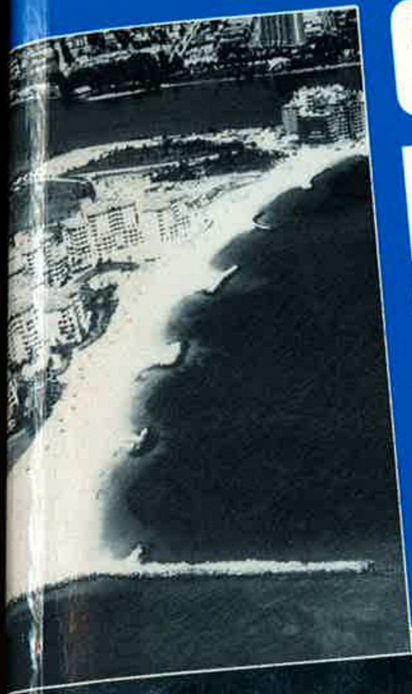
COASTAL ENGINEERING PRACTICE '92



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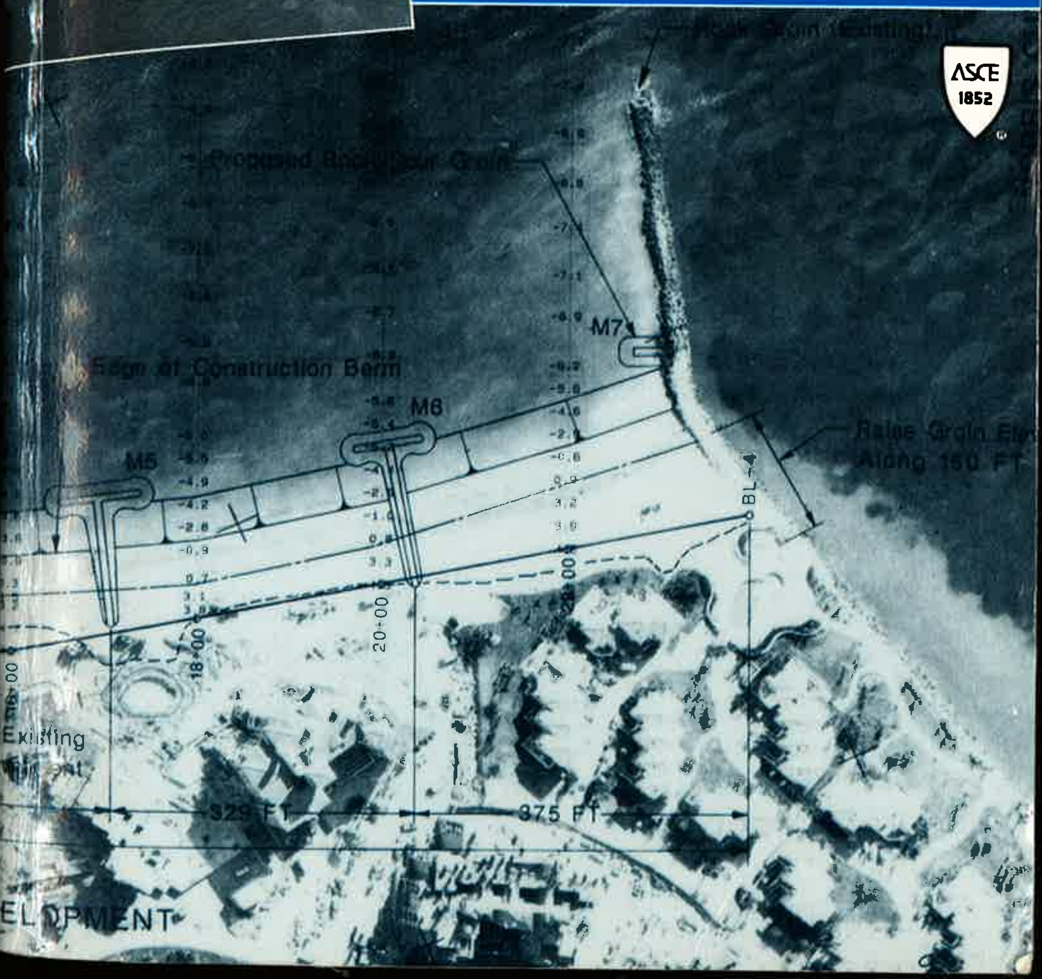

BEACH NOURISHMENT WITH ARAGONITE AND TUNED STRUCTURES

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ABSTRACT: The first full-scale use in the United States of imported aragonite sand for beach restoration was undertaken at Fisher Island, Florida, between December 1990 and April 1991. About 20,000 cy of existing rubble and sand were excavated from the project beach. Approximately 30,000 cy of aragonite fill were then barged from the Bahamas, placed by truck, and stabilized by seven rock structures designed 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.

In April, 1991, construction was completed on the first full-scale beach nourishment project to utilize oolitic aragonite in the United States. The project is located along the Atlantic shoreline of Fisher Island, Dade County, Florida (Figure 1). 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.

As a result of the navigation project which created Fisher Island in 1904, the site can be considered to comprise an independent lit-

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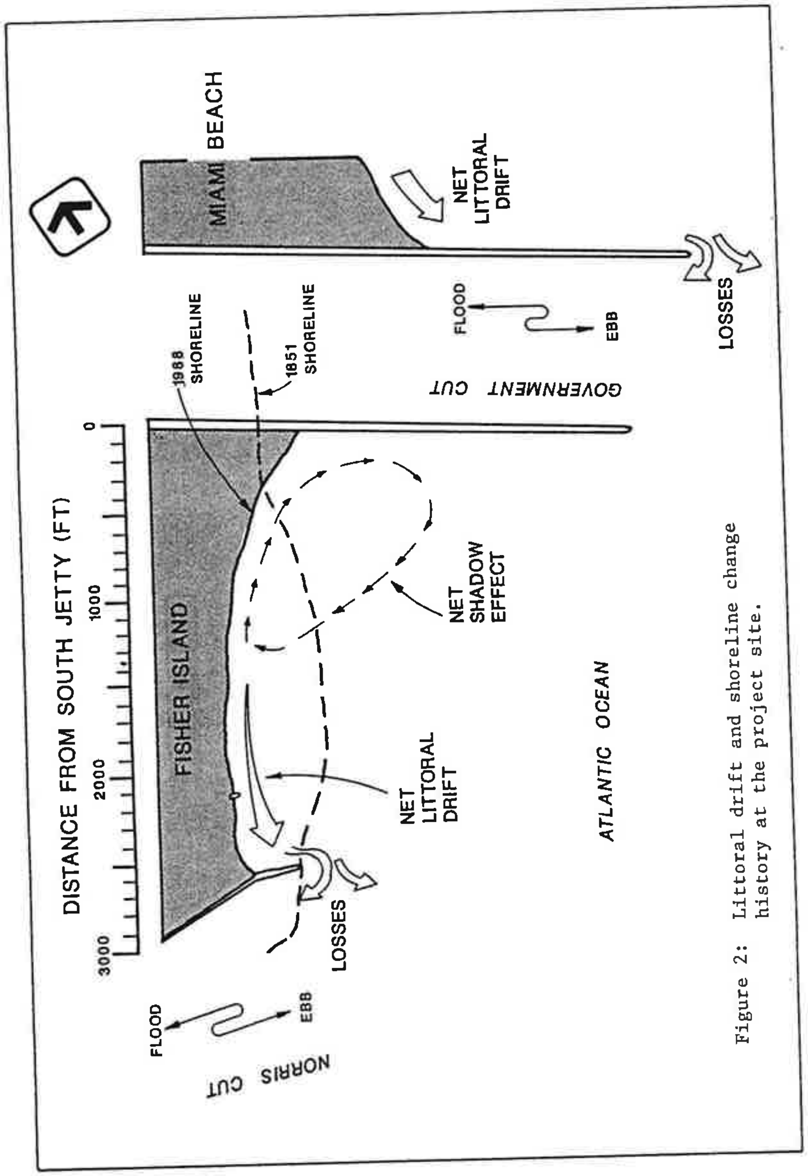

Figure 2: Littoral drift and shoreline change history at the project site.

Grid-based wave refraction analysis of the area suggested that the shadow effect of Government Cut and its jetties extends to between 500 ft and 1500 ft south of the south jetty. A strong gradient exists beginning 1500 ft south of the jetty where the net southerly littoral drift potential rapidly accelerates to perhaps 120,000 cy/yr towards the island's southern end (Bodge 1989).

Stabilization Requirements - 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).

Dominant northerly wave energy eroded at least the southern half of the Fisher Island shoreline. The eroded material was partially impounded against the southern terminal groin and was eventually bypassed to Norris Cut and apparently lost to tidal currents. Southerly wave energy transported existing sand northwards towards the jetties. This material partially impounded against the south jetty or circulated clockwise in the jetty's lee -- returning to the shoreline about 1500 ft south of the jetty. Overall, then, Fisher Island represented a more-or-less isolated littoral cell.

It became evident that fairly rigorous stabilization would be required to ensure a reasonable life for any beach restoration project south of the jetties. Fortunately, the area's littoral isolation meant that structural stabilization of the beach fill would pose minimal adverse impacts upon adjacent (downdrift) beaches.

Sand Source - Offshore sand deposits suitable for beach restoration were previously identified as part of adjacent projects at Miami Beach and Key Biscayne (Bodge and Rosen, 1988). However, many of these sources were environmentally sensitive or more or less "reserved" for future Federal restoration projects.

It then became evident that a hydraulic dredge and fill project would not be practicable. This was due to difficulties in obtaining permits for offshore dredging for a private project and, especially, for hydrualic filling near the nearshore seagrass beds. Offshore borrowing also approached uneconomical costs because of the anticipated small fill volumes required for the project. Suitable upland sources were likewise scarce and expensive.

A decision was then made to use imported aragonite. Aragonite, barged from the Bahamas, could be 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

Geology. Oolitic aragonite is composed of calcium carbonate crystallized in the orthorhombic crystal system which occurs in the form of smooth spherical or ellipsoidal shapes (Cunningham 1966). Aragonite is thought to precipitate from seawater due to a biologically-induced increase in pH (Kuenen 1933), and/or due to colder oceanic waters which flow onto the warm, shallow Bahama Banks (Newell et al. 1960; Miller-Way et al. 1987). Carbonate beaches which are dominated by aragonite do not occur in Florida, but aragonite is a common component of many sub-tropical Florida beaches (Thorp 1939). The beaches and seabeds of the Bahamas, on the other hand, are composed primarily of aragonite.

Previous Experience. The only known quasi-prototype beach restoration using aragonite was a small test project involving 1000 tons (or about 800 cy) placed at about MHW by truck-haul. The project was executed in 1965-66 at Pepper Park, two miles north of Fort Pierce Inlet, Florida (Cunningham 1966). Because of the small quantity of fill material and inadequate controls, the results of this small scale test were inconclusive.

Laboratory Studies. Saltwater wave tank tests conducted by CERC (Monroe 1969) and unpublished results from laboratory tests conducted by the U.S. Army Corps of Engineers (1985) 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.

Effective Grain Size - From settling tube comparisons (Campbell 1983), 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 (Olsen and Bodge 1991).

Other Properties. Despite the laboratory tests, concerns remain regarding aragonite's potential in the prototype for abrasion, dissolution, cementation, and effects to benthic and pelagic assemblages. These properites and their potential effects upon the project success are discussed by Olsen and Bodge (1991).

DESIGN EVOLUTION & PERMITTING

In September, 1988, our firm was contracted to design and permit a beach restoration project at Fisher Island. Four months later, by January, 1989, the schematic design was completed and all permit applications had been submitted. The permit process involved the U.S. Army Corps of Engineers (COE) and its sister agencies including U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries (NMF); the State of Florida Dept. of Natural Resources (DNR) Division of Beaches and Shores (DBS) and Division of State Lands; the State of Florida Dept. of Environmental Regulation (DER); and the Dade County Dept. of Enviromental Resources Management (DERM).

Initial Design. The initial design involved the placement of about 60,000 cubic yards (50,000 CY below MHW) of aragonite along 2030 feet of shoreline in a 75- to 100-ft wide berm at +6 ft NGVD. This would result in a 65-ft wide creation or increase of the beach at the MHWL. The toe of the construction template was about 100 ft from the existing MHWL, and the predicted toe of the equilibrated fill was about 200 to 300 ft from the MHWL. The fill would be stabilized by four rock groins (with minor T-heads) spaced 440-ft to 680-ft along the project area and by one rock spur attached to the existing structure at the south end of the beach. The project covered 7.0 acres in total, of which 5.6 Ac were below the MHWL. It was estimated that 1.7 acres of rock/sand with attached epibiota would be covered, and another 0.36 acres of rock/sand/epibiota would be covered of which 25% -- or 0.09 Ac -- included seagrasses.

In April, 1989, USFWS recommended deletion of the <u>northern</u> 440 feet of the fill project below MHW in order to eliminate impacts to diverse algal beds and seagrass within 100 feet of the shoreline. In May, DERM expressed concern over seagrass impacts along the <u>southern</u> 550 ft (approximately) of the project. The differences in seagrass discovery between the agents and the Engineer's consultant probably derived from seasonal differences.

Modification #1. In response, the berm width was reduced by about 40 feet along the southern 600 ft (approx.) of the fill area. The southernmost groin was replaced by two shorter groins to stabilize the reduced fill. The project now employed five groins (with minor T-heads) spaced from 330-ft to 560-ft along the project in addition to the spur groin. This modification was possible because the beach along the southern end of the project could be widened in the <u>landward</u> direction to retain a reasonable width. Permit revisions were submitted in June and July of 1989.

In June, USFWS released its Section 7 (Endangered Species Act, 1973) finding which concluded that the project would affect a small area and would be a good opportunity to study aragonite effects upon sea turtle nesting. However, USFWS also re-voiced its concern about potential seagrass impacts at the northern end of the project. DER and DERM joined the chorus and recommended that the fill not extend beyond 40 to 50 feet from the existing shoreline anywhere along the project area. While the project's modification accomodated this recommendation along the southern end of the project, it was impossible to implement along the remainder of the project.

That is, the existing shoreline along the central and northern project area was almost vertical rock. At an estimated 1:10 equilibrium slope and a 7-ft vertical difference between the berm elevation and toe-closure, it was impossible to create a beach which would extend less than 70 feet from the shoreline. From July through September, the Engineer submitted multiple reports to each agency explaining these problems in great technical detail.

Final Design. By October, 1989, it was clear that the environmental agencies would not relent in their objections and the process was bogged down. Discussions between the Engineer and Owner resulted in a modified master plan whereby the northern half of the oceanfront development was shifted slightly landward and the original seaward landscaping revetment was scalloped to allow pocket beaches. The final design evolved from this plan (Figure 3).

The fill was shifted so that the toe of the equilibrium fill fell generally landward of an agreed-upon limit of seagrass along the southern section of the project and within 50 feet of the shoreline along the northern and central sections. To accomplish this, the existing rock and sand along the upland would be excavated above +2 ft NGVD (i.e., above MHWL), and replaced by aragonite fill to a berm elevation of +5 to +6 ft. The overall fill requirement was slightly reduced to 56,000 cy; however, now only 31,000 cy were below MHW. Areal impacts below the MHWL were reduced to 3.6 Ac.

Stabilization became especially important in order to minimize encroachment of the fill upon the seagrass beds. Six rock T-head groins (resembling attached nearshore breakwaters) were employed along the fill area in addition to the original spur groin. Alongshore spacing was fairly uniform. The placement and lengths of the heads were in part determined by seagrass patches which were to be protected. The orientation of the heads were also "tuned" to the incident wave energy to increase fill stability (see below).

Permit modifications were issued in December, 1989. The modified plan was satisfactory to the environmental agencies: DERM, COE, and DER each issued formal or informal intents-to-issue permits by February of 1990. However, by March 1990, the DNR Div. of Beaches and Shores issued an objection to the project because of its extensive and unorthodox use of structures. This objection was overcome within several weeks after the Engineer justified the evolution and theory behind the project's design.

Significant and costly requirements for biological, physical, and sea-turtle monitoring were added as permit conditions for periods of at least 3- to 5-years after construction. This included requirements for a surety bond for removal of the structures -- all of which were agreed to by the Owner. By early April, all of the regulatory agencies which had so far actively participated in the process now supported the project.

The last player, the DNR Division of State Lands, recommended permit denial in late April. The agency apparently took issue with the biological and shoreline-armoring evaluations prepared by DER and DNR. After many "bounds of jurisdiction" arguments between all of the parties involved, the issue was resolved by early May.

All permits were essentially complete by June, 1990. The process required about 1.5 years and two major project modifications. Fortunately, however, this was an example of how a project was improved through the permitting process.

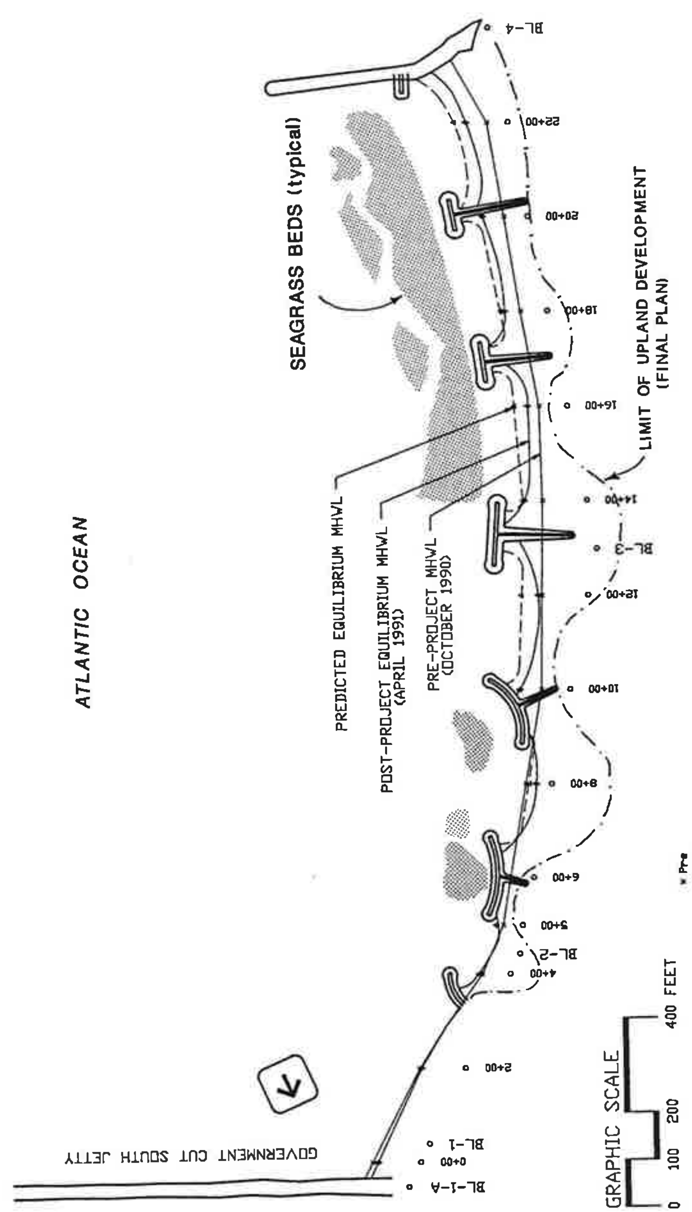

Figure 3: Planform of Fisher Island beach restoration project.

It can probably be said that all parties involved with the project's permitting left the process satisfied and even enthusiastic about the project. The modified design minimized potential impacts to nearshore seagrasses and biota. It pleased the Owner because its curvilinear planform and rock headlands purposefully reflected the very elegant Mediterranean character of the oceanfront development. The project's stability was also enhanced by the pocket beach and headland design which would probably not have been permitted if it were not for the need to protect nearshore habitat. The State of Florida and the coastal engineering community also benefited from the opportunity to study (at the private sector's expense) the physical and biological performance of aragonite beach fill and the prototype shoreline response of a beach fill amidst "tuned" structures. Of course, none of these improvements nor benefits would have been possible without the Owner's willingness to work with the Engineer and the regulatory agencies and modify the oceanfront master plan, and to bear the considerable expense of the permitting process and monitoring conditions of the permits.

FINAL DESIGN DETAILS

Beach Fill Template. The desired post-equilibration fill profile was drawn with 1:10 slope (see below) over each of ten sections taken through the project beach. The required fill volume was computed from simple geometric considerations of these profiles and the fillits which were anticipated in the structures' lee. Allowances were also made for the excavation of the existing beach above +2 ft NGVD and for the curvilinear planform of the backshore.

Construction templates were then drawn with 1:5 slope at each of the ten sections which would geometrically yield the total fill requirement. No attempt was made to mechanically "pre-establish" the fillets in the structures' lee.

The total fill requirement thus far represented a geometric, or "in-place" volume. A compaction allowance of 26% was assumed for purchasing requirements (see below). This figure was based upon a simple in-house experiment where aragonite from the borrow source was shaken down in a coffee can placed upon the rattling motor of the author's MGB. Dry aragonite reduced in volume by 20%; wet (saturated) aragonite reduced in volume by 31%.

Slope. The design equilibrium beach slope was also uncertain. Data describing beach slope vs. aragonite grain size were unavailable for project design. Surveys of Bahamian beaches dominated by aragonite 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 (USACE 1984). 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 foreshore slope of a 1987 beachfill at adjacent Key Biscayne (using offshore sand about 1.3 times coarser than the aragonite grain size) was about 1:9. Based upon all of these studies, a nominal equilibrium slope of 1:10 was adopted for the project. The 1:5 construction slope was selected by engineering intuition.

Structure Design. The stabilizing structures were designed for locally mined 2- to 5-ft limerock (sp. gr. = 2.2) with 1:2 sideslopes underlain by Nicolon 500 geotextile. The planform design makes use of the classically known behavior of a sandy shoreline perched between fixed headlands (Yasso 1965; Silvester 1970; Silvester and Ho 1972; among others). The structure's orientations were determined by the local wave direction to impose a littoral drift pattern which yields optimum project performance (Olsen and Bodge 1991). In brief, the endpoints of each structure were located so that a line drawn between adjacent structures would form a prescribed angle relative to the average local wave angle. The latter was determined through refraction analysis and through inspection of the pre-project shoreline orientation.

The headlands were shore-connected to preclude fill "blow-outs" which might occur if the headlands are flanked in a storm. Such blow-outs may impact the nearshore grassbeds. The curvilinear shapes were also adapted to enhance the Mediterranean ambience of the design; such "tuned" headland planforms are typical in Eastern Europe (Spataru 1990).

PROJECT CONSTRUCTION

Construction began in December 1990 and was mostly completed by March, 1991. Approximately 20,000 CY of material was initially excavated across the project planform above +2 ft NGVD. (MHW is about +1.8 ft NGVD). The cut included rubble, rock, sand, and heavy debris which was spoiled on the upland's interior for other use. The contractor was forced to continually maintain the cut as unexpected nearshore sands migrated shoreward to fill the excavated berm. (As an aside, observation of this process supported arguments that limited beach scraping can effectively accelerate berm recovery or yield net berm accretion.) The rock structures were built after the berm excavation and prior to beach fill placement.

The aragonite was barged 60 miles (one-way) to the site in 2000-ton loads from Marcona Ocean Industries' mining operation at Ocean Cay, Bahamas. (Unit conversions are discussed below.) After clearing customs, the aragonite was offloaded by a conveyor directly into dump trucks at a berth on the island's north side. The trucks delivered the aragonite to the beach less than one half-mile away.

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.

PROJECT PERFORMANCE TO DATE

Volume and Compaction. By correlating post-construction aerial photography and surveys from April, 1991, the in-place aragonite fill volume was computed as 25,000 cubic yards (cy).

Records show that 42,950 short "natural" tons were imported. A short "natural" ton includes 6% moisture (characteristic of dredged aragonite after at least 24 hours' stockpile) and is assumed by Marcona to correspond to about 0.74 cubic yards in a natural (non-compacted) state. Hence, about 31,800 cy are thought to have been placed in total. The compaction is therefore:

$$\frac{\text{PLACED VOLUME} - \text{INPLACE VOLUME}}{\text{PLACED VOLUME}} = \frac{31800-25000}{31800} = 21.4\% \qquad (1)$$

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

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 4). A composite grain size distribution taken across the post-project beach profile suggests a median diameter about 0.27 mm with 3% finer than 0.107 mm and less than 0.5% finer than 0.074 mm. This distribution is <u>identical</u> to that measured from the Ocean Cay stockpile during project design. No changes in the fraction of fines were measured. The first annual monitoring report (Olsen Assoc., 1991) describes how grain size varies across the profile.

Beach Slope. The average post-project foreshore slope measured in April 1991 and again in October 1991 is about 1:9.0 (nelecting profiles immediately adjacent to the structures). This is slightly steeper than the 1:10 estimate conservatively adopted for design.

The 1:5 construction slope estimate was, however, too steep. The aragonite assumed its equilibrium slope almost immediately upon placement. This may have been due to the shallow closure depths (about -6 ft MHW). In hindsight a 1:8 slope would have been better.

Planform. The equilibrium MHWL planform was predicted during the design process through engineering intuition (guided by the spiral-bay literature mentioned above). Figure 3, presented earlier, compares the first post-project MHWL with the predicted planform. The predicted shape of the shoreline curvature agrees fairly well with the measured shoreline -- considering that the post-construction MHWL is about 20 ft landward of the predicted MHWL along the northern four cells. This feature is highlighted by two representative profiles shown in Figure 5.

The complete reason for this shortfall is not altogether certain. The project was underfilled during construction at the direction of the Owner. (The design in-place volume requirement was 26,200 cy.

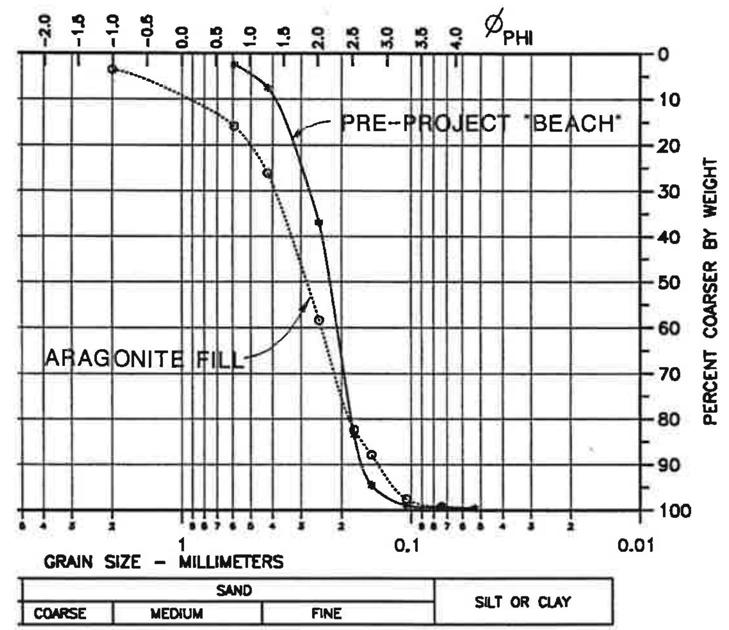

Figure 4: Grain size distributions of scarce pre-project beach and of aragonite beach fill.

The measured in-place fill was 25,000 cy; i.e., 5% less.) However, this deficiency cannot account for the entire shortfall. It is possible that the volumes of the fillets were underestimated during the computation of the design volume requirement, but is more likely that the contractor over-excavated the existing beach below +2.0 ft NGVD. In this project, however, underfill is more desirable than overfill because of the need to avoid impacts to seagrasses.

The October 1991 planform is shown in Figure 6. No <u>net</u> shoreline retreat is apparent; however a southward shift in the cells (reflective of wave conditions during the photo/survey) is noted.

Volume Change. Figure 6 depicts estimated 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 20 cubic yards, or 0.08%. The reasons for the apparent northern shift of the material (about 1500 cy) is uncertain. The Owner has not mechanically moved any sand. 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

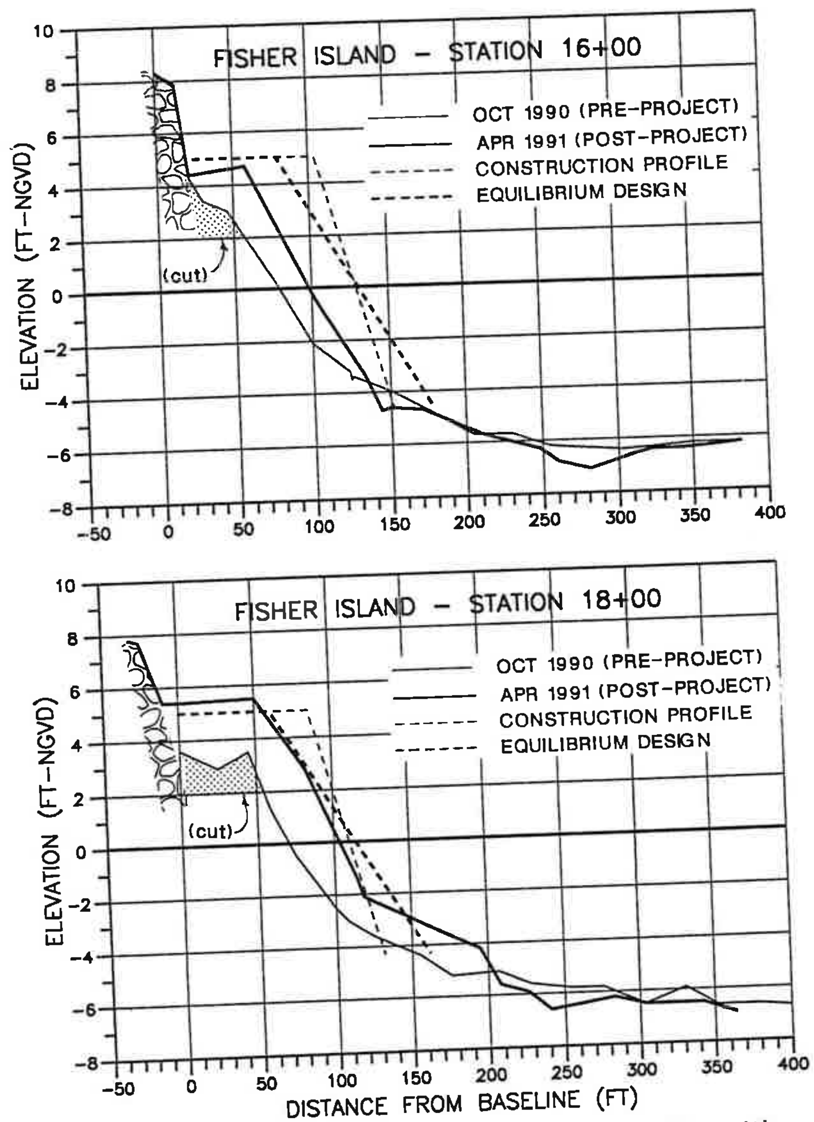

Figure 5: Typical pre- and post-project beach profiles with design construction and equilibrium templates shown by dashed lines. Rock revetment is by others.

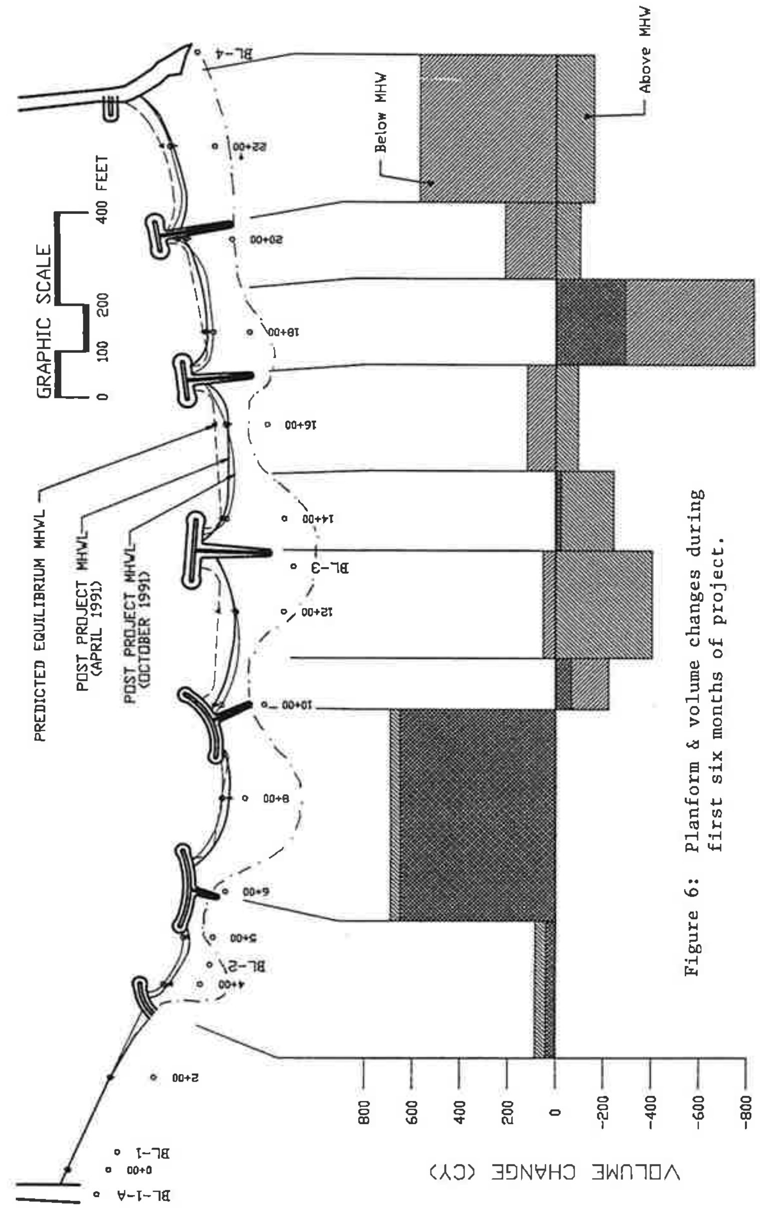

Figure 6: Planform & volume changes during first six months of project.

net loss of up to 2,000 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 volume computation and comparison difficult. The monitored profiles conform to stations selected prior to the project and do not describe the fill geometry well; additional profiles will be added in the next six months to improve geometric resolution. This will hopefully improve our understanding of the transport paths.

Compaction. Penetrometer readings taken about one month after construction averaged about 275 to 325 psi at 6", and about 700 psi at 12". Values at an adjacent carbonate beach were 300 to 350 psi at 6" and 600 to 650 psi at 12". The aragonite fill is said to be surficially soft. Tracks had to be added to the development's rake tractor, and two-wheeled drive vehicles become very quickly stuck.

Environmental. Benthic and infaunal data were forthcoming 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, DNR did not allow histology 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 beach (where there was no beach prior to the project). Six nests were found in 1991 (post construction) compared to twelve in 1990 (pre-project). 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). A 1-yr report is due in Novemeber 1991.

SUMMARY

In summary, imported aragonite beach fill stabilized by a highly-tuned structural field was used at a south-Florida island resort in order to minimize hydraulic dredge-and-fill impacts, minimize impact to nearshore habitats, and to create a unique enhancement to the elegant upland development. The use of imported aragonite was the first of its kind in the United States. Much of the final design evolved during the permitting process -- which fortunately resulted in an improved beach restoration project.

To date, the project is performing as per predictions. Adverse physical or biological behavior has not yet been identified. 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. Numerical guidance on design beach slope and compaction is included in the manuscript.

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