FIELD SURVEYS & DESIGN FOR BEACH RESTORATION USING ARTIFICIAL REEF SUBMERGED BREAKWATERS ST. EUSTATIUS, NETHERLANDS ANTILLES

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February 2005

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Introduction

This report presents the results of field surveys that were performed in November 2004 to develop a design for beach restoration and stabilization for the coast of the Lower Town of Oranjestad, located in Orangebaai on the West coast of the island of St. Eustatius (Statia). Reference the previous reported dated June 2004 titled: "Beach Stabilization Alternatives for Oranjestad, St. Eustatius, Netherlands Antilles" performed By Lee E. Harris, Ph.D., P.E. Figure 1 shows the study area photographed in May 2004, and Figure 2 shows the study area and profile lines surveyed in November 2004.

Figure 1. Aerial Oblique Photograph of Study Area (photo date May 2004)

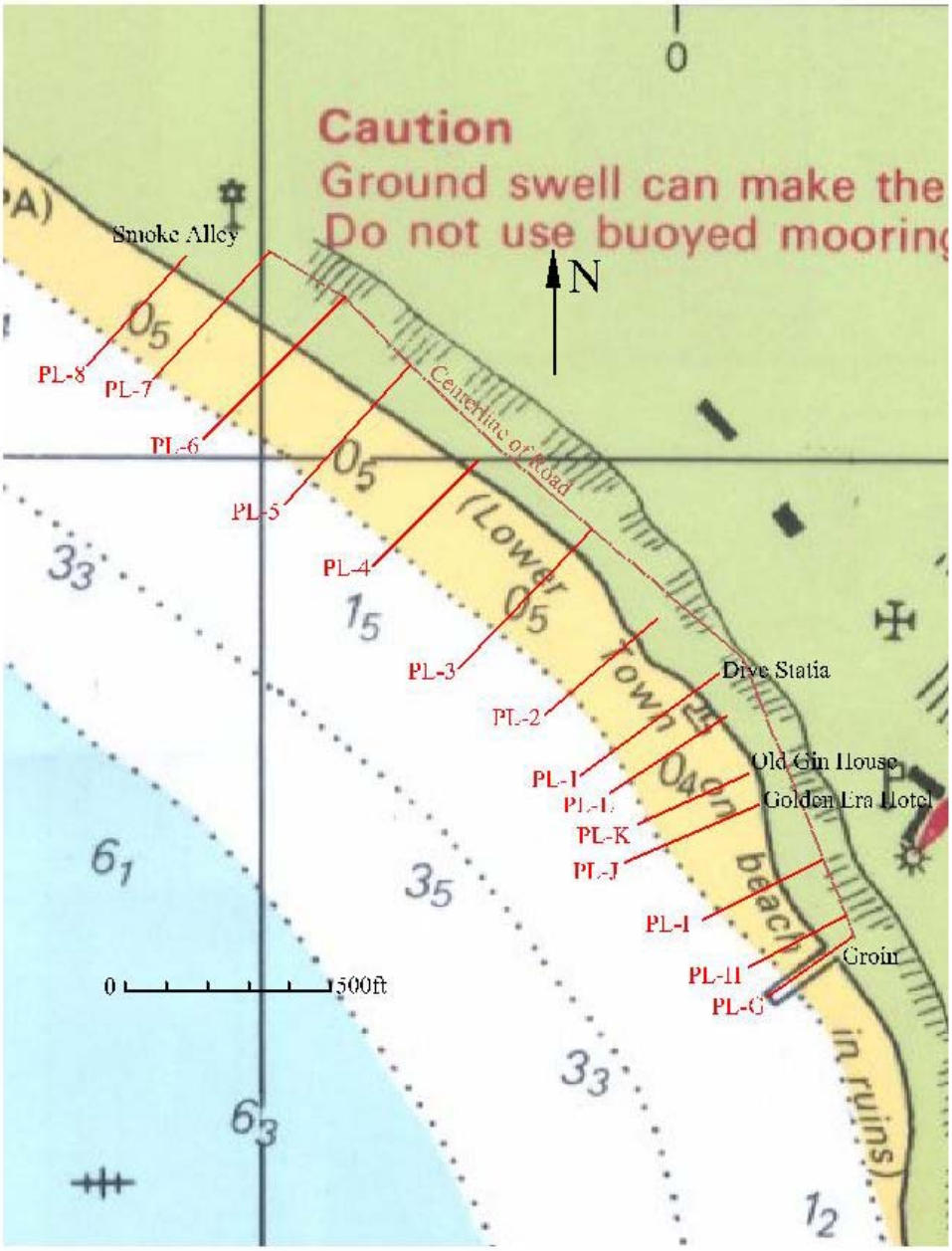


Figure 2. Study Area and Profile Lines

As shown in Figure 2, 14 profile lines were established for the field work performed in November 2004. From Dive Statia north to Smoke Alley the profile lines are numbered 1 through 8, and from the existing groin north through the hotel zone the profile lines are numbered G through L. Beach profile surveys and offshore jet probes to determine sand thickness and depth to hard bottom were performing using these profile lines for location, and these profiles lines are used to present the data.

Tide Data

No tide stations or predicted tides are available for the island of St. Eustatius. The nearest tide station and predicted tides are for St. Barts, and the predicted tides for that station for the dates of the November 2004 field work are shown in Figures 2 through 6. The predicted tides show that during daylight hours for the field work performed for this report in November 2004, the water levels are from 1 to 1.5 feet above MLLW (mean lower low water, the low tide datum).

During the November field work, periodic measurements of the water level were taken at the concrete pier at the Golden Era Hotel in the hotel zone. These water levels were used to adjust the survey data and depth measurements to the same water level datum.

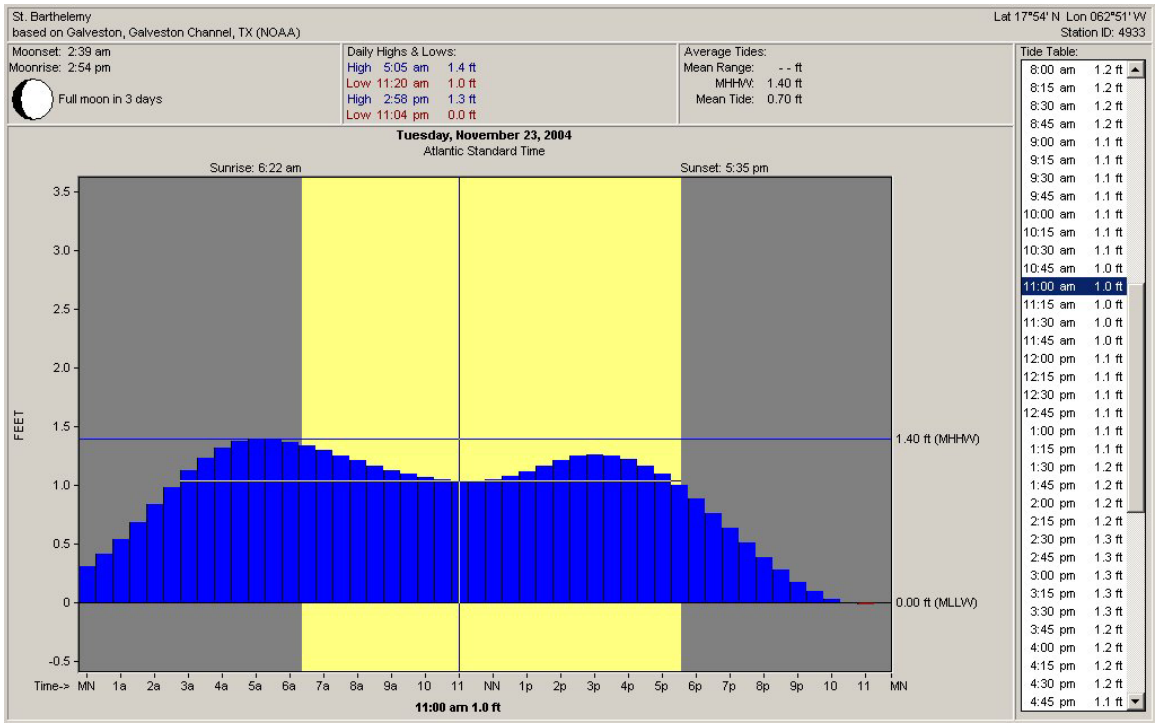


Figure 3. Tide Data for 23 November 2004

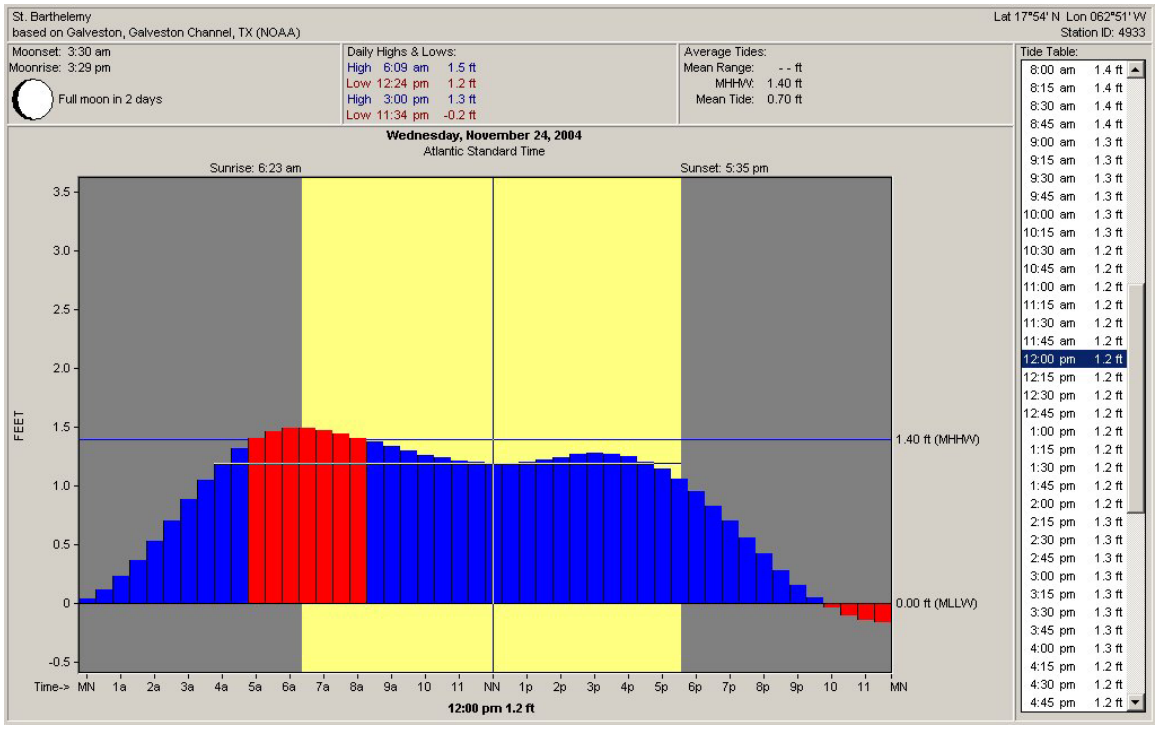


Figure 4. Tide Data for 24 November 2004

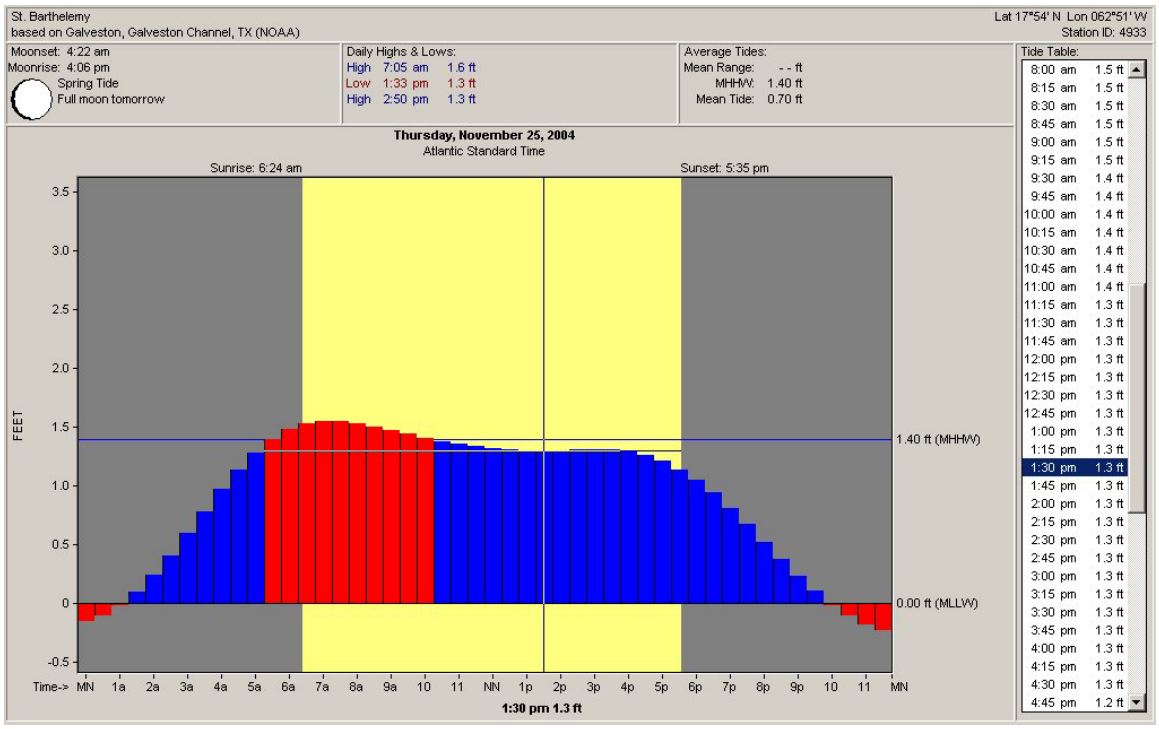


Figure 5. Tide Data for 25 November 2004

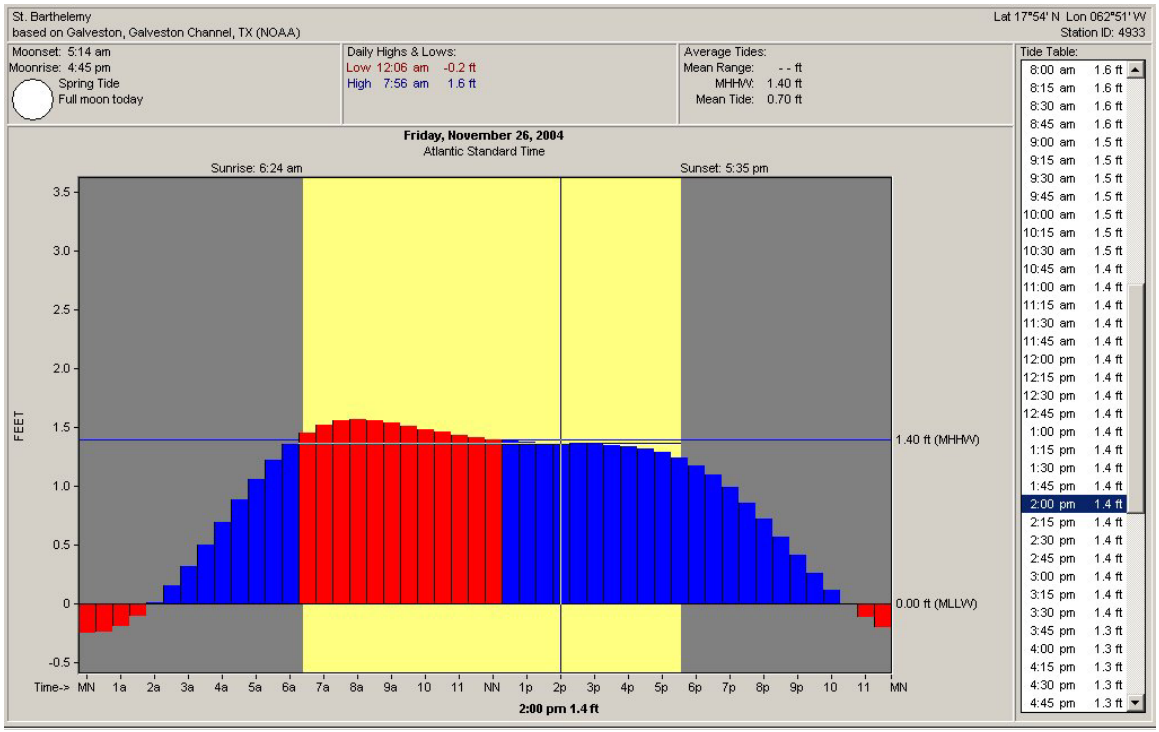


Figure 6. Tide Data for 26 November 2004

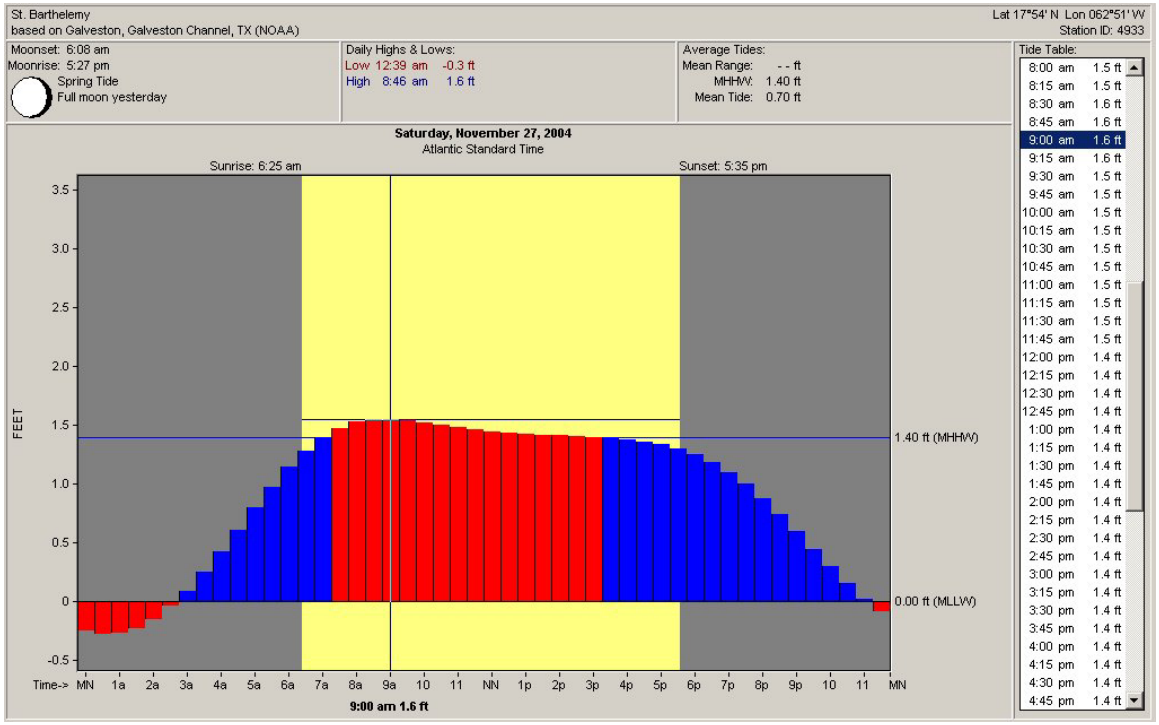


Figure 7. Tide Data for 27 November 2004

Beach Profile Survey Data

The locations of the profile lines used for this study are shown in Figure 2. Table 1 lists the profile lines surveyed, with distances of each profile line north of the groin (as measured along the road) and offshore distances to the submerged historic wall. Profile lines J, K, and L are in the area of the hotels, and profile lines 1 through 8 are from Dive Statia to Smoke Alley. Table 1 shows that the offshore distance and elevations of the historic wall vary, and these variations are plotted in Figures 8 and 9. The variation in distance offshore is due to both the variation in the position of the wall as well as the curvature of the shoreline. The offshore distances of the historical wall and the water depths are used to determine the position of offshore breakwaters.

Table 1. Beach Profile Line Locations and Distances

Line #	Profile Line Name & Location	Distance North of the Groin along road (feet)	Distance Offshore of the Wall from the shore(feet)	Top Elevation of the Wall (feet)
J	Golden Era Hotel pier	389	160.9	-8
K	Gin House little pier	466	190.2	-7.5
L	NW property corner at Gin House	627	237.8	-9
1	Dive Statia (old dock)	740	268.3	-10
2	Big Wall (at Fisherman Village)	956	248.4	-9.5
3	Midpoint – set IR - picnic table	1239	187.0	-7
4	2nd Wall-Methodist Church sign	1550	239.6	-11
5	Grassy Knoll	1817	221.0	-8
6	Tumbled Down Wall	2063	307.7	-9
7	Middle Window in Shore parallel Wall	2232	291.6	-9.5
8	Smoke Alley	2478	285.4	-10.5

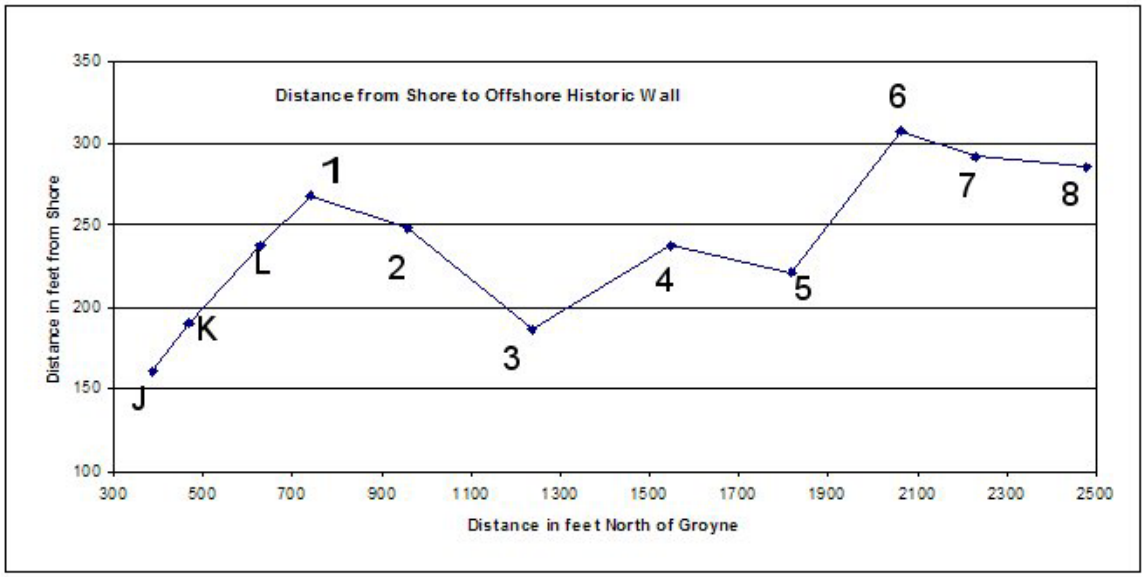


Figure 8. Offshore Distance of Historic Wall

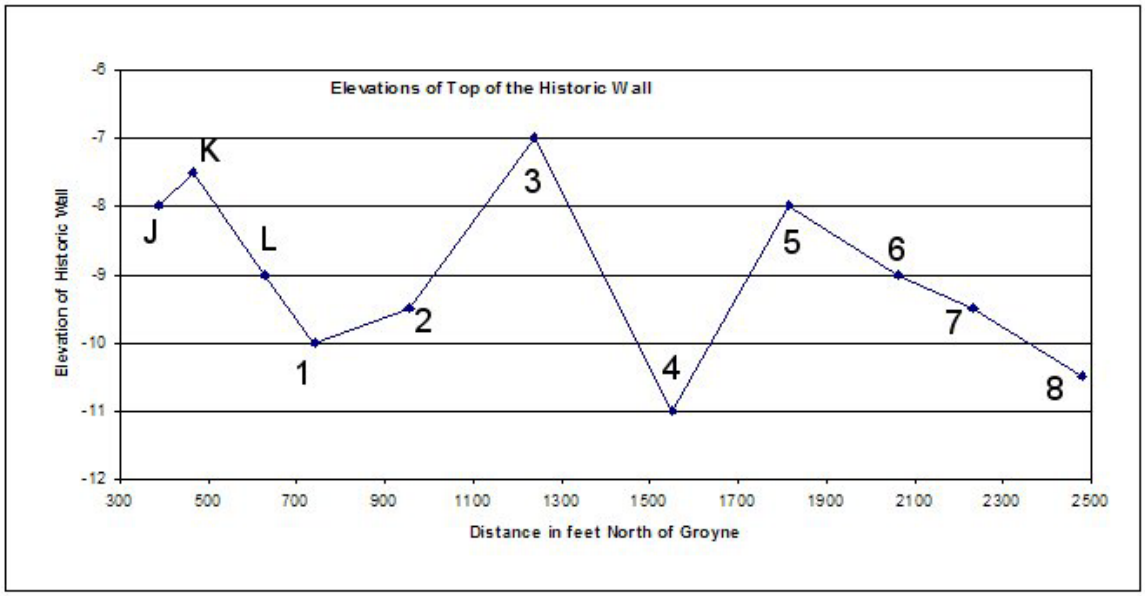


Figure 9. Elevations of Historic Wall

The profile data for the hotel zone are plotted in Figure 10, along with the profile of the existing groin. Profile lines for Dive Statia to Smoke Alley are plotted in Figures 11 and 12. The beach profile data are used to determine quantities of sand necessary to restore the beach. This beach profile data can also be used as a baseline to determine changes in the offshore bathymetry.

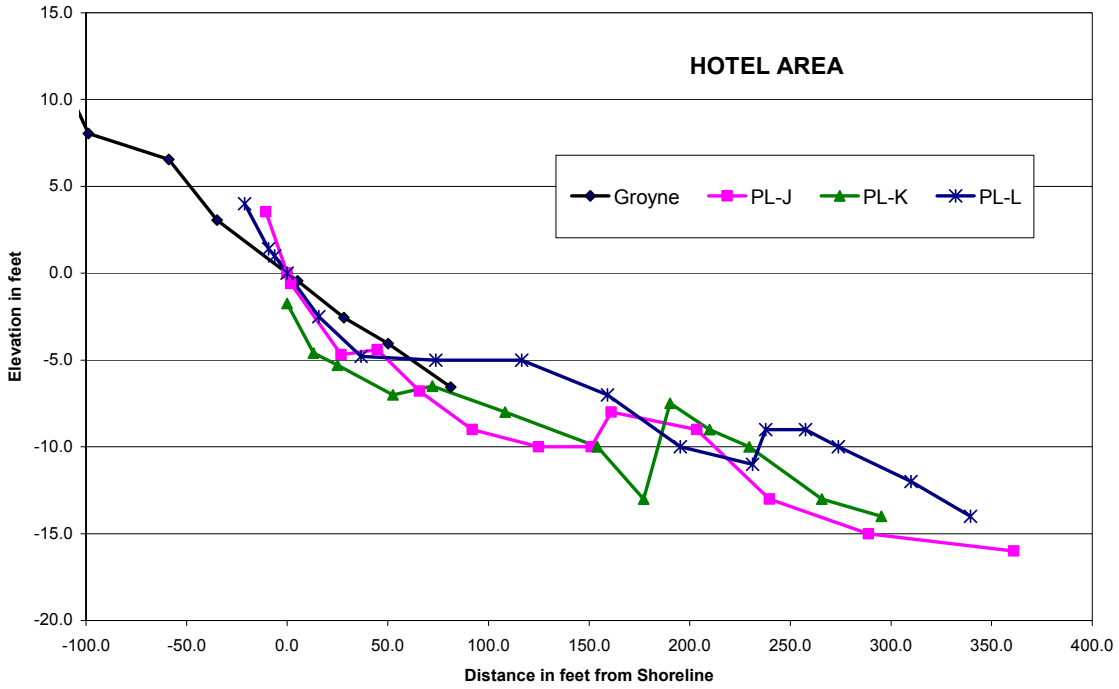


Figure 10. Beach Profile Lines in Hotel Area

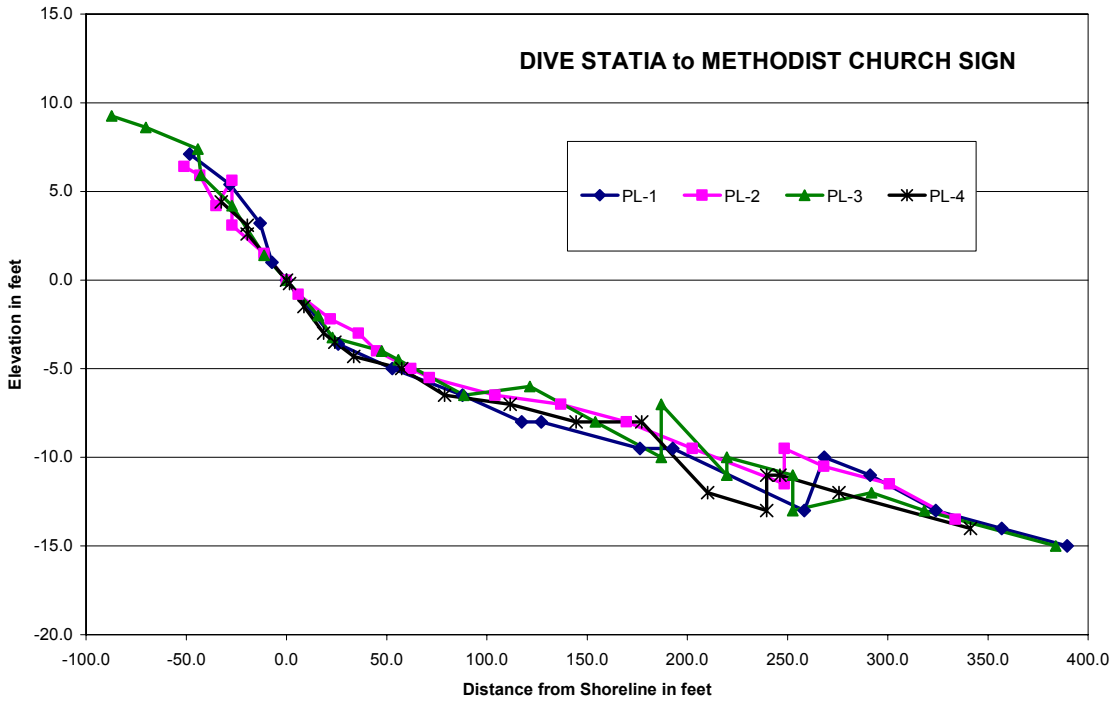


Figure 11. Beach Profile Lines from Dive Statia to Methodist Church Sign

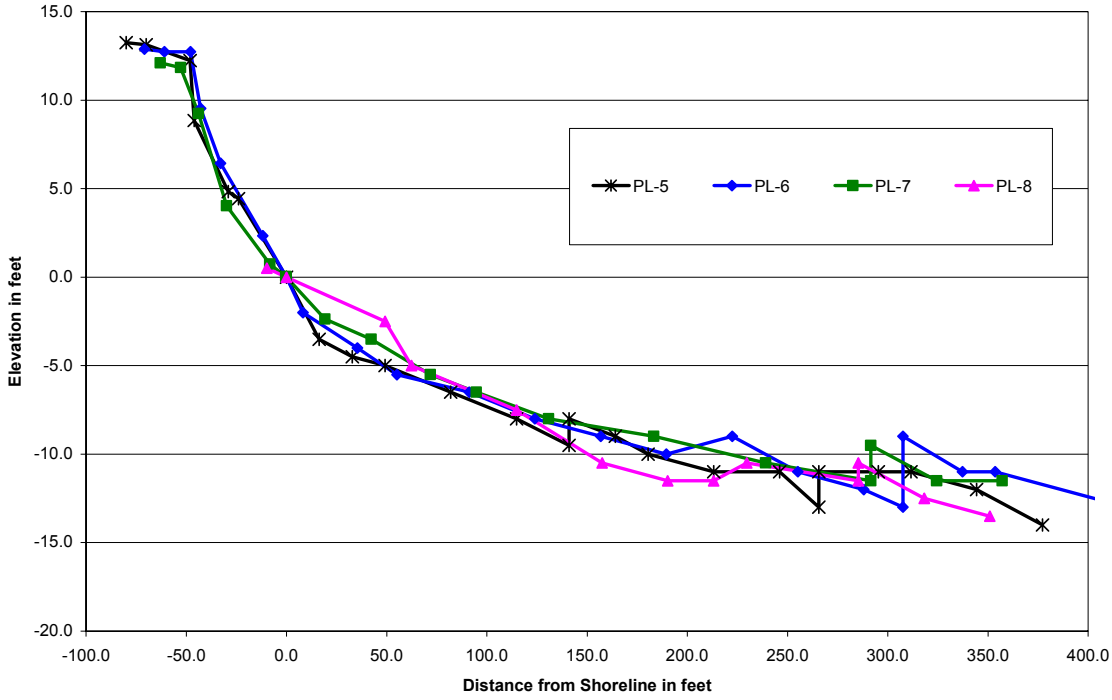


Figure 12. Beach Profile Lines from North of Dive Statia to Smoke Alley

Jet Probe Data

Jet probes were performed using a 3-inch water jet pump, hoses and 2-inch steel pipe to determine the sand thickness and depth to rock in the vicinity of the historical wall. Jet probe locations were measured from the wall and water depths on the diver's computer and the distance below the bottom at which hard bottom was encountered were recorded. Figure 13 shows this field work being performed.

Data from the jet probes are shown in Figure 14, with data shown in order of from south of the groin north to Smoke Alley. Distances for the locations of the jet probe data are given as positive offshore (to the west) of the wall, and distances are given as negative landward (to the east) of the wall. The data show a variable wall width and depth, with increasing sand thickness offshore of the wall.

Additional jet probes were taken further offshore in water depths of over 20 feet, and sand thicknesses of over 8 feet (deeper than the length of the jet probe) were encountered. Sand samples were taken from the jet probe holes, and revealed good beach compatible sand. This indicates that large volumes of beach compatible sand are available offshore that can be used to restore the beaches in this area.

Figure 13. Water Jet Probes being Performed

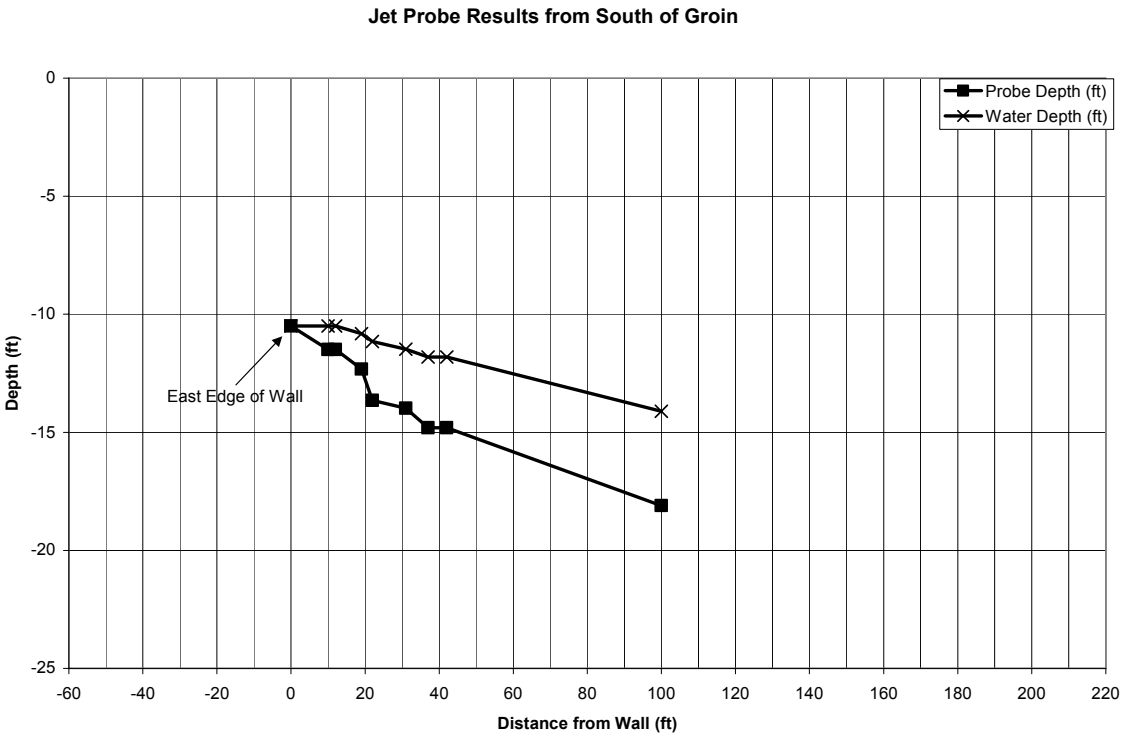
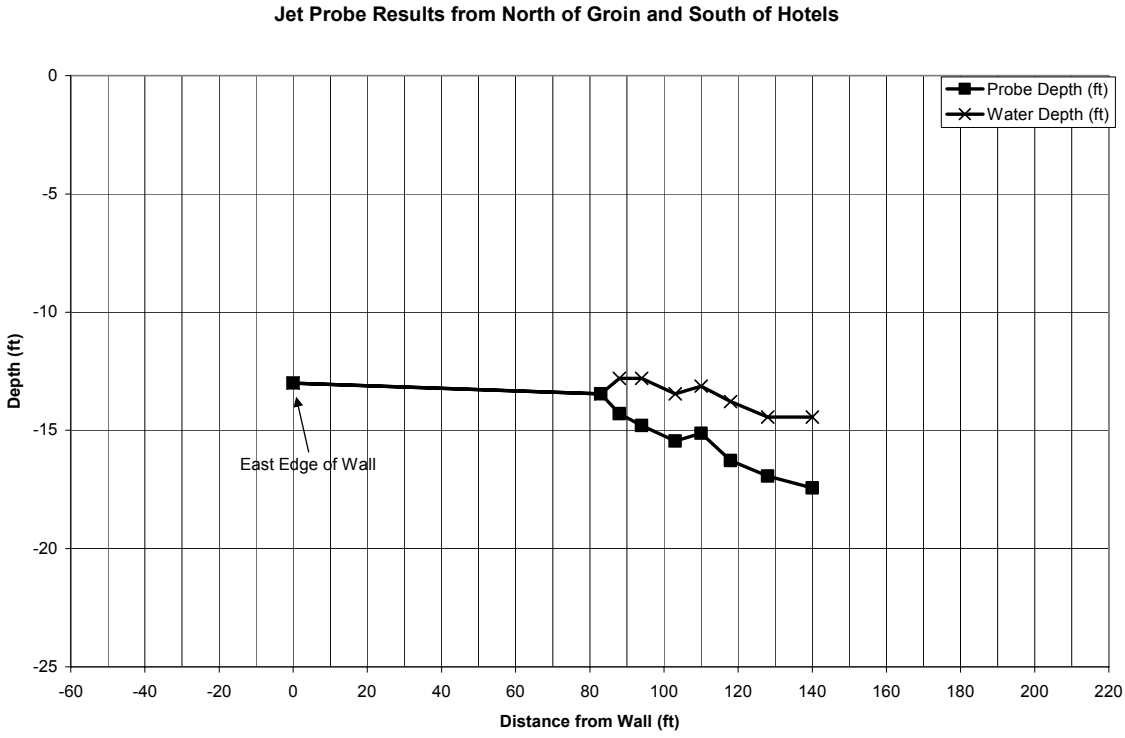


Figure 14. Jet Probe Data



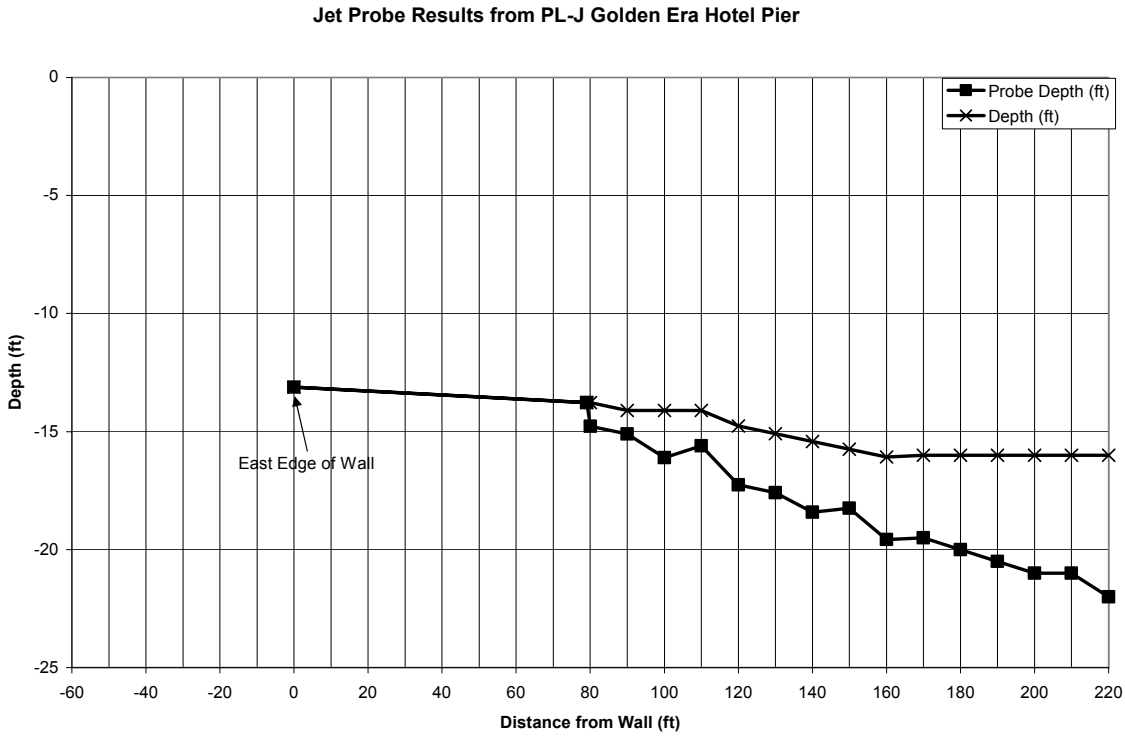
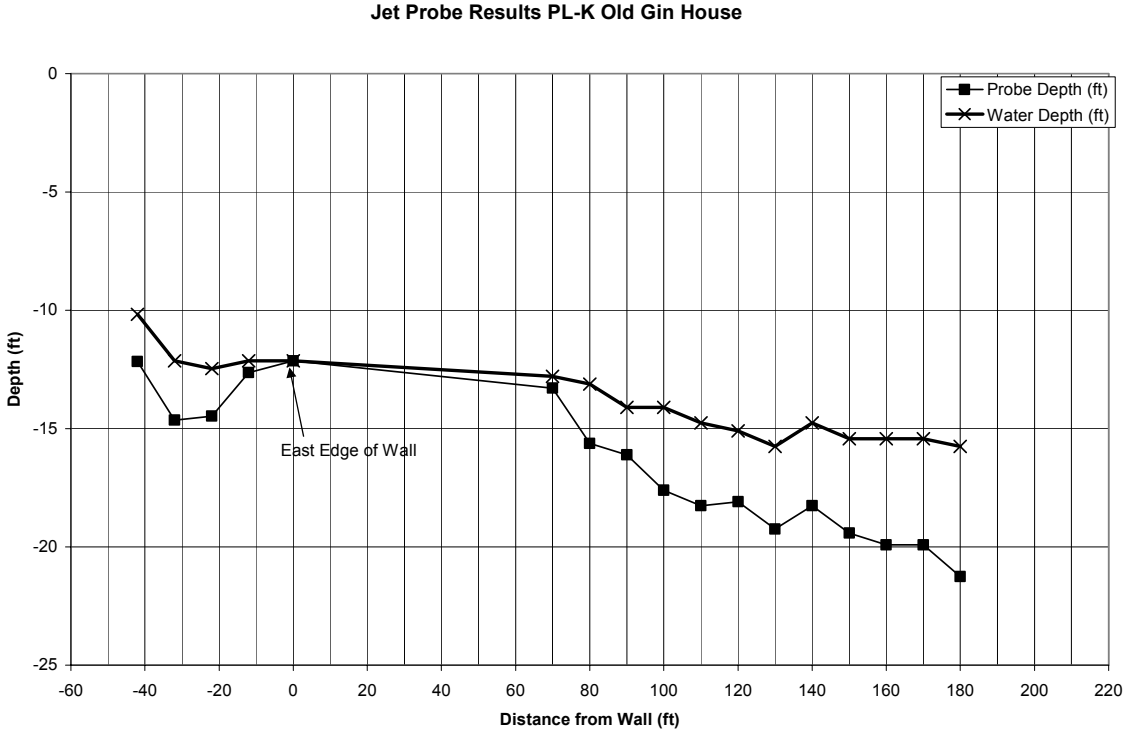


Figure 15. Jet Probe Data (continued)



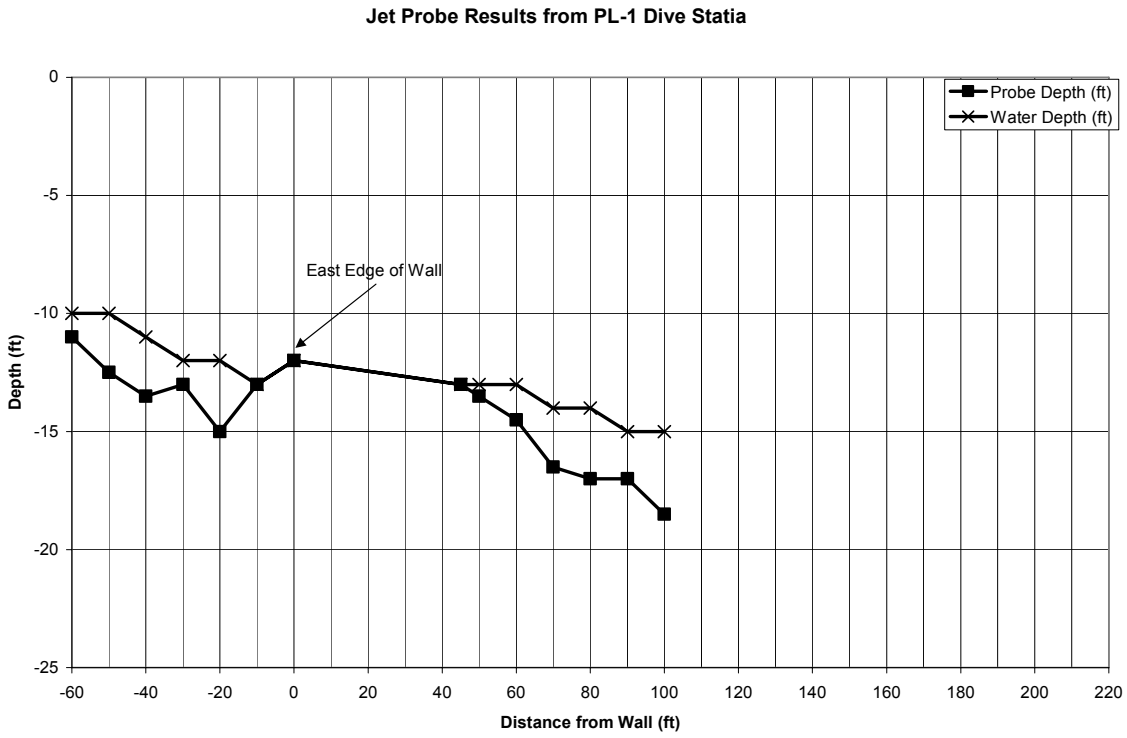
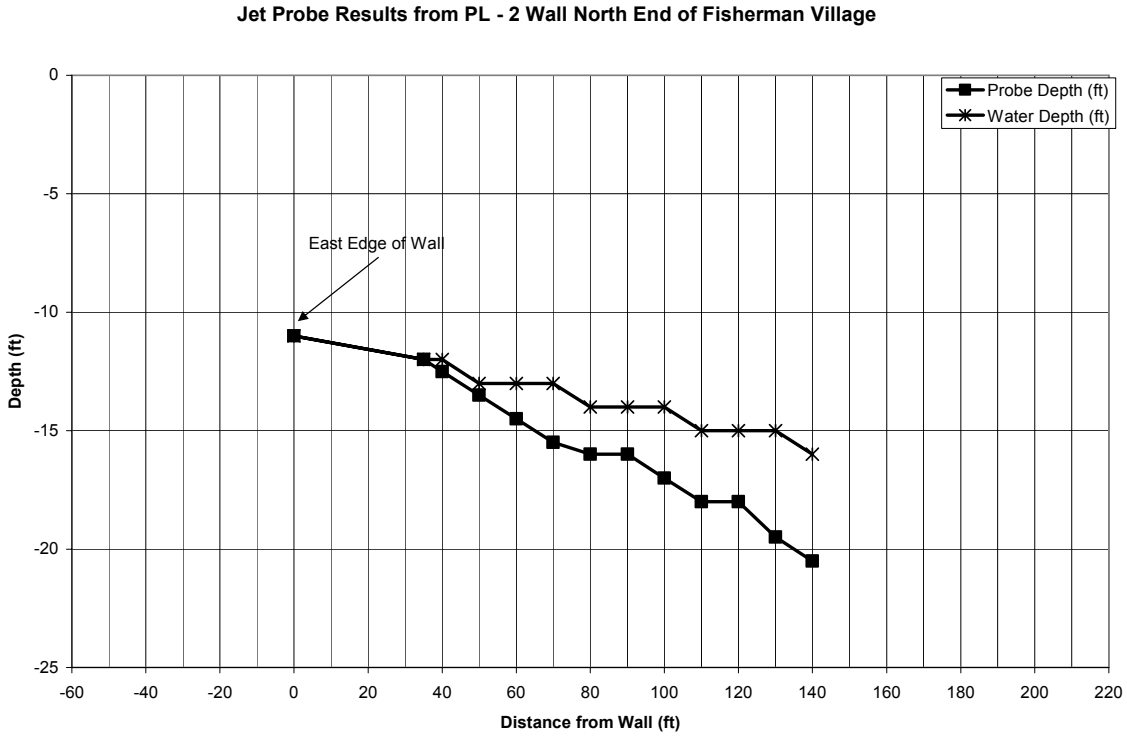


Figure 16. Jet Probe Data (continued)



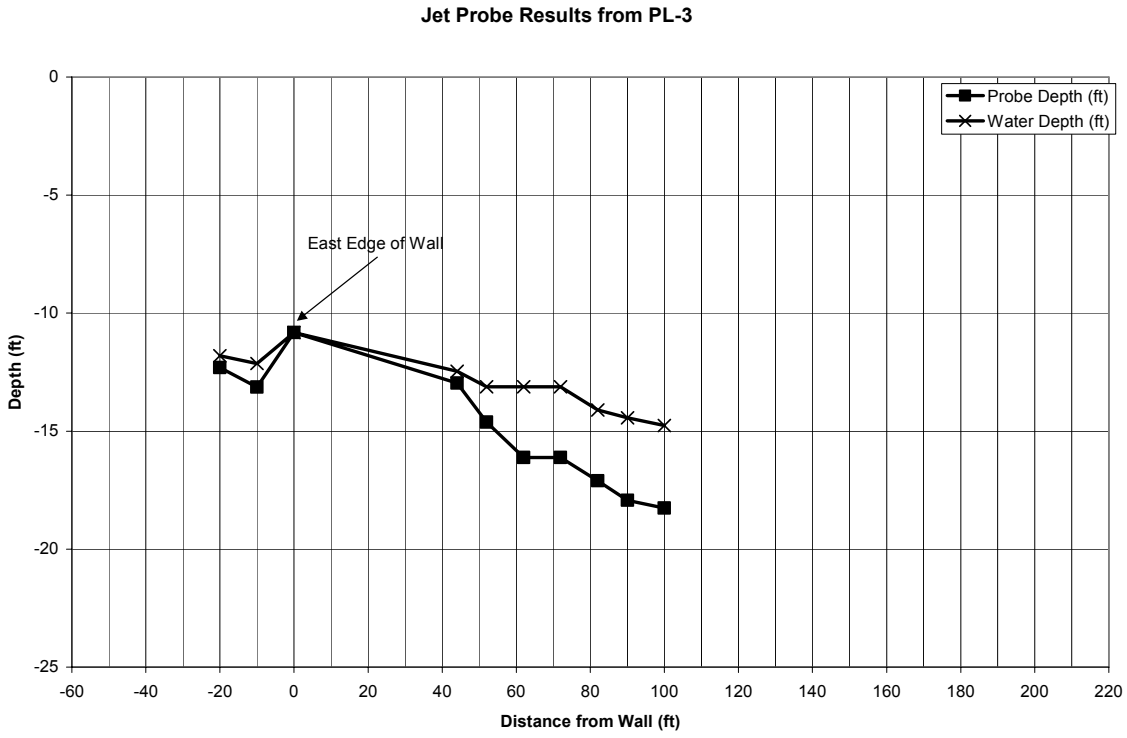
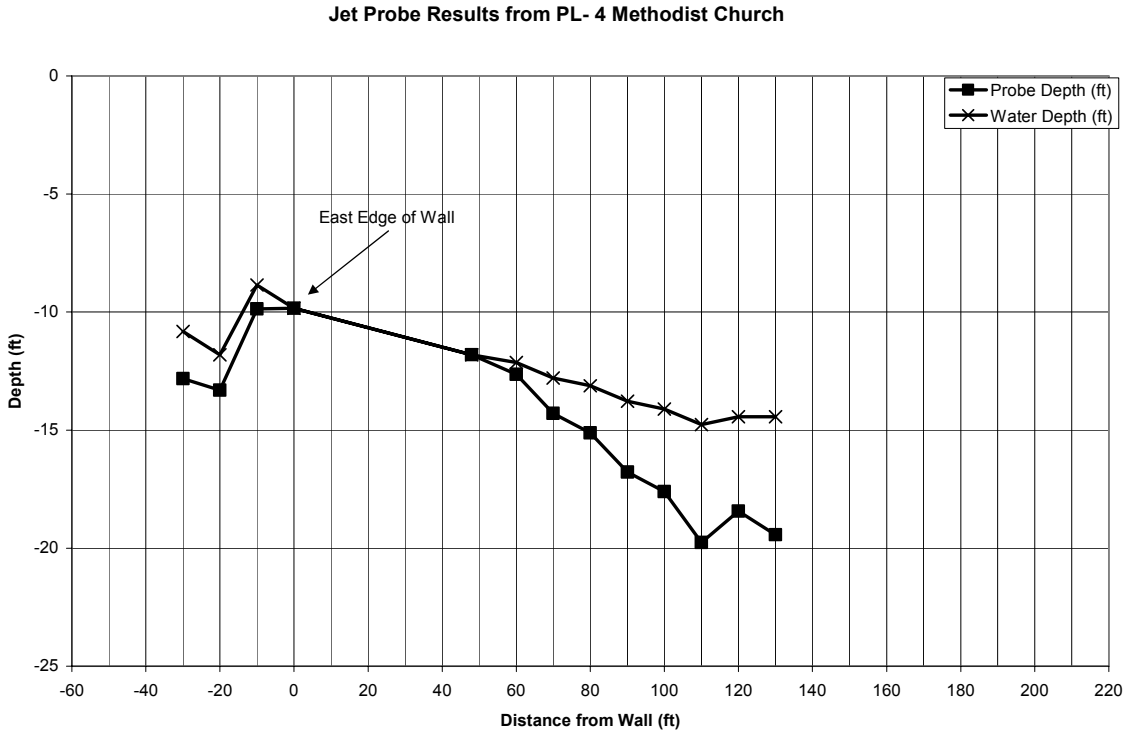


Figure 17. Jet Probe Data (continued)



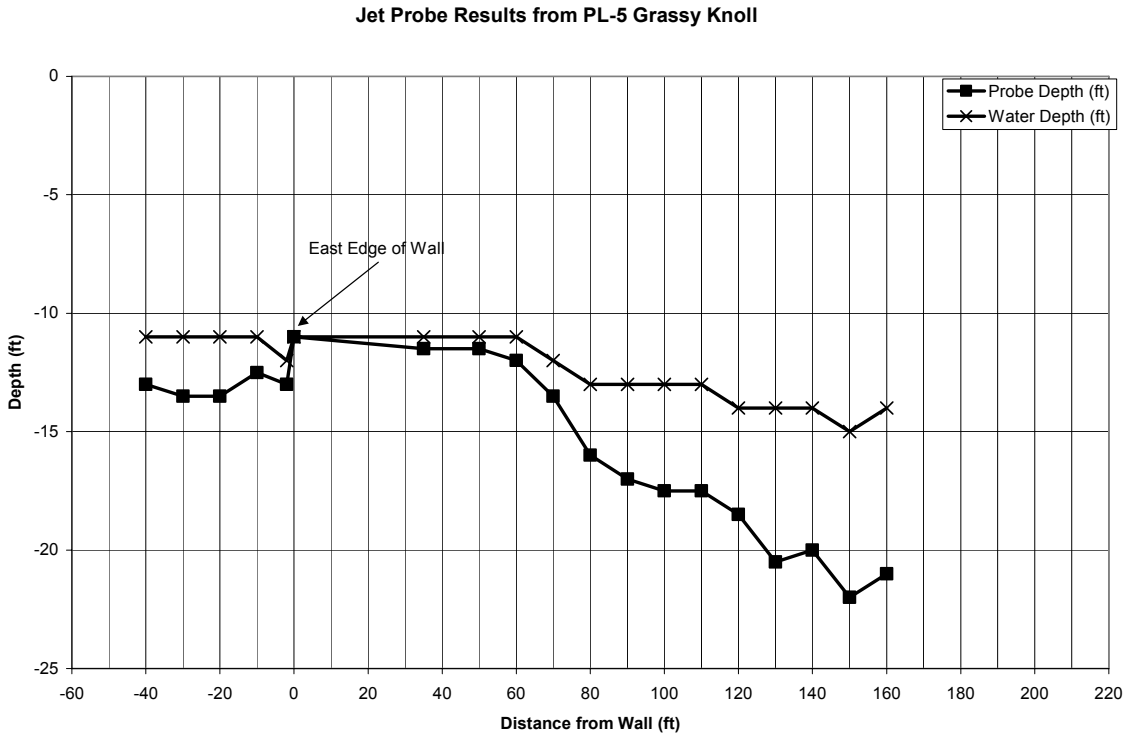
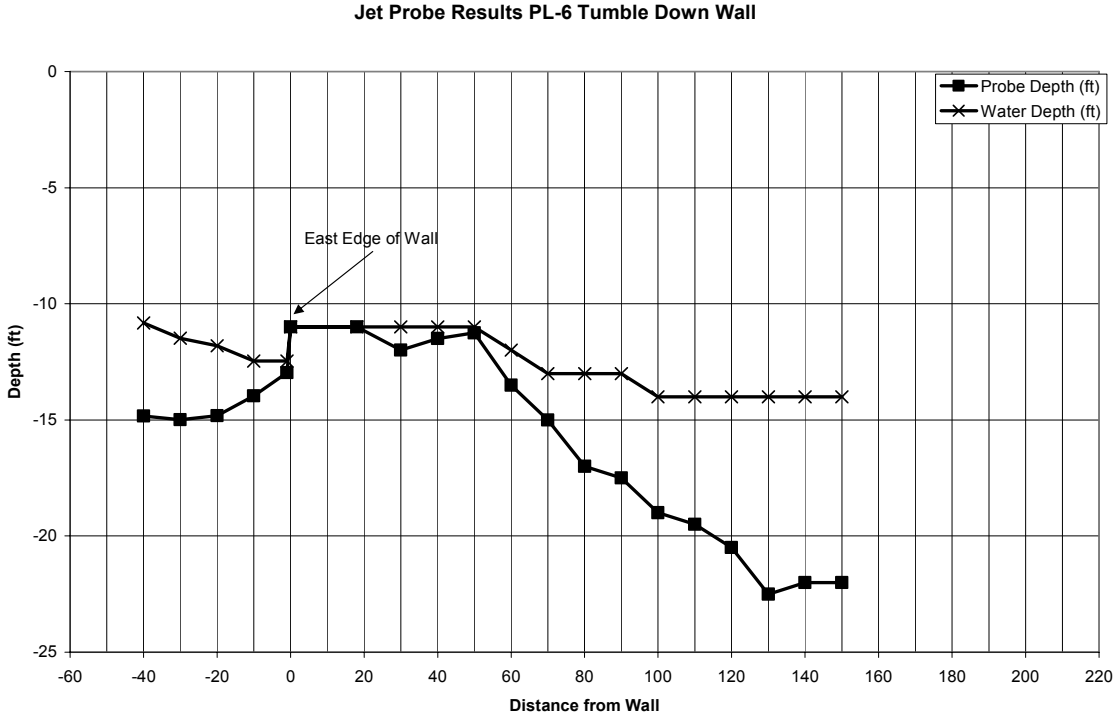


Figure 18. Jet Probe Data (continued)



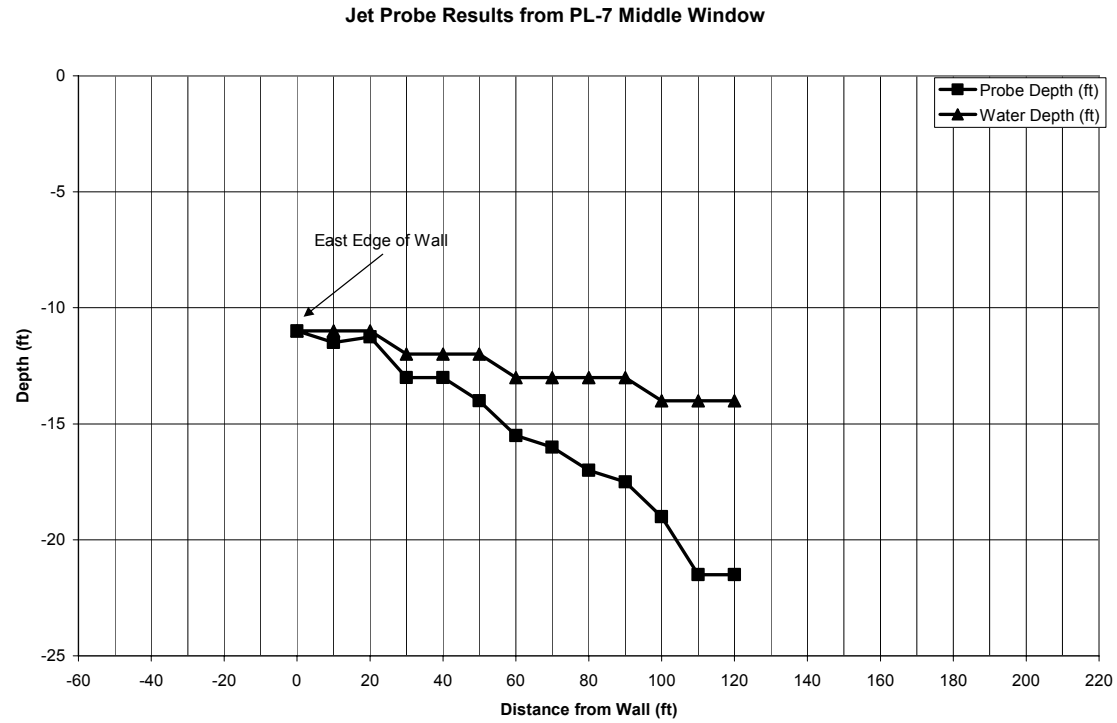


Figure 19. Jet Probe Data (continued)

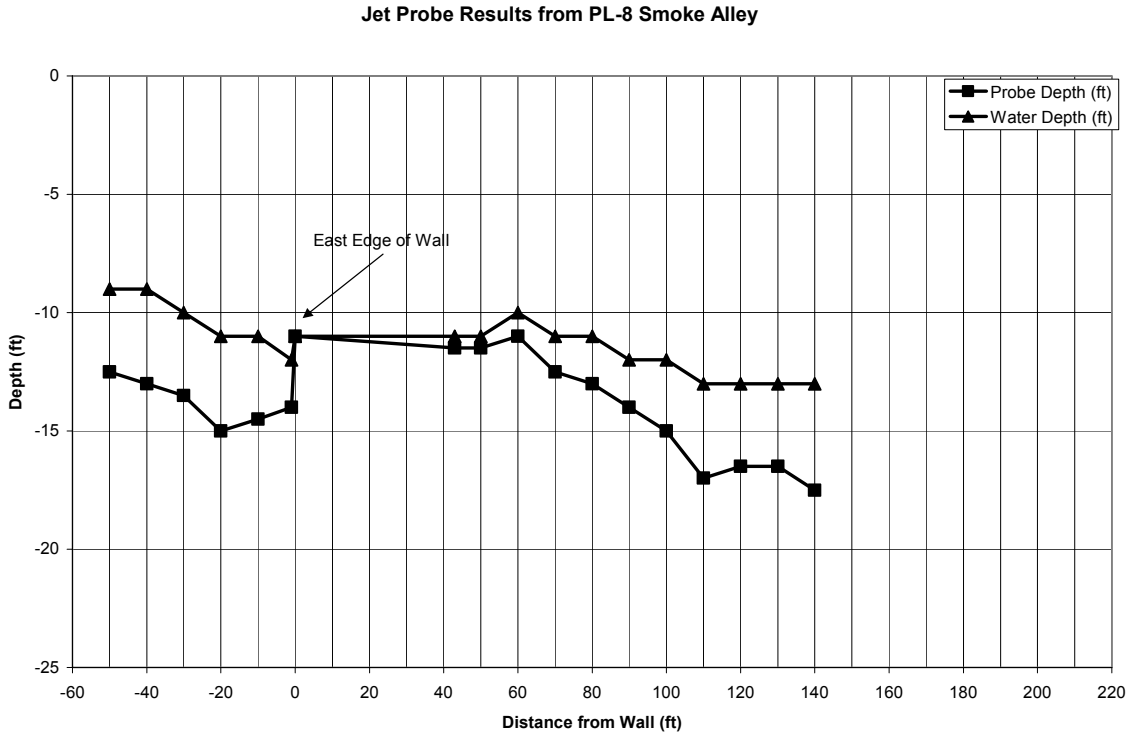


Figure 20. Jet Probe Data (continued)

Proposed Breakwater Design Layout

Based on the results of the beach profile surveys and jet probes, a design layout for three offshore breakwaters was developed. The Figure below shows the locations of the three proposed submerged artificial reef breakwaters relative to the profile lines, historic wall, depth contours and shoreline. Each of the 300-foot long 30-feet wide breakwater segments are constructed with 250 Goliath-size Reef Ball units, for a total of 750 units. In addition to reducing wave action to assist with beach stabilization, the artificial reef breakwaters will provide environmental enhancement and snorkel trails.

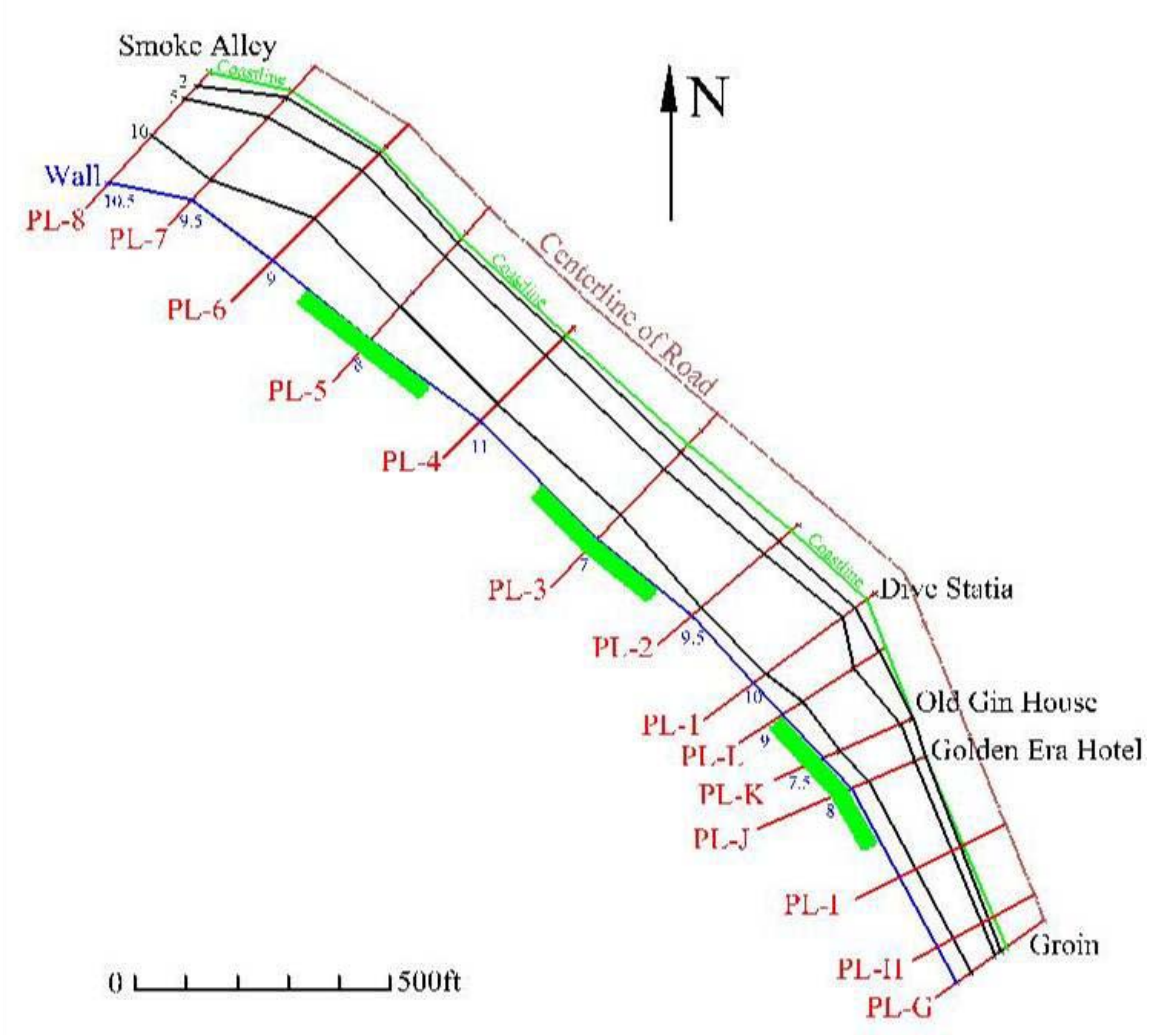


Figure 21. Locations of the 3 Proposed Submerged Artificial Reef Breakwaters

Details of the breakwaters are shown in the diagrams and photographs that follow, with the breakwaters approximately centered on Profile Lines K in the hotel area, Profile Line 3 north of Dive Statia and Profile Line 5 south of Smoke Alley. The areas in which the breakwaters are located are shown in the photographs on the following page.

Figure 22. Aerial View of the Locations for the 3 Submerged Breakwaters.

Figure 23. View North showing the Locations of the Center and Northern Breakwaters.

As shown in the photographs above, the proposed breakwaters are located immediately seaward of the historic wall in order to reduce cultural impacts, to take advantage of the shallower depths, and to provide an enhanced environmental and snorkeling reef in these areas. Detailed dimensions for each of the three breakwaters are shown in the figures on the following pages.

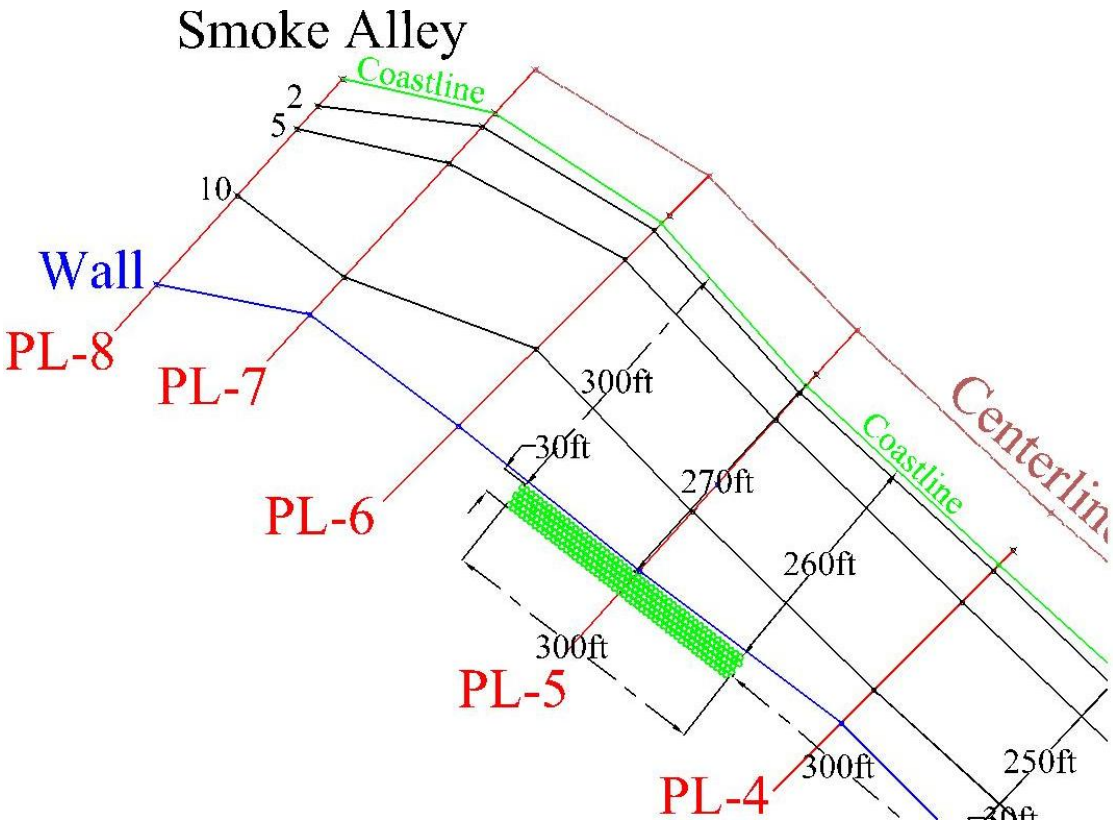


Figure 24. Northernmost Submerged Artificial Reef Breakwater

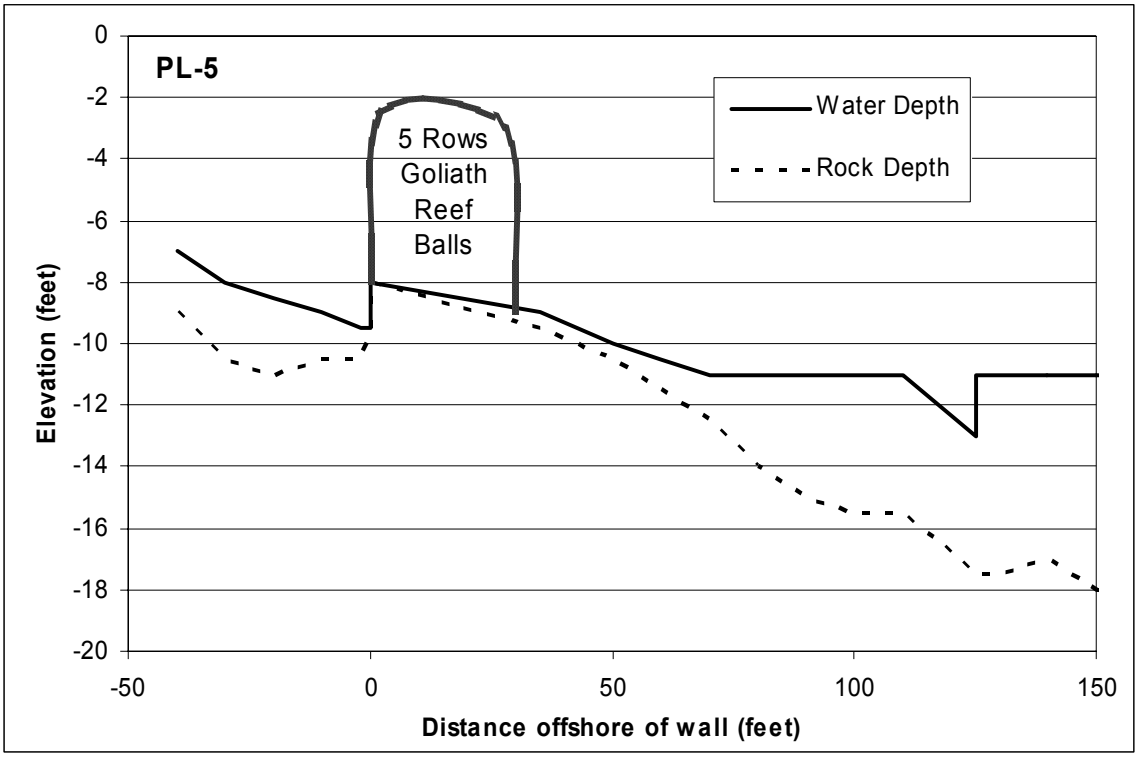


Figure 25. Profile View of Northern Breakwater – South of Smoke Alley.

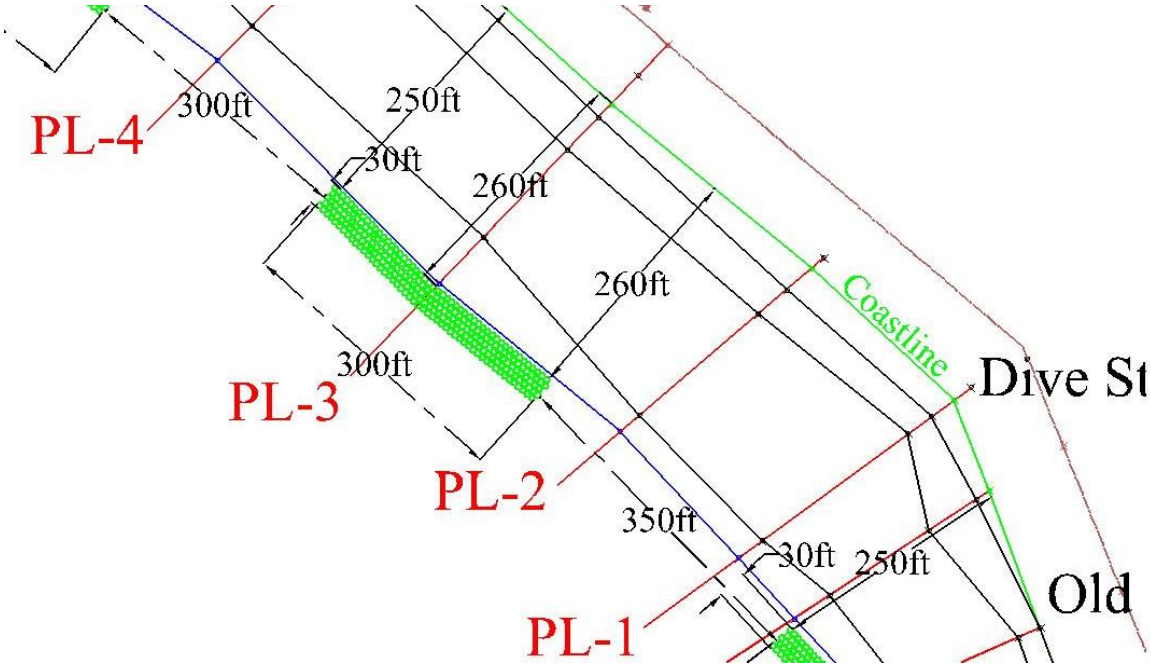


Figure 26. Center Submerged Artificial Reef Breakwater

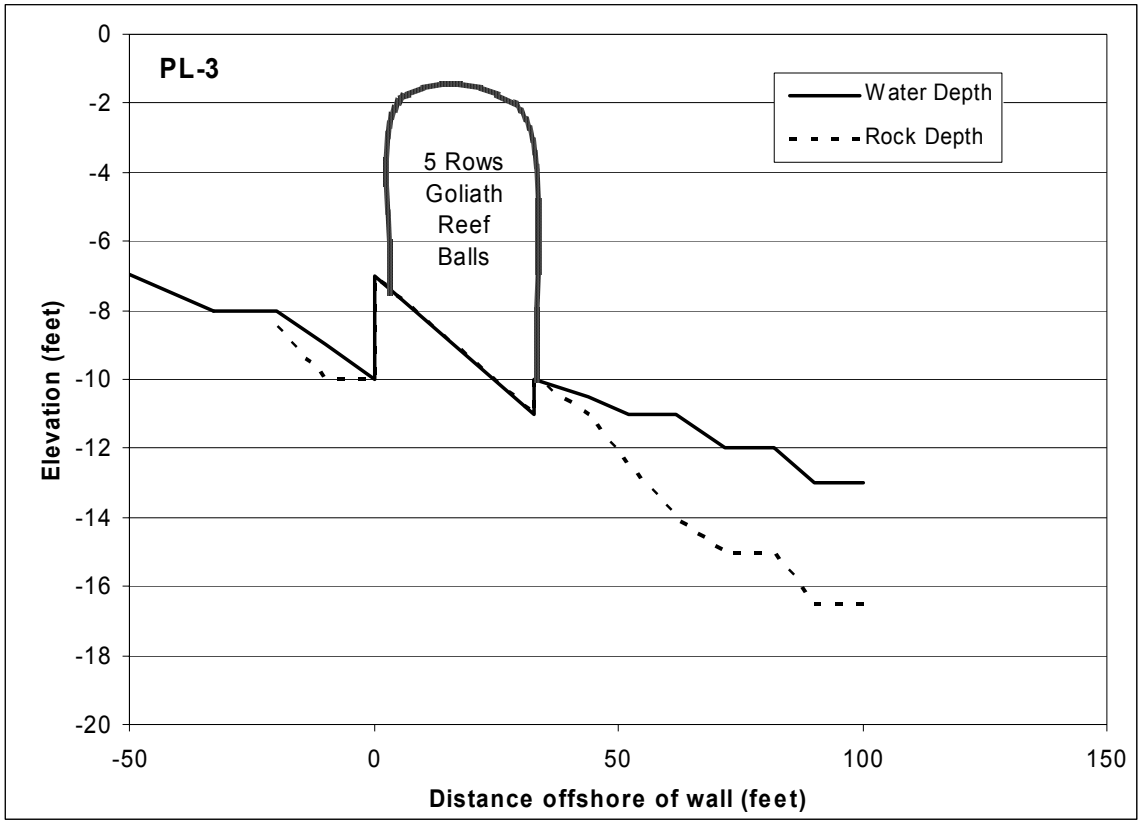


Figure 27. Profile View of Center Breakwater – North of Dive Statia

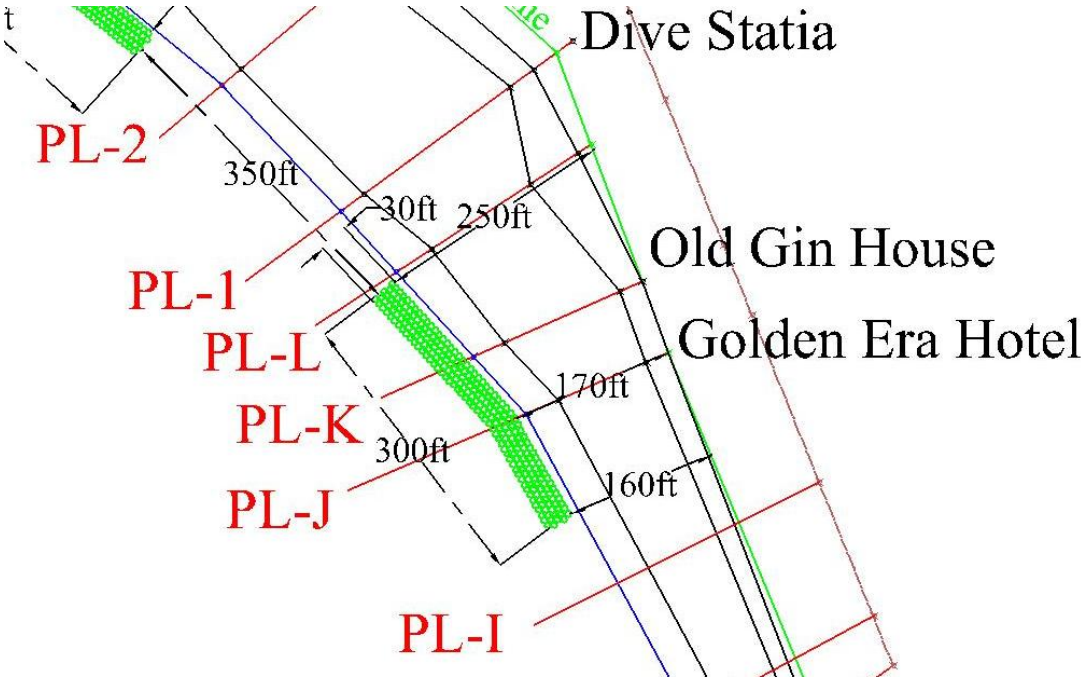


Figure 28. Submerged Artificial Reef Breakwater in the Hotel Area

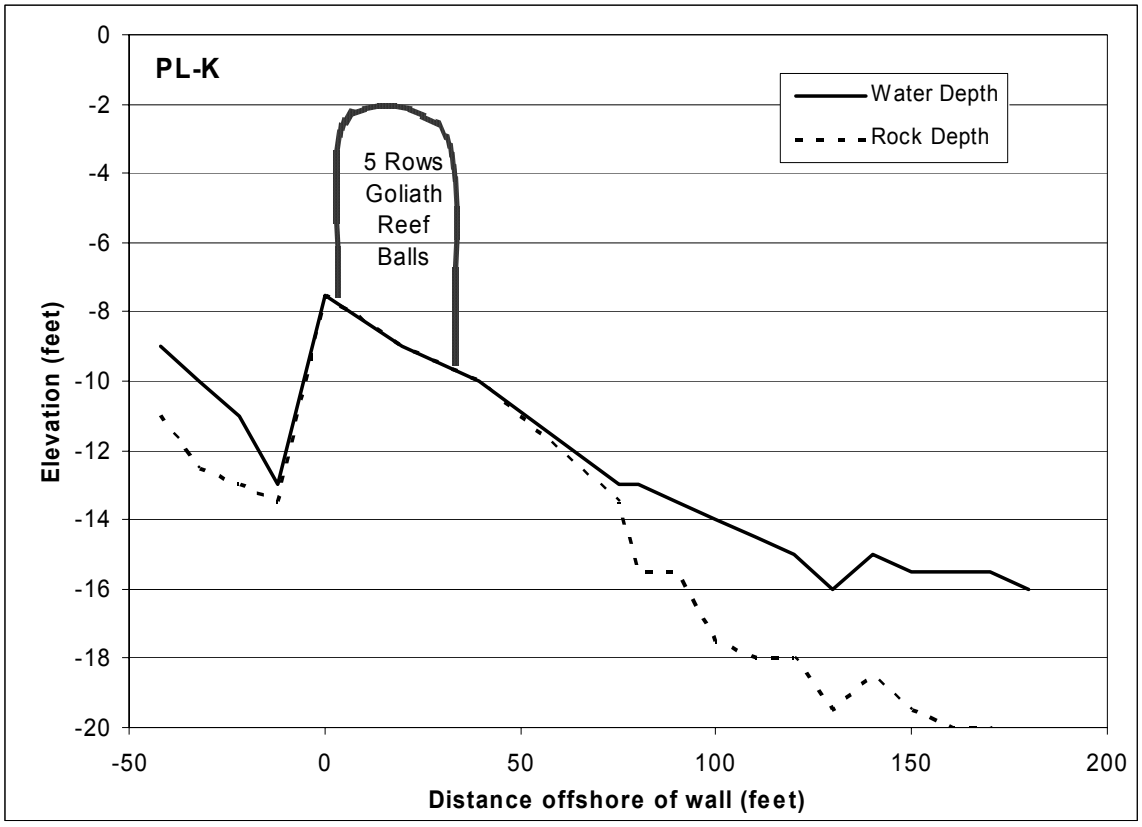


Figure 29. Profile View of Southern Breakwater – Hotel Area

Figure 30. Location of the Submerged Artificial Reef Breakwater in the Hotel Area

The photograph above shows the area in which the submerged artificial reef breakwater is proposed for the hotel zone. The breakwater is landward of the anchorage area, shown by the moored ships. The location is seaward of the historic wall, approximately 160 feet offshore at the southern end and 250 feet offshore at the northern end. The photographs below and on the following page are of the Grand Cayman breakwater, and shows what the 5-row Reef Ball breakwater will look like from above the water surface.

Figure 31. 5-Row Submerged Reef Ball Breakwater in Grand Cayman

Figure 32. 5-Row Submerged Reef Ball Breakwater in Grand Cayman (Reef Ball artificial reef is landward of deeper natural reef)

Proposed Beach Nourishment

The results of the jet probes show that substantial amounts of sand are located offshore of the historical wall. Locals report that sand was transported from the beach and deposited offshore from recent hurricanes. The jet probe data and graphs show that the sand thickness increases as you go offshore from the wall, and in water depths of 15 to 20 feet sand thickness of 3 to over 8 feet were measured. Sand samples taken during the jet probes show that all of the sand is identical to that on the beach, so that this offshore sand is an excellent source of beach sand.

It is recommended that the offshore sand be used for beach nourishment, so that an adequate recreational beach can be provided. This should be performed in conjunction with the breakwater fabrication and installation, to take advantage of the man-power and equipment already working in this area. In addition, it is preferable to perform the sand placement as soon after the installation of the breakwater as possible, in order to not disturb the marine growth that will be developing on the artificial breakwater units.

A major beach nourishment project would involve widening the beach substantially, to allow for future erosion losses. This would require a sand volume on the order of at least 500 cubic feet per foot of shoreline (47 cubic meters per meter). For this amount of sand were placed on the 1100 feet (330m) of shoreline length between PL-2 (Fisherman's Village) to PL-6 (south of Smoke Alley) would require a sand volume of 550,000 cubic feet = 15,600 cubic meters of sand. Placement of this large volume would require the use of a substantial dredge offshore.

The proposed artificial reef breakwaters are designed to assist with maintaining sand on the beach, as well as encouraging natural sand accretion on the beach due to the reduced wave action in the lee of the breakwaters. In order to have useable recreational beach as soon as possible, it is recommended that sand be added to the beach at the same time the breakwaters are deployed offshore.

In order to determine the minimum amount of sand that should be added to the beach, a comparison to the existing sand beach at Dive Statia (PL-1) is plotted in the graph below. The distance data for PL-3 are adjusted so that the position of the existing sand bottom offshore of PL-3 at elevation -3.3 feet (-1m) coincides with the -3.3 feet elevation on the PL-1 profile. This graph shows that the beach at PL-1 is as much as 20 feet (6m) wider and has an elevation that averages about 1 foot above the profile at PL-3 over a distance of approximately 50 feet. This is a cross-sectional area of 50 square feet which would be a sand volume of 50 cubic feet per foot of shoreline length (4.65 cubic meters per meter of shoreline). For this amount of sand were placed on the 1100 feet (335m) of shoreline length between PL-2 (Fisherman's Village) to PL-6 (south of Smoke Alley) would require a sand volume of 55,000 cubic feet = 1560 cubic meters of sand. This volume of sand could be placed using smaller equipment, such as a boat mounted pump. The beach would be built out 20 feet wider and 1 to 2 feet of sand thickness above the existing rocky shore.

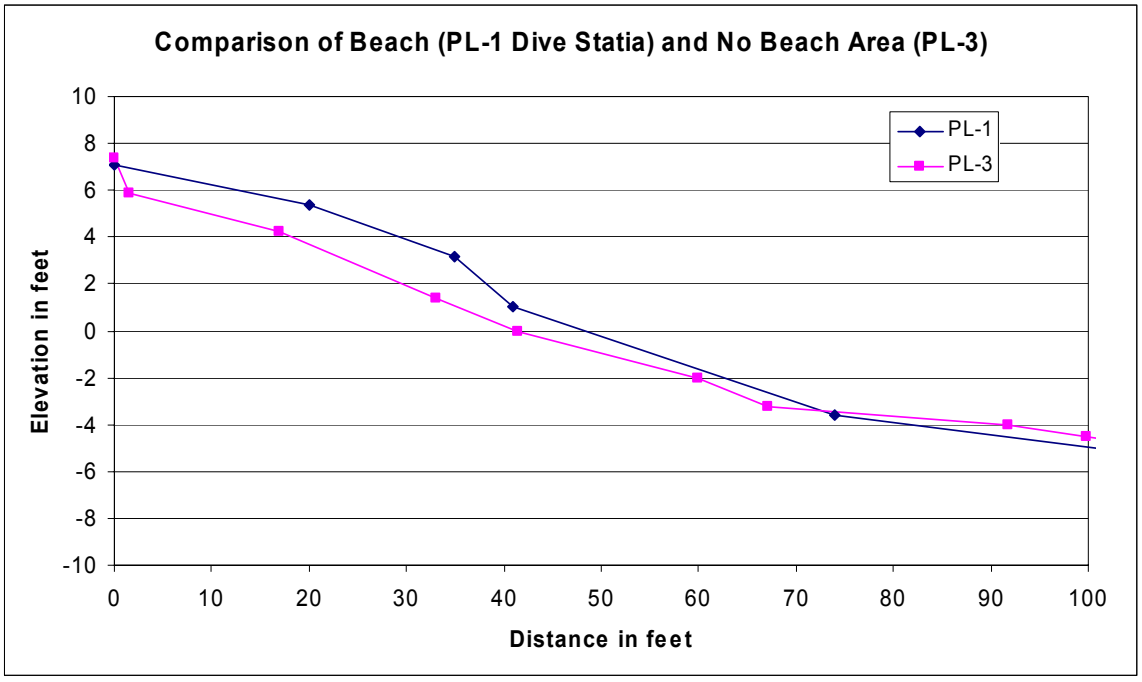


Figure 33. Comparison of Beach at PL-1 (Dive Statia) to No Beach at PL-3

Construction Activities

This section of the report describes the sequence of construction activities. There is room for the construction activities to be performed along the coastline on both sides of the road, as shown in the aerial photograph below. Molds for fabricating the Reef Ball units can be set up along the road with concrete delivered by trucks. A crane can be used to set the completed Reef Ball units out into the water, and then lift bags can be utilized to float the units above the bottom, with a small boat towing them out to the deployment site. The deployment site area is marked out in advance using steel rods and string on the bottom, and lines and buoys. Once the Reef Ball units are set in place, holes are drilled into the rock bottom so that fiberglass rods can be inserted through sleeves in the Reef Ball units and extend into the bottom to provide resistance of the units to sliding during storm events.

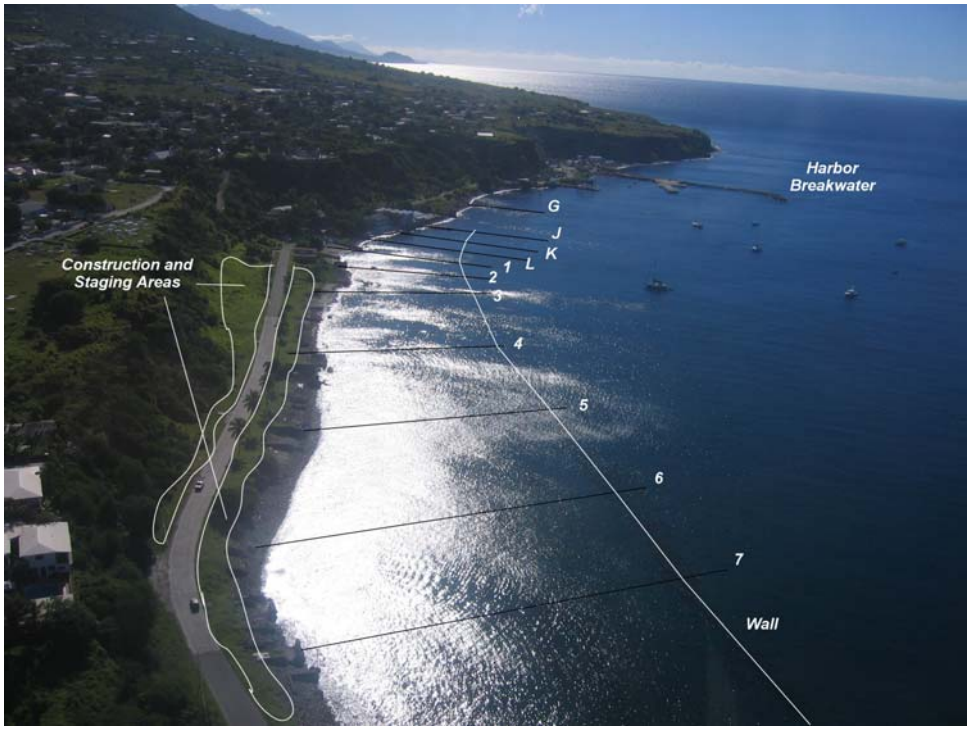


Figure 34. Locations of the Proposed Construction and Staging Areas

The first step is to order and ship the Reef Ball molds and supplies to Statia. The number of Reef Ball molds that are required depends on the time allotted for fabricating the units and number of personnel available. The process consists of setting up the molds, pouring concrete into the molds, and breaking down the molds. Each mold can be used to fabricate 2 units per day, using multiple bases for each mold. This requires taking the molds off completed units, setting them up for the next pour and having concrete delivered and put into the molds, and repeating this cycle once in the morning and again in the afternoon each day.

For example, using 10 molds and fabricating 2 units per day per mold would produce 20 units per day. This would require 37.5 days = 7.5 weeks to construct 750 reef units. However, as with any project, time is required to develop an efficient system, and delays will occur due to weather and other factors, so that a 3-month time period is a more realistic time estimate for this example. Other factors that will govern the construction time are an adequate supply and dependable delivery of concrete, concrete truck sizes, a sufficient number of laborers and the ability of the laborers to fabricate 2 units per day. Limitations in those factors could limit the production to one unit per mold per day.

The table below lists all of the available Reef Ball unit sizes. Based on the survey data the tallest Reef Ball units, the Goliath Balls, will be required to construct the breakwaters. Using 750 Goliath Balls, the total volume of concrete required is 750 cubic meters = 980 cubic yards, or approximately 1,000 cubic yards of concrete.

Table 2. Reef Ball™ Sizes, Weights, Volume & Number of Holes

Style	Width	Height	Weight	Concrete Volume	# Holes
Goliath Ball	6 feet (1.83m)	5 feet (1.52m)	4,000-6,000 lbs (1800-2700 kg)	1.3 yard (1.0 m^3)	25-40
Super Ball	6 feet (1.83m)	4.5 feet (1.37m)	4,000-6,000 lbs (1800-2700 kg)	1.3 yard (1.0 m^3)	22-34
Ultra Ball	5.5 feet (1.83m)	4.3 feet (1.31m)	3,500-4,500 lbs (1600-2000 kg)	0.9 yard (0.7m^3)	22-34
Reef Ball	6 feet (1.83m)	3.8 feet (1.22m)	3000-4200 lbs (1350-1900 kg)	0.75 yard (0.6m^3)	22-34
Pallet Ball	4 feet (1.22m)	2.9 feet (0.9m)	1500-2200 lbs (700-1000 kg)	0.33 yard (0.25m^3)	17-24
Bay Ball	3 feet (0.9m)	2 feet (0.61m)	375-750 lbs (170-340 kg)	0.10 yard (0.08m^3)	11-16
Mini-Bay Ball	2.5 feet (0.76m)	1.75 feet (0.53m)	150-200 lbs (70-90 kg)	less than four 50 lb bags	8-12
Lo-Pro Ball	2 feet (0.61m)	1.5 feet (0.46m)	80-130 lbs (35-60 kg)	less than two 50 lb bags	6-10
Oyster Ball	1.5 feet (0.46m)	1 foot (0.30m)	30-45 lbs (15-20 kg)	less than one 50 lb bag	6-8

Another factor to optimize the number of molds is to consider the available sizes of the concrete trucks, so that all of the concrete delivered to the site can be utilized. Using 10 and 10.5 cubic yard trucks would provide enough concrete for 7.7 and 8 Goliath Balls, respectively. Therefore having 8, 15, 23, or 30 molds would utilize all of the concrete that can be delivered by 1, 2, 3 or 4 trucks at a time, as long as sufficient supplies of concrete and man-power are available.

Heavy construction equipment required at the fabrication site includes front end loaders to move the completed reef units around and a crane to set the units out into the water. Prices of concrete and heavy equipment were obtained from Gordon Clark at Trico Supplies NV, and are summarized in the table below.

Table 3. Concrete and Equipment Prices (from Trico Suppies Nov. 2004)

Item	Cost/Size
Concrete 3,000 to 4,000 psi	US$100 to 130 per cubic yard
Concrete trucks	10 and 10.5 cubic yard trucks
Front end loaders	US$75 to 100 per hour
Utility loader with fork or bucket	US$75 per hour
20-ton crane	US$100 per hour
35-ton crane	US$150 per hour

In order to commence this project, contracts will need to be made between the Reef Beach Company and local contractors. Depending on the availability on Statia of manpower, equipment and concrete supply, the most cost effective work plan can be formulated, and the appropriate number of molds and other supplies can be determined. Project supervisors from Reef Beach will be on-site to oversee all mobilization, fabrication, staging and deployment work. Based on similar projects constructed in the Caribbean, the following is a cost estimate for this project:

Table 4. Project Cost Estimates

Item	Cost (US$)
Mobilization – includes cost of purchasing and shipping molds, supplies and equipment to Statia	93,500
Fabrication – includes the cost of manpower, heavy equipment, concrete and supervision for fabricating artificial reef units and staging on land	645,400
Deployment – includes the cost of manpower, heavy equipment, supplies and supervision for deploying artificial reef units offshore	511,900
Coral work – includes cost of manpower, supplies and equipment for coral propagation on the artificial reef units	59,000
Monitoring – includes engineering and scientific monitoring of project construction, project completion and post-project monitoring annually for 2 years	51,400
TOTAL PROJECT COST =	1,361,200