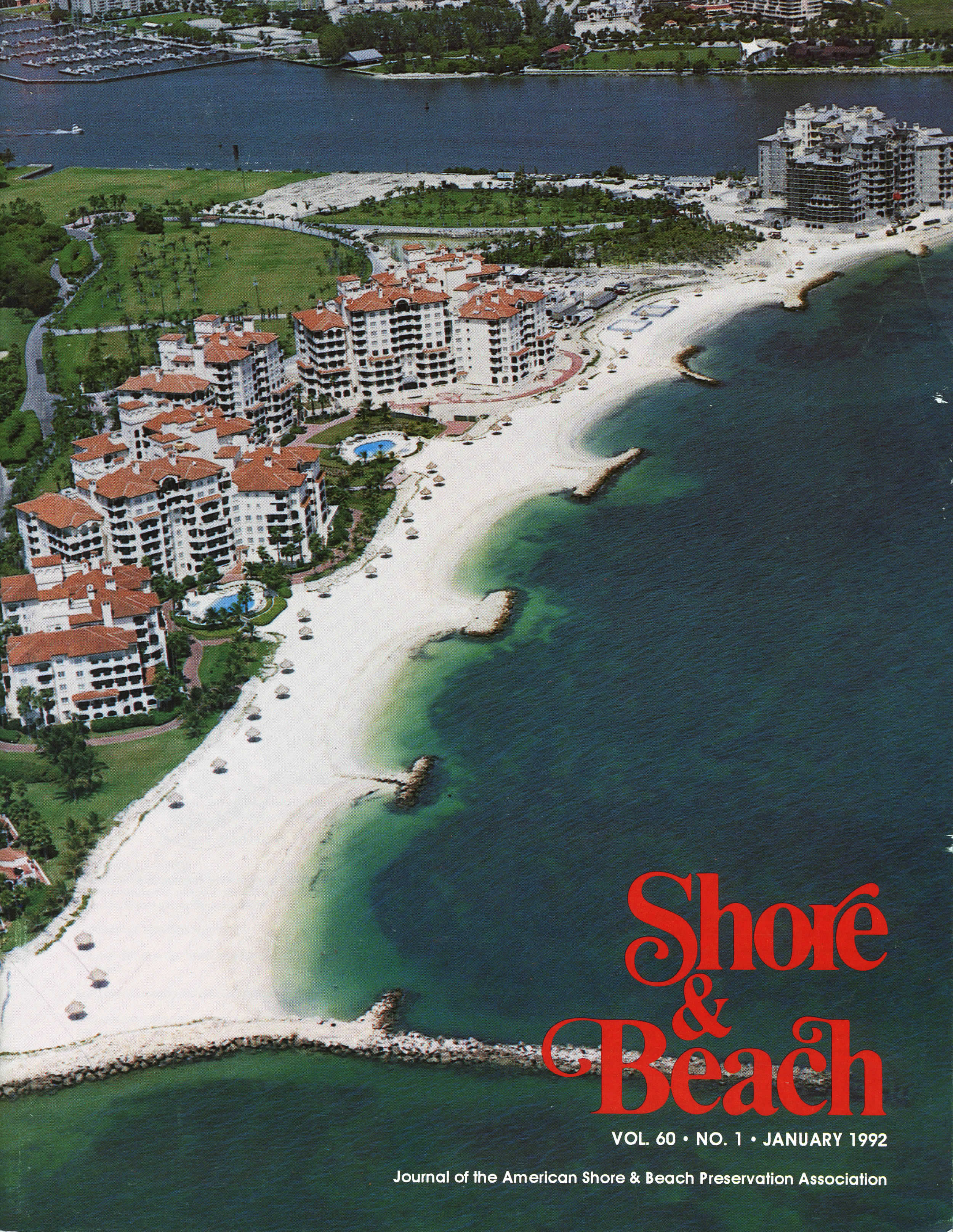

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Aragonite Beachfill at Fisher Island, Florida

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ABSTRACT:

IN THE FIRST FULL-SCALE use in the United States of imported aragonite sand for beach restoration, approximately 23,000 m^3 of fill were barged from the Bahamas, placed by truck, and stabilized by seven rock structures along 620 m of shoreline at Fisher Island, Florida. The structures emulate a Mediterranean-style design and are "tuned" to the incident wave field to minimize fill losses and impacts to nearshore sea grass beds. Six-month monitoring results suggest that the project is performing as per predictions. No adverse impacts nor physical decay of the aragonite have been observed to date.

INTRODUCTION

Oolitic aragonite sand is calcium carbonate crystallized in smooth ellipsoidal shapes and is the primary constituent of most Caribbean beaches. Aragonite commercially mined in the Bahamas has been proposed as a candidate source of compatible beach fill for south Florida since the early 1960's. Until last year, however, the material has never been deemed sufficiently cost effective in comparison to locally dredged offshore sands to justify its actual application.

Twenty-five years ago *Shore and Beach* published the only known reference to a trial use of aragonite upon a Florida Beach[6]. This was a small test project involving truck-haul placement of about 600 m^3 at MHW at Pepper Park, three kilometers north of Ft. Pierce Inlet, Florida. The results of this small-scale test were inconclusive due to the small quantity of fill and inadequate controls.

Recently, an ideal opportunity for a full-scale use of aragonite beach fill arose at Fisher Island, Florida, immediately south of Miami Beach (Figure 1). A project involving about 23,000 m^3 of aragonite imported from the Bahamas was completed along this island's Atlantic shoreline in April 1991. Fisher Island is a private residential and resort development consisting predominately of multi-family dwellings. The local scarcity and environmental sensitivity of upland and offshore sand sources, the developer's interest in creating a unique and attractive beachfront, and the relatively modest size of the beach fill requirement made imported Bahamian aragonite an excellent candidate for beach nourishment material at the site.

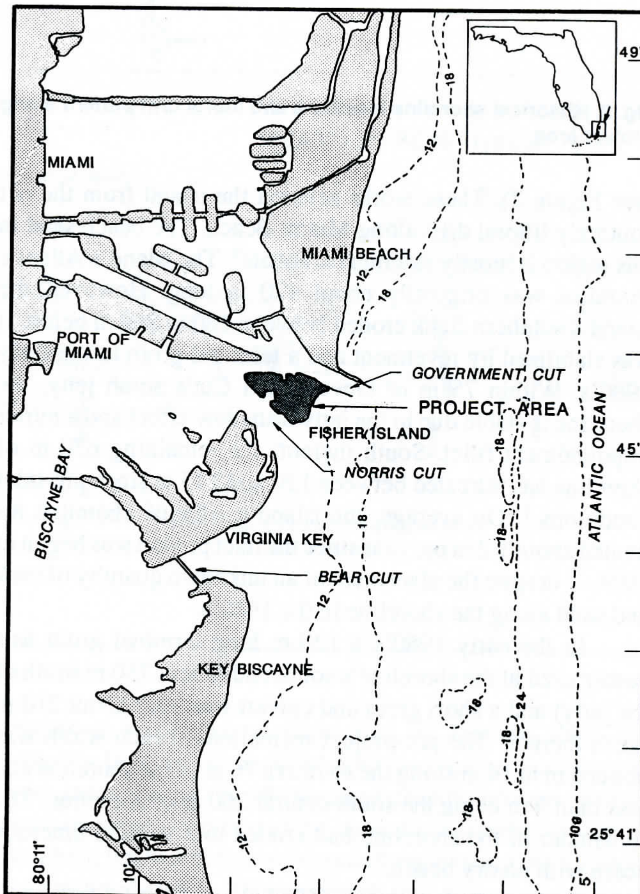

Fig. 1. Locaton map of project area.

The project also includes an unusual use of structures intended, in part, to accent the upland's elegant Mediterranean architecture. The initial need for structural stabilization was obviated by the site's littoral isolation whereby sand is readily lost from the island but not recovered. The final planform-design of the structures and the fill evolved during the permitting process when it was found that stability was also needed to minimize encroachment of the fill upon environmentally sensitive nearshore seagrass beds.

SITE CHARACTERISTICS

Fisher Island became an island by the excavation and stabilization of Government Cut inlet between 1904 and 1929

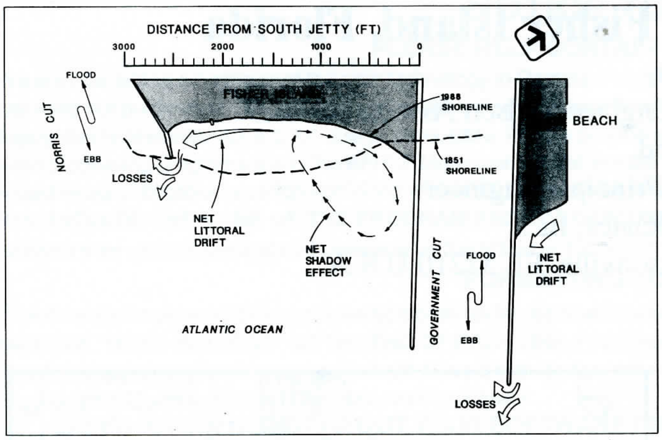

Fig. 2. Historical shoreline locations and litoral drift pattern along project area.

(see Figure 2). These works severed the island from the net southerly littoral drift along Miami Beach. The beach sand in this region is mostly calcium carbonate[8]. The island's Atlantic shoreline was originally about 920 m long. However, the island's southern flank eroded between 180 to 260 m before it was stabilized by revetment and a terminal groin in the early 1980's. Within 75 m of Government Cut's south jetty, the shoreline is stable due to the jetty's shadow effect and a minor impoundment fillet. South thereof, the remaining 670 m of shoreline has retreated between 120 and 145 m since pre-inlet conditions [1]. On average, the island's Atlantic shoreline retreated about 1.2 m per year since the inlet project was begun in 1904 — despite the placement of an unknown quantity of rock and sand along the shoreline in the 1940's.

In the early 1980's a 120-m long terminal groin was constructed at the shoreline's south end (about 750 m south of the jetty) and a short groin and culvert was built about 210 m north thereof. The pre-project recreational beach width was about 6 m to 14 m along the southern 76 m of the shoreline and less than 3 m along the south-central 260 m of shoreline. The remainder of the shoreline had eroded to a vertical limerock scarp with no dry beach.

Seagrass beds were identified about 40 m from the pre-project MHWL along the southern half of the shoreline, and in scattered patches within 15 to 27 m of the MHWL along the northern half. No threatened nor endangered species were noted along the project area; and sea turtle nesting was thought to be rare due to the lack of sandy beaches [5].

Grid-based wave refraction analysis of the area suggested that the shadow effect of Government Cut and its jetties extends to between 150 m and 460 m south of the south jetty. A strong gradient exists beginning 460 m south of the jetty where the net southerly littoral drift potential rapidly accelerates to perhaps 90,000 m^3/yr towards the island's southern end [1].

Material eroded from the island's southern shoreline was partially impounded against the southern terminal groin by the dominant northerly wave energy, eventually bypassed to Norris Cut and apparently lost to tidal currents. Southerly wave energy transported existing sand northwards — where it was partially impounded against the south jetty or circulated clockwise in the jetty's lee and returned to the shoreline about 460 m south of the jetty.

Government Cut effectively precludes sediment from naturally reaching Fisher Island from Miami Beach (located to the north). Norris Cut and the island's southern terminal groin, in addition to the net southerly drift, restricts the sediment supply from Virginia Key (located to the south).

Overall, then, Fisher Island represents a more-or-less isolated littoral cell. This required that fairly rigorous stabilization be employed to ensure a reasonable life for any beach restoration project south of the jetties. The area's littoral isolation also meant that structural stabilization of the beach fill would pose minimal adverse impacts upon adjacent (downdrift) beaches.

It was anticipated that obtaining permits for a typical hydraulic dredge and fill project at this site would be difficult. This was primarily because of perceived potential impacts of hydraulic filling near the local seagrass beds. It was also believed that permitting offshore borrow activities for a private project would be difficult at an area where available sand is becoming "scarce" in the face of current public projects at nearby Miami Beach and Key Biscayne [3]. Offshore borrowing also approached uneconomical costs because of the small fill volumes required for the project. Suitable upland sources were likewise scarce and expensive.

On the other hand, aragonite could be barged from the Bahamas at a competitive price and placed in a dry state. This would eliminate potential impacts of offshore dredging and would minimize nearshore turbidity during construction. The project's uniqueness and the natural brilliance of the material would also strongly accent the character of the upland resort development.

OOLITIC ARAGONITE AS BEACH FILL

Oolitic aragonite is composed of calcium carbonate crystallized in the orthorhombic crystal system which occurs in the form of smooth spherical or ellipsoidal shapes [6]. Aragonite is thought to precipitate from seawater due to a biologically-induced increase in pH [7], and/or due to colder oceanic waters which flow onto the warm, shallow Bahama Banks [9,11]. Carbonate beaches which are dominated by aragonite do not occur in Florida, but aragonite is a common component of many subtropical Florida beaches [16]. The beaches and seabeds of the Bahamas, on the other hand, are composed primarily of aragonite.

Since the late 1960's, aragonite has been routinely exported to the United States for industrial uses such as cement, agricultural feed and lime, filtration media, glass manufacturing, and flue-gas desulfurization.

From settling tube comparisons [4], aragonite potentially behaves as a quartz sand with an equivalent median grain size which is 1.36 times coarser than that measured by sieve analysis

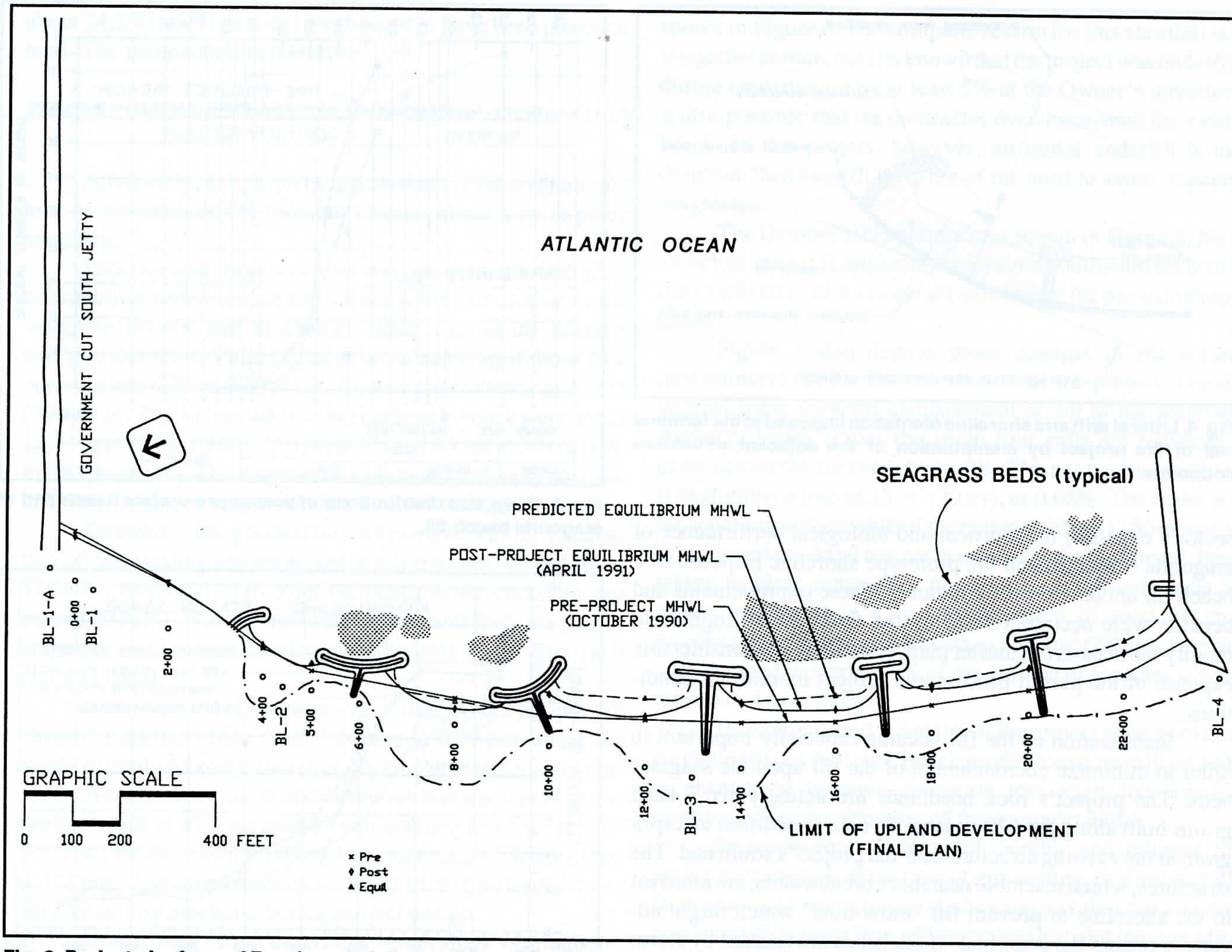

Fig. 3. Project planform of Beach restoration at Fisher Island, Florida.

(Olsen and Bodge 1991)[12].

Saltwater wave tank tests conducted by CERC (Monroe 1969)[10] and unpublished results from laboratory tests conducted by the U.S. Army Corps of Engineers[18] concluded that aragonite sand "appears suitable for beach renourishment material." The former tests noted slightly less erosion of the aragonite than similar-size quartz sand at the still water level. The latter tests included abrasion evaluation, wet/dry testing in fresh and sea water, solution testing for acid rain conditions, detail microscopic constituent determination, x-ray diffraction analysis, bulk specific gravity, and absorption.

Nonetheless, concerns remain regarding aragonite's potential in the prototype for abrasion, dissolution, cementation, and effects to benthic and pelagic assemblages. These properties and their potential effects upon the project's success were discussed by Olsen and Bodge[12] prior to the completion of the project.

PROJECT DESIGN

Permit applications for an aragonite beach restoration project at Fisher Island were filed by January 1989. The project's final design evolved after two major modifications were made during the 18-month permitting process. Briefly, these included alteration of the upland master plan to shift the beach fill landward, thus substantially relocating the fill above the existing MHWL. To accomplish this, a landscaping revetment was scalloped around the ocean front development to create pocket beaches which would be stabilized by the project's artificial rock headlands (Figure 3). The existing rock, cobble, and sand above +0.6 m NGVD (i.e., above MHW) would be excavated and replaced by aragonite fill to a berm elevation of +1.5 to +1.8 m with a width of 12 to 30 meters. (Details of the project's evolution are described in Bodge 1992)[2].

In the present case, the permitting process resulted in significant improvements to the project which may not have been otherwise possible without the interests brought to bear by each of the involved parties. The modified design minimized potential impacts to near shore seagrasses and biota, increased fill stability, and enhanced the oceanfront's Mediterranean character with a curvilinear plan form and rock headlands. The project also offers the opportunity to study (at the private

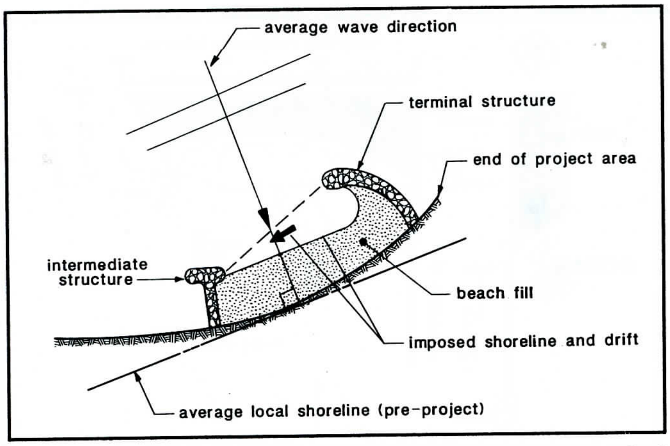

Fig. 4. Littoral drift and shoreline oientation imposed at the terminal cell of the project by manipulation of the adjacent structures endpoints.

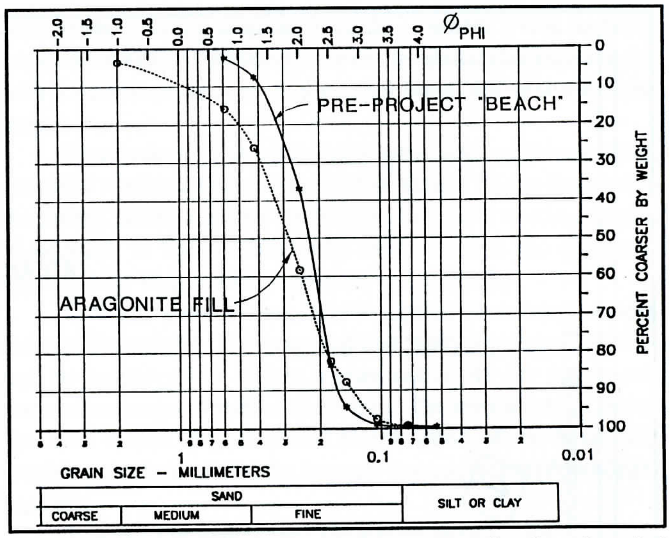

Fig. 5. Grain size distributions of scarce pre-project beach and of aragonite beach fill.

sector's expense) the physical and biological performance of aragonite beach fill and the prototype shoreline response of a beach fill amidst "tuned" structures. These improvements and benefits were accommodated by the Owner's willingness to modify the oceanfront master plan, and to bear the considerable expense of the permit process and project monitoring conditions.

Stabilization of the fill became especially important in order to minimize encroachment of the fill upon the seagrass beds. The project's rock headlands are actually six T-head groins built along the 620-m long fill area in addition to a spur groin at the existing structure near the project's south end. The structures, which resemble nearshore breakwaters, are attached to the shoreline to prevent fill "blow-outs" which might adversely impact the grass beds if the heads are flanked by storm waves and currents.

The placement and lengths of the heads were in part determined by the locations of seagrass patches which were to be protected. The orientation of the heads was also "tuned" to the incident wave energy to increase fill stability[12]. Specifically, the endpoints of the structure's heads which bordered each cell were located so that a line between the heads would form a specified angle relative to the average *wave* angle (Figure 4). This specified angle was determined for each cell in order to impose an average net drift direction and magnitude within the cell. This, in turn, had been pre-determined to optimize fill stability. That is, a slight northerly drift was imposed at the project's *south* end, and a stronger southerly drift was imposed at the project's *north* end within the jetty shadow. No net drift direction was imposed along the center of the project.

The roots of this simple design process — and the prediction of the equilibrium planform which would result from the design — were inspired by classic headland and spiral-bay behavior[13,16,19] and reinforced by descriptions of such structures in eastern Europe [15].

PROJECT CONSTRUCTION

Construction began in December 1990 and was mostly

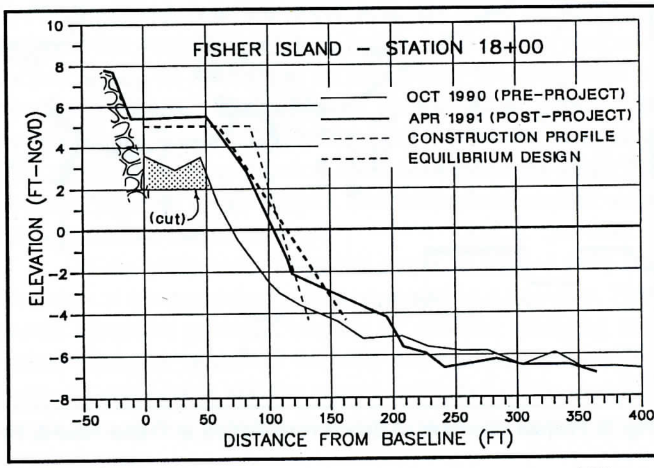

Fig. 6. Pre- and Post-project beach profiles near center of fill area.

completed by March, 1991. At least 15,300 m^3 (20,000 cy) of rock, sand, and debris were initially excavated across the project planform above MHW; however, unexpected nearshore sands continually migrated shoreward to fill the excavated berm. The rock structures were built after the berm excavation and prior to beach fill placement.

The aragonite was barged 100 km (60 miles) one-way to the site in 1800 metric ton (2000-t) loads from Marcona Ocean Industries' mining operation at Ocean Cay, Bahamas. The aragonite was off-loaded by a conveyor directly into dump trucks at a berth on the island's north side, and was then trucked to the beach about 800 meters (1/2-mile) away.

Compaction - By correlating post-construction aerial photography and surveys from April, 1991, the in-place aragonite fill volume was computed as 19,130 m^3 (25,000 cy). Records show that 42,950 short "natural" tons were imported. A short "natural" ton is 907 kg (2000 lbs) and includes 6% moisture (characteristic of dredged aragonite after at least 24 hours' stockpile). It is assumed by Marcona to correspond to about 0.57 m^3 (0.74 cy) in a natural, non- compacted state. Hence, about 24,330 m³ (31,800 cy) are thought to have been placed in total. The compaction is therefore:

$$\frac{\text{PLACED VOLUME - INPLACE VOLUME}}{\text{PLACED VOLUME}} = \frac{24330\,m^3 - 19130\,m^3}{24330\,m^3} = 21.4\%$$

Alternately, this project suggests that 1.72 short "natural" tons (which include 6% moisture) equals about 1 cy in-place aragonite.

Penetrometer measurements taken about one month after construction yield compaction values which are similar at the aragonite fill site and at another beach site on the island's southern shoreline. Values in the aragonite averaged about 20.7 bar at 15 cm (275 to 325 psi at 6"), and about 48 bar at 30 cm (700 psi at 12"). Values at the other carbonate beach were about 22.4 bar at 15 cm (300 to 350 psi at 6") and 43 bar at 30 cm (600 to 650 psi at 12"). The aragonite is said to be surficially soft and difficult for non- tracked vehicles to drive through.

Turbidity - The greatest turbidity source was the excavation of the existing shoreline and wash from the placed rock. Turbidity beyond 150 m from the beach never exceeded nor neared 29 NTU. White cloudiness in the water from the placed aragonite was localized and vanished within hours after each cell was filled.

Grain Size - Median grain size of the limited, pre-project "beach" material varied from 0.24 mm to 0.21 mm along the north/ central and south shoreline segments, respectively (Figure 5). A composite grain size distribution taken across the post-project beach profile suggests a median diameter of about 0.27 mm with 3% finer than 0.107 mm and less than 0.5% finer than 0.074 mm. The distribution is identical to that measured from the Ocean Cay stockpile during project design.

Beach Slope - Data describing beach slope vs. aragonite grain size were unavailable for project design. Surveys of Bahamian beaches revealed an "active" profile slope below MHW and above -6 ft MTL of about 1:7. However, these beaches were composed of very coarse, well-sorted aragonite with median grain size $d_{50} > 0.5$ mm.

Field data correlating median grain size and foreshore slope reflect quartz/feldspar beaches[17]. Since aragonite is thought to behave like quartz which is 1.36 times greater in size, the 0.27 mm aragonite fill size was converted to a 0.37 mm quartz equivalent. The data suggest a slope of 1:7.4 to 1:10 for this grain size for low- and moderate-wave energies, respectively.

The average post-project foreshore slope measured in April 1991 and again in October 1991 was about 1:9.0 (neglecting profiles immediately adjacent to the structures).

PROJECT PERFORMANCE

Physical - Figure 3 compares the first post-project MHWL with the predicted equilibrium planform. The predicted shoreline curvature agrees fairly well with the measured shoreline — considering that the post-construction MHWL is about 6 m (20 ft) landward of the predicted MHWL along the northern four cells. This feature is high lighted by two representative profiles shown in Figure 6. The complete reason for this shortfall is not altogether certain, but it is known that the project was underfilled during construction by at least 5% at the Owner's direction. It is also possible that the contractor over-excavated the existing beach. In this project, however, an initial underfill is more desirable than overfill be cause of the need to avoid impacts to seagrasses.

The October 1991 planform is shown in Figure 7. No *net* shoreline retreat is apparent; however a southward shift in the cells (reflective of wave conditions during the photo/survey) is noted.

Figure 7 also depicts gross changes in fill volumes (preliminary) for the first six months of the project. The data suggest some seaward displacement of fill at the south end. Apparent losses across the south four cells are balanced by gains across the northern two cells. The net computed change is negligible: a loss of 15 m³ (20 cy), or 0.08%. The reasons for the apparent northern shift of the material (about 1150 m³ or 1500 cy) is uncertain. Sand has not been mechanically moved. Beach raking to clear seagrass is done on a cell-by-cell basis and should not result in a net displacement of sand. (It may, however, result in a net loss of up to 1500 m³ (2000 cy) per year — if the sand comprises 5% of the volume of seagrass which is removed almost daily.)

The complicated geometry of the project makes volumetric comparisons difficult. Beach profile locations will be added or changed to improve geometric resolution and hopefully improve our under standing of the transport paths.

Environmental - Six-month benthic and infaunal data were under analysis at the time of this writing. Preliminary data from sea- turtle monitoring studies suggest that the aragonite was about 2°C cooler than a Florida sand test plot imported from Juno Beach. However, histology was not permitted to determine if this affected turtle sex. Good success in hatching ratio was reported in both sand types, although success was improved in aragonite during heavy rains (because the aragonite is a good drying agent which prevented nest flooding). Turtles were attracted to the areas of new aragonite beach where there was no beach prior to the project. Six nests were found in the 1991 post-construction beach compared to twelve at the 1990 pre-project shoreline. The reduction may be due to increased site lighting, and is not necessarily ascribed to the aragonite fill (Alexis Schulman, Univ. of Miami - personal communication). Suffocation from the aragonite was not observed.

Social - To date, response to the project by upland residents is very positive. Residents are pleased with the opportunity to enjoy the recreational oceanfront and are candidly enamored by the aragonite's brilliance. Maintenance personnel have thus far not complained of significant increases in sand deposition in pools or buildings — either by wind- or human-borne carriage.

SUMMARY

The importation of Bahamian aragonite, stabilized by a highly-tuned structural field, allowed restoration of an insular

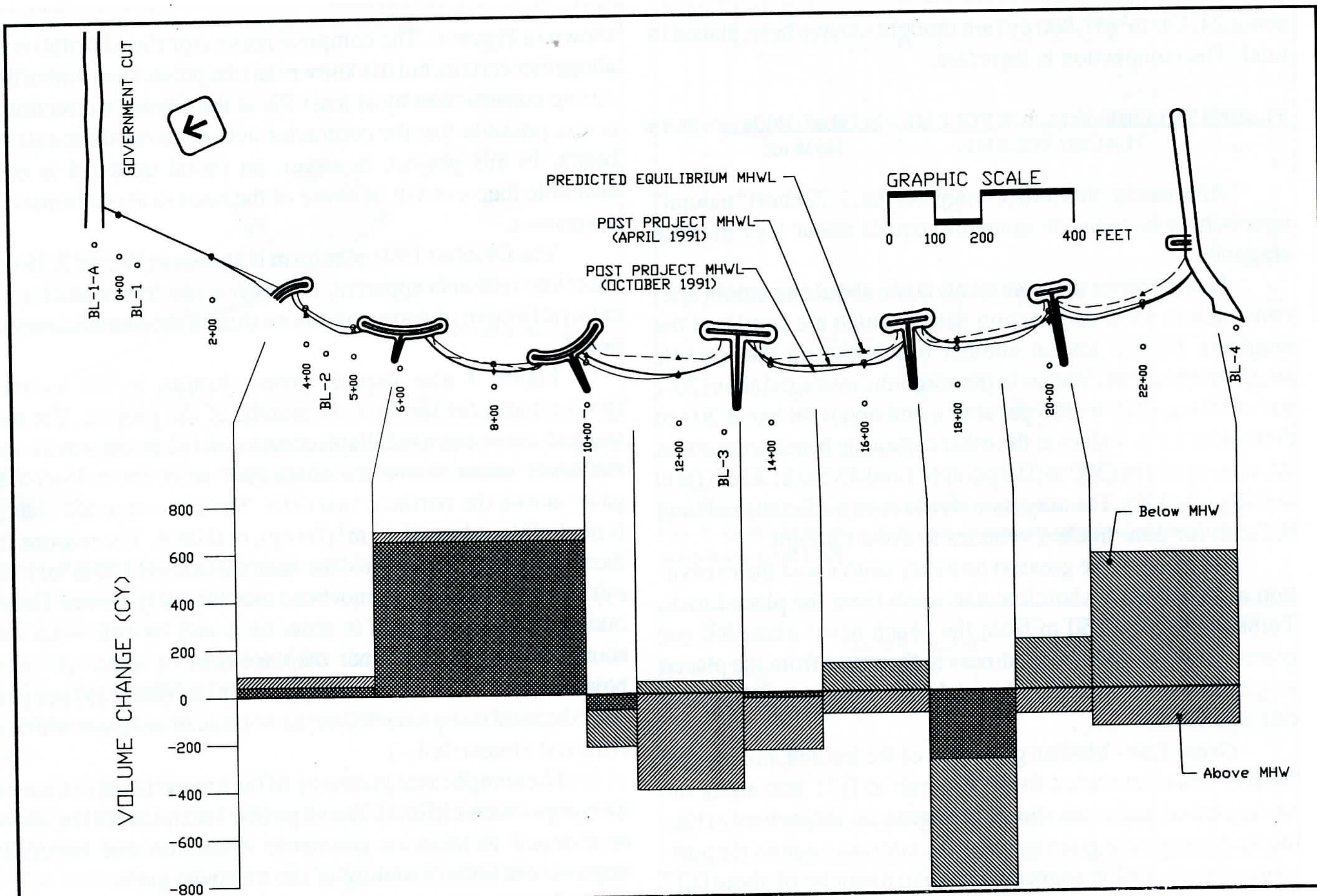

Fig. 7. Planform and volumetric changes measured during first six-month interval after project construction.

shoreline in south Florida which was severely eroded by an updrift navigation project and which was located near environmentally sensitive sea grass beds. This was the first large-scale use of aragonite for beach restoration in the United States.

To date, the project is performing as per predictions. Adverse physical or biological behavior has not yet been observed. After 6 months, there is no apparent loss of net fill volume, although there is an as-of-yet unexplained northward shift in the fill.

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