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INNOVATIVE SHORE PROTECTION IN HAWAII

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INTRODUCTION

Section 227 of the Water Resource and Development Act of 1996, authorized the National Shoreline Erosion Control Development and Demonstration Program. The Program is aimed at advancing the state-of-the-art in coastal shoreline protection. As part of the Section 227 Program, Sacred Falls Beach Park on the Island of Oahu, Hawaii, has been chosen as demonstration project site. Sacred Falls Beach Park is located in the village of Hauula on the island of Oahu, Hawaii (Figure 1). The project site is an approximate 370-ft reach of undeveloped shoreline. Continual, yet manageable, erosion of the beach at Sacred Falls Beach Park has reduced beach width to a point that it is almost totally submerged during high tide. Some deterioration of the coastal highway is evident. Recreation use of this tourist destination is currently minimal due to lack of existing beach width.

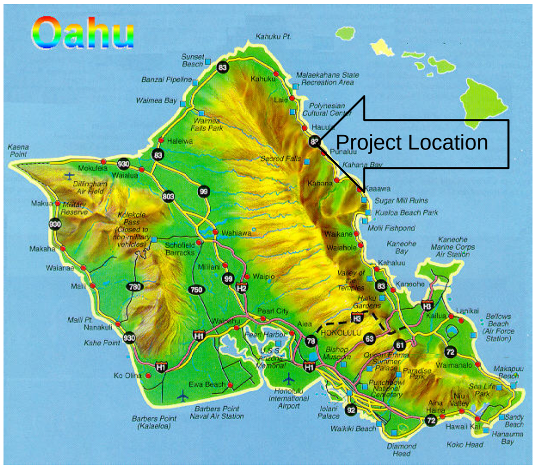

Figure 1. Project location at Sacred Falls Beach Park, Hauula, Oahu

EXISTING CORAL RUBBLE SITE

On the Kihei coast of the Island of Maui, on a wide, shallow fringing reef flat, are natural emergent mounds of coral rubble that extend several hundred feet from the reef towards shore (Figures 2). The formation of these low elevation, flat sloped, groin-like mounds, has coincided with significant accretion of the sandy shoreline landward of them. Historical aerial photographs show that these rubble mounds, while staying in the same general location, have grown, changed shape, and migrated toward the shore over time. The rubble mounds appear to act as "dynamic groins", responding to changes in site conditions (wave energy, availability of material, storms) while continuing to exert a stabilizing influence on the shoreline. These natural groins are not as obtrusive and visible as more traditional groin structures, and have "weathered" winter season westerly storm waves and two passing hurricanes since the beginning of their formation in the early 1970's.

Figure 2. Aerial photograph from 1997 showing prototype site located in Kihei, Island of Maui, Hawaii.

The three existing rubble groins at Kihei vary in size and shape, but have similar general features as follows; 1) 200 to 400 feet long, low crest elevation (+1.0 to +1.5 feet referenced to mean sea level), broad crested (width above MSL of approximately 40 feet on the stem and 100 to 180 feet at the seaward head, 2) a fan shape when viewed from above, with a stem and a wide head, somewhat similar to a traditional T-head groin, 3) varying side slopes from very flat where exposed to direct wave approach to almost vertical on the lee sides of the stem; and 4) a composition of coral cobbles averaging 1 to 4 inches in size, mixed with sand and scattered cobbles up to 1-foot in size. Both in structure geometry and construction materials used, it is proposed that the project design emulates and improve on naturally occurring structures similar to those found at Kihei, Maui. These low, mild-sloped, and wide structures are comprised of deposits of coral rubble. The plan is to build a low-crested semi-emergent fan shaped structures in the center of the project area. The usefulness of low profile fan shaped groins built using innovative techniques and materials is to be demonstrated at the Sacred Falls site.

CONCEPT SHAPE DEVELOPMENT

The coral cobble shapes at Kihei were generalized into two shapes, referred to as "Mushroom" and "Fan". The shapes were chosen to simulate the general configuration of the mounds. A third shape, a "T-head" breakwater, was analyzed to compare effectiveness of the proposed shapes with that of a more traditional engineered solution. The crest length of each structure was 50 meters. The mushroom and fan shapes are 18 m wide at their centers and the structures' stems are 8 m wide. Water depth in the near vicinity of the structures was -1 m (mean lower low water) and the crest elevations were +0.24 m (MLLW). The side slopes were 1V:1.5H in all cases. To maximize effectiveness, the structures were located close to shore, with the landward edge of the crest 15 m from shore. The preferred result of the proposed structures was a protected shoreline. A stable beach was also desired. The structures function by reducing wave energy through the processes of refraction, diffraction, shoaling, breaking, reflection, and bottom friction. Studies showed that the proper combination of these wave-transforming processes will lead to energy reduction and salient growth in the lee of the structures.

SACRED FALLS SITE CHARACTERIZATION

The bathymetry and topography at the project site were compiled from a detailed topographic survey conducted for this project that extended from the highway to a depth of 1.2 m, and from high-resolution lidar data. The project vicinity (Figure 3) has historically been subject to significant chronic erosion problems, as has much of the windward coastline of Oahu. At the Sacred Falls site an approximate 370-foot-long reach of undeveloped shoreline is located between private residences protected by seawalls. There are limited amounts of sand in front of the seawalls. The beach extends landward to the coastal highway and is narrow, essentially inundated at high tide; and the highway is protected by randomly dumped boulders and concrete pile butts. A wide fringing reef extends along the coast, with the 12-foot depth located approximately 2,500 feet offshore. The shallow reef bottom is a mixture of rubble, sand and scattered reef blocks over a hard limestone reef rock substrate. Coral cover on the reef flat is low, and the rubble, sand and boulder bottom has about a 50% algal cover. Sea urchins and brittle star are common and fishes are sparse. The nearshore waters are generally safe for swimming, except for occasional high surf conditions and resultant strong currents. Use by both subsistence and sport fishermen is moderate to high along the coast, with both pole fishing from shore and net fishing on the reef flat.

Figure 3. Bathymetry at Sacred Falls site (contours in feet referenced to MLLW)

The Sacred Falls site is directly exposed to the prevailing northeast tradewind waves, as well as refracted and diffracted winter season north swell. Although the fringing reef limits the wave energy reaching the shore, the presence of numerous shore protection structures both north and south of the site attest to pervasive erosion. During the winter season, high waves coupled with high tide occasionally inundate the coastal highway. Makao Beach, located just north of the project site, is a narrow calcareous sand beach, with a maximum beach width at high tide of about 3.0 m, and has a history of chronic erosion. The majority of the shoreline at Makao Beach is presently stabilized by rock revetment to protect the coastal highway. Drogue studies indicate that circulation in the area is primarily driven by waves. The extensive reef system causes the waves to break offshore, thus limiting the wave energy that reaches shore. The breaking waves generate mass transport and wave setup inside the reef, resulting in a south to southeast current that runs across the reef flat and exits out the sand channel.

CONCEPTUAL DESIGN

Numerical modeling, STWAVE, COULWAVE and REFDIF-1 were used to examine the effects of concept shapes on waves approaching the project site. Model input was based on the deepwater wave transformation results for the deepwater wave from 090°. The input wave conditions were 0.62 m wave height with a period of 9.1 seconds and a direction of 050° at a water depth of 1.5 m. For the model runs, the base of the structures were at elevation –1.0 m, the structures were 1.24 m high, and the water depth was 1.46 m. The wave front contours show the refraction and diffraction patterns due to the structure and show the mechanism for salient formation. The patterns are similar for each structure. The wave heights are shown to dramatically decrease behind each structure due to breaking, refraction, and diffraction energy losses. The structures are energy reduction devices that are expected to provide a depositional environment at the shore. Wave energy was calculated in a 50 m by 5 m box in the lee of the structure oriented alongshore. The energy in the box for each structure was evaluated and compared with the same area for the existing condition. Model results show significant wave energy reduction in the lee of the structures. Model results show little difference between the structures.

STRUCTURE DESIGN CONCEPTS

The goals of this project are to design relatively low cost and easy to construct structures that can be used to stabilize and protect the shoreline. Ideally the structure would be constructable using primarily manpower with limited equipment and machinery. Preliminary concept development therefore focused on materials that are readily available, easy to deploy and can be linked together to form a stable reef structure. Preliminary concepts include the following:

Concrete Pipe Sections – Concrete pipe sections constitute a readily available, durable, and stackable material that could be deployed in remote locations. The configurations of the T-head and fan shaped structures would be achieved by using 29-inch diameter, 2-foot high sections of concrete pipe, stacked in two layers. The structures would require between 1,600 (T-head) to 2,800 (fan shape) units. Each unit weighs about 430 pounds. Units would be clipped together and the top layer attached to the bottom layer to produce a cohesive, stable reef structure.

Plastic Highway Barriers – Plastic highway barriers come in many shapes and dimensions, one of which is 42 inches high, 90 inches long and 25.5 inches wide at the base. These units weigh 120 pounds empty. They could be filled with 6.3 cubic feet of concrete and weigh 1,062 pounds, and still be neutrally buoyant in the water. They could be floated to the site, and then flooded to place them on the seafloor. Submerged weight would be 531 pounds. To build the reef structures, the barriers could be placed one alongside the other, with an upside down unit in between. They also interlock end to end. The entire reef width could be cabled together through aligned slots in the middle of each unit. Between 646 and 1,039 units would be required to build the T-head and fan shape structures, respectively.

Geotextile Tubes – The reef structures could also be built with geotextile tubes. The units investigated are 4.5 feet high, 17 feet wide, and slope approximately 1 vertical to 3 horizontal. Two units, 164 feet long, placed alongside each other could form the T-head reef structure. The dry weight of each tube is 3,280 pounds. Approximately 330 cubic yards of sand is required to fill each tube.

Rubblemound Fishpond Wall Structure - Rock-walled fishponds were common along Hawaii’s shorelines before western contact with the islands in the 18th century. Research on these ponds has indicated that the rock work was relatively sophisticated and included larger stones to anchor the base, flat capstones, scour aprons, and sloped seaward faces. Stone sizes ranged from 3 manstone size (a stone that can be handled by 3 men) at the base to 1 and 2 manstone size in the core. Small rocks were often placed in the voids to improve the filtering capacity of the walls. A weakness of the traditional fishponds from a shore protection perspective is that the relatively small stone sizes are vulnerable to damage and transport during storm waves. The possibility of storm waves spreading lava rocks across a coral reef area and the difficulties associated with the resulting cleanup, are serious environmental risks that would render unlikely the possibility of obtaining permits for fishpond type structures for shore protection. A possible innovative beach stabilization method, however, could utilize small stones in the tradition of the Hawaiian fishponds, together with modern geogrid mattress or basket technology. Small stones could be placed manually into high strength, composite mesh baskets or mattresses. The mattresses or baskets, available in a variety of sizes, could then be used to build a fishpond type rubble mound wall or reef type structure. Each individual mattress or basket is linked to the surrounding mattress/basket to provide overall structural stability. The mesh structures would hold the rocks together, and prevent them from being spread across the reef.

CONCLUSION

As previously noted the project is currently in the conceptual design phase with subsequent detailed design and construction to be accomplished in 2006. The conference presentation and paper will focus on documentation of the field investigation and conceptual design phases of the demonstration project. Conceptual design alternatives will be presented along with possible small-scale construction techniques that can facilitate implementation of shore protection strategies in remote island settings. Future phases of the project including detailed design, construction, monitoring and assessment will also be presented.

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