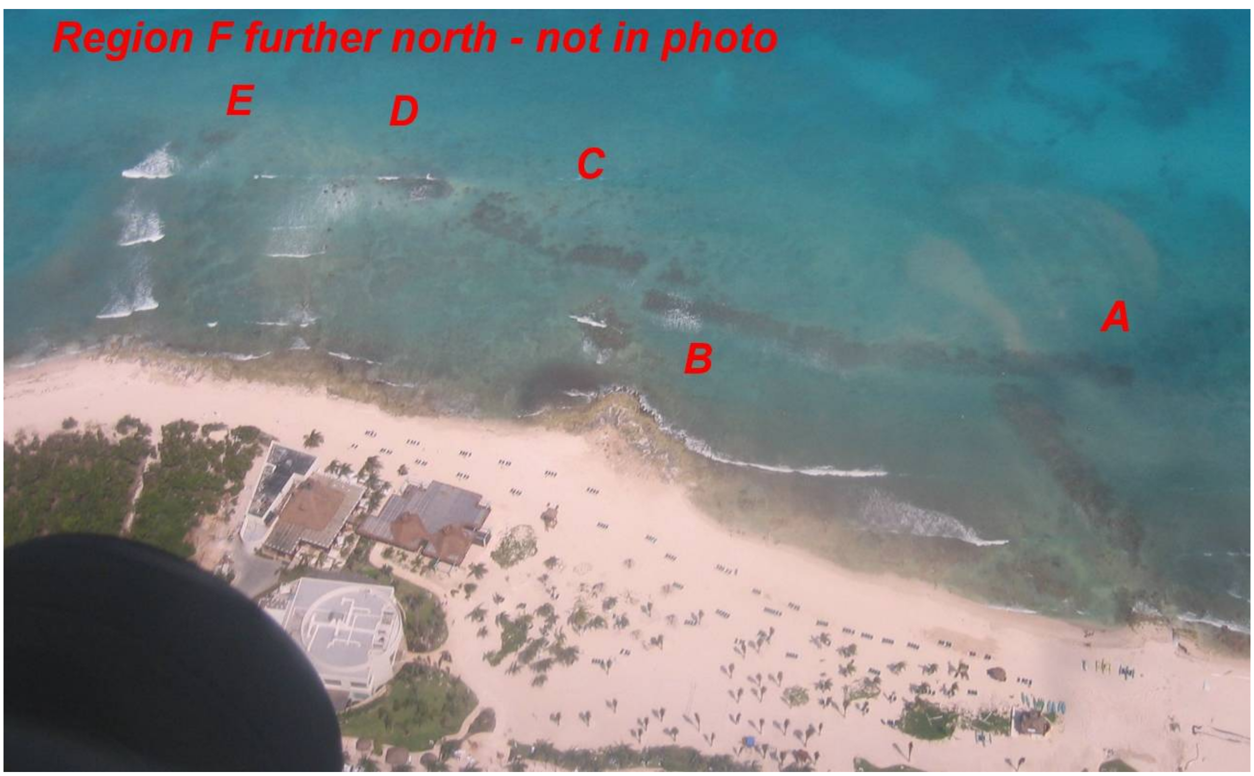

Figure 8. Post-Hurricane Ivan Aerial Photograph Close-up

Figures 7 and 8 show that the Reef Ball breakwater regions A and B remained unchanged after impacted by Hurricane Ivan. A close-up aerial photograph of that area is shown in Figure 9. This was the first breakwater portion to be constructed, and inspection of the units indicates that the concrete quality, fabrication of anchoring sleeves, and anchoring was satisfactory. Hence this part of the breakwater performed well under the wave attack due to the major hurricanes. Figure 10 shows the overlap of the Reef Ball breakwater at regions B and C. This overlap is greater than necessary, and was not the most effective use of the Reef Ball units.

Figure 9. Aerial Photograph – Region A-B

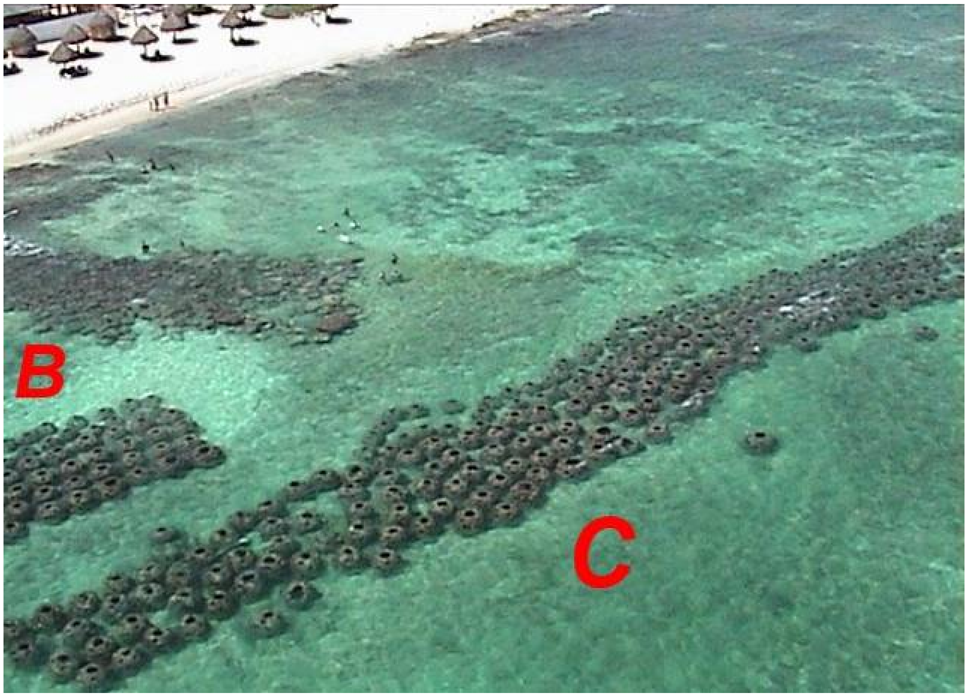

Figure 10. Aerial Photograph – Region B-C

Figures 7 and 8 show that the Reef Ball breakwater regions C, D, and E did not survive well after impacted by Hurricane Ivan. A close-up aerial photograph of that area is shown in Figure 11. This breakwater portion was constructed after regions A and B, and inspection of the units indicates that the concrete quality, fabrication of anchoring sleeves, and anchoring was not satisfactory. Hence this part of the breakwater failed under the wave attack from the major hurricanes. Inspections revealed poor quality concrete, omission of the concrete additives, omission or unusable anchoring sleeves, and the resulting lack of any anchoring on most of the units in this region. This resulted in movement and breakage of many of the units in this area, as shown in the aerial photographs and Marenter survey.

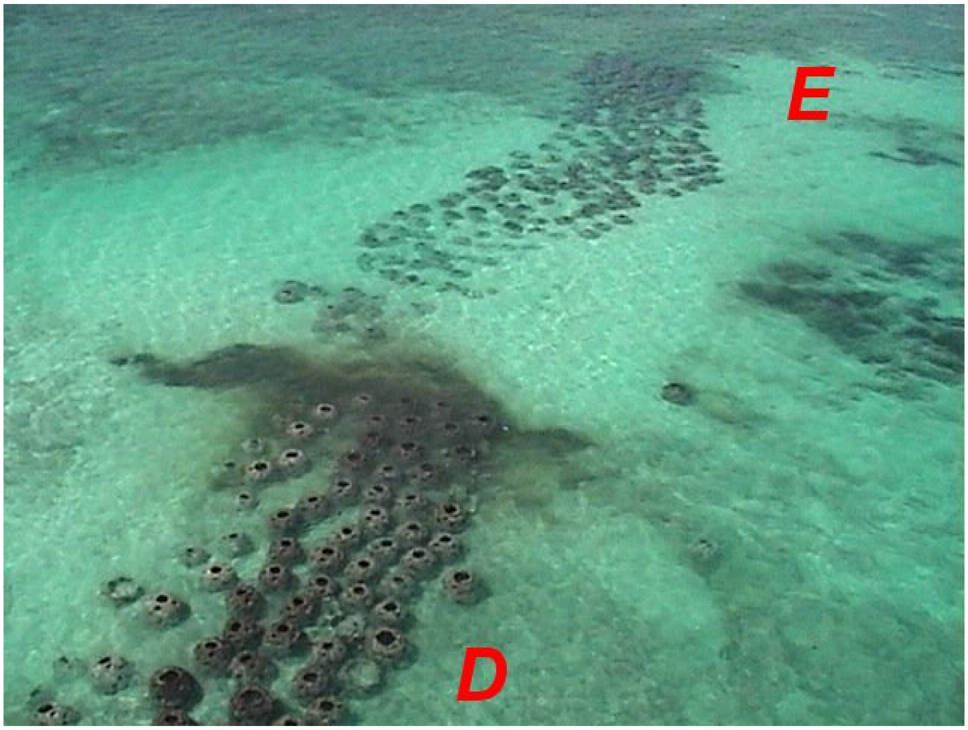

Figure 11. Aerial Photograph – Region D-E

Field inspections showed that the best constructed regions of the breakwater were regions A and B, with significantly decreasing quality control for the other parts of the breakwater. Major problems were the poor concrete quality (no additives), fabrication (no useable anchor rod sleeves), and installation (no fiberglass anchors used, often due to the lack of adequate anchor sleeves due to poor fabrication). In addition, the overall crest height of the breakwater was not at a sufficiently high or uniform elevation to provide the effectiveness for wave attenuation that was recommended.

Another problem is the 3 units in the area between the shore and the breakwater in region D, as shown in Figures 5 and 7. Figure 12 shows that these 3 units were left in that position after construction and before Hurricane Ivan, as they are in the same locations both prior to and after being impacted by Hurricane Ivan. Note that in these aerial photographs, these 3 units are located on a sand shoal, which may have been the reason that they were not deployed out on the breakwater (the units may have run aground on the shallow sand shoal during deployment, and not able to be moved).

As built, left.
After storm, below

Figure 12. 3 Reef Ball Units Shoreward of Region D in the As-built Photograph on the Right, and Post-Hurricane Ivan Aerial Photograph on the Left. Note the 3 Reef Ball units shoreward of the breakwater in both photographs, and the displaced units in the breakwater after Hurricane Ivan.

Summary and Recommendations

As per our meeting with Marenter and Mayan Palace representatives on 6 August 2005, the condition, performance, and problems with the breakwaters and recommendations for improvements are presented below.

Successful Aspects of the Project

1. Survivability – Breakwater Region A was the best portion constructed and survived better than other parts of the breakwater. Region B performed almost as well, but Regions C, D, and especially E performed poorly. Region F survived adequately, but was deployed too deep to be effective as a breakwater.

2. Beach stabilization - sand has accumulated on the upper part of the beach. However, the lack of adequate breakwater height, width, uniformity, anchoring and quality of the Reef Ball units does not provide the level of wave attenuation required to stabilize the beach to the desired level.

3. Environmental enhancement - the Reef Ball units have been successful biologically, with lots of benthic growth and fishes on the artificial reef units.

4. Ecotourism – the breakwater does provide an artificial reef for snorkeling, but only during calm weather, due to the inadequate height and width of the breakwater.

Problems with the Project

1. Reef Ball unit breakage – many units in the northern one-half of the breakwater have broken, which is due to poor concrete quality and lack of additives.

2. Lack of anchor rods – the required anchor rods were not installed, particularly in the northern area of the project. This was primarily due to poor fabrication, which either:
    a. omitted the required anchor rod sleeves in the Reef Ball units, or
    b. the PVC pipe was pulled out too early so the sleeve closed, or
    c. the PVC pipe was not pulled out at all.

   These fabrication errors led to the inability for the contractor to properly anchor the Reef Ball units. It was also apparent that there were not enough fiberglass rods available to properly anchor the breakwater units.

3. Reef Ball unit movement – due to insufficient anchoring, as in #2 above.

4. Insufficient wave attenuation – due to the breakage and movement of the Reef Ball units, the breakwater does not provide the wave attenuation desired. Also, the poor layout of the breakwater, with the proper size units not installed at the proper water depths, does not provide the recommended design structure elevation (many of the Reef Ball units were deployed in too deep water depths, and a uniform crest height of the breakwater was not achieved in the northern half of the project). As recommended in the design, the different sizes of Reef Ball units must be used according to the water depths in which they are deployed. Smaller units should be used in shallower depths, and larger units in deeper depths, so that a uniform breakwater crest elevation is achieved. As per the recommendations, the primary factor in achieving wave attenuation is a uniform and high crest elevation, achieved by using the proper sized unit depending on water depths.

5. Ecotourism – the breakwater does provide an artificial reef for snorkeling, but only during calm weather, due to the inadequate height and width of the breakwater. This is due to insufficient wave attenuation, as in Item 4 above.

6. Rocky shore – difficult entry into the water for guests, due to rocks. Better wave attenuation would allow for more natural sand accretion, and many of the small rocks in the area can be removed.

Recommendations

1. Restore the Reef Ball breakwater to the recommended design – remove the broken units (place broken pieces inside the other Reef Ball units), move displaced units and/or add additional units to restore the minimum 5-unit width with adequate and uniform crest elevation.

2. Increase the breakwater width – due to the inadequate and non-uniform breakwater crest height, additional rows of Reef Ball units should be added in all areas in which a full 5 rows of units all at the same elevation (just below the mean low tide level) A minimum of 5 rows of breakwater units all with the same top elevation just below the design low water level is required to achieve the desired wave attenuation. In areas where this crest elevation cannot be achieved, the breakwater should either be moved into shallower water closer to shore, or the number of rows increased by adding additional units shoreward of the breakwater.

3. Install anchor rods – install the required anchor rods in the Reef Ball units, and where this is not possible, add additional Reef Ball units that can be anchored around the outside of existing units, so the existing units are held in place.

4. Improve the breakwater – move the existing units and/or add additional rows of Reef Ball units so that the crest elevation of the breakwater will be as high in the water as possible, using the correct size units to achieve a uniform crest elevation, as per the original design recommendations.

5. Provide a protected snorkel and swimming area inside the breakwater, so guests do not have to go out to the breakwater for snorkeling when the seas are rough. This can be accomplished very economically by fabricating smaller standard Reef Ball and "layer cake" units that can be deployed midway between the shore and the breakwater as a snorkel trail.

6. Beach – rocks can be removed and sand can be added to the beach in order to create a beach more rapidly than waiting for natural sand accretion.

7. The monitoring of the beach and breakwater area originally recommended should be performed. Due to the lack of monitoring, the recommendations provided in this report are limited.