Proceedings of the 3 rd International Surfing Reef Symposium, Raglan, New Zealand,
June 22-25, 2003.

High Density Polyethylene Pipe Reef for Surfing and Shore Protection

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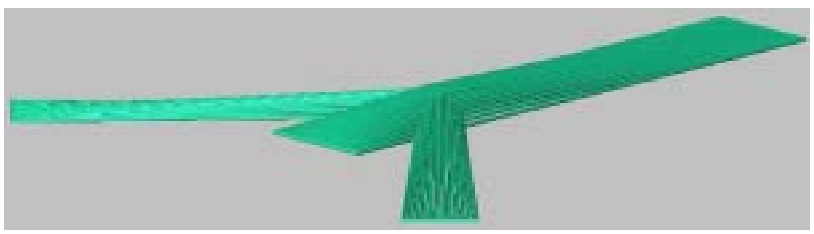

There is a need to find additional tools, methods or systems that will improve the success in managing coastal erosion. Historically, beach erosion has been treated with rock revetments, groins, sea walls, or beach fill. The final report of the beach study for the San Diego Regional Beach Sand Project Final Environmental Impact Report/Environmental Assessment included the conclusion that an offshore wave-shoaling reef may provide a new approach for managing specific eroded beach areas. The study looked to natural reefs as evidence of this conclusion. Such a reef would force the erosive wave energy further offshore with the potential of producing sand accretion patterns inshore and create a recreational resource.

Our focused investigations centering on the Oil Piers Site in Ventura County, California have yielded a new approach to create a wave-shoaling reef that will force the erosive shoaling wave forces offshore to encourage accretion and the eventual return of the historic beach at Oil Piers. A wave-shoaling reef will stabilize and protect the investment of beach fill without interrupting the local sand transport.

Oil Piers History and Study Premise

A bathymetric study conducted at the site for the pier removals in 1997 identified a triangular shaped sand bar when the piers were present. Inshore of this distinctive sand bar was a larger sand beach than the current condition. Recreational waves would break along the sand bar as noted by many historic photos of the pier. The waves and the beach were lost. This is unfortunate event gave us one small area where we could focus and refine our assumptions with the goal to bring the waves back to that area or any area.

Reef Material Selection

The approach of the preliminary reef material investigations was to find a suitable construction material that met the following criteria:

1. Environmentally inert and tough hardy material that will not degrade in the ocean.
2. Material that has history of use in the ocean.
3. Material that lends itself to a structural design that is changeable in the x, y, and z axes.
4. Can be utilized in a structure that can survive the 100-year storm.
5. As safe, or safer, than existing inter-tidal reefs for bathers and surfers.
6. Can be combined in a structure that is easy to install or remove.
7. Easily fabricated into different configurations.
8. Cost effective.

Scientific Merit of the reef design as an Erosion Control Structure

Salient formation (seaward bulging shoreline and wider beach) has often been documented as an unintended by product of offshore breakwaters built to reduce wave energy for mooring areas and as the objective of some breakwater projects. Traditionally, these offshore breakwaters have been designed as partially submerged seawalls or rubble mounds parallel to the shoreline. An artificial reef can operate as an erosion control structure in the same manner as an offshore breakwater, acting as a submerged breakwater that reduces wave energy landward of the structure and inducing a sediment transport gradient that results in a perturbation in the shoreline planform. Artificial reefs are being considered as a means of reducing shore erosion and increasing the size and persistence of sandy beaches in California[1, 2]. The reef configuration and location has been developed for the Oil Piers Site as a means of re-producing previous bathymetric contours and dissipating wave energy, thus restoring the wider beach and surfing resource lost since the removal of the pier.

The Y-shaped artificial reef proposed here has several distinct advantages over other artificial reef designs – most importantly its effectiveness in creating a wave shadow, its stability, and its ease of removal.

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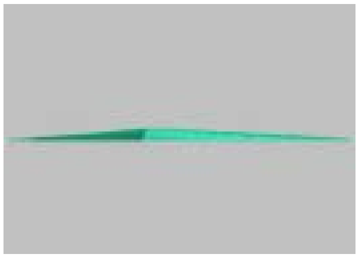
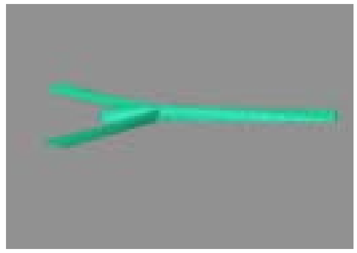
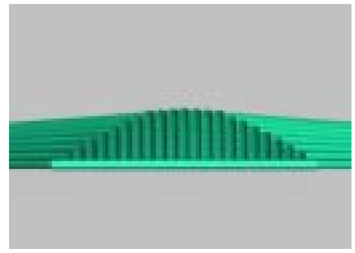
[1] BEACON, 2001. *SOUTH CENTRAL COAST, BEACH ENHANCEMENT PROGRAM, CRITERIA AND CONCEPT DESIGN.* Prepared by Moffatt & Nichol, Engineers.

[2] SANDAG, 2001; *REGIONAL BEACH SAND RETENTION STRATEGY FINAL REPORT.* Prepared by Moffatt & Nichol Engineers, Everest Coastal and MEC Analytical Systems.

First, the Y-shaped artificial reef dissipates wave energy over a wide range of wave conditions and directions. The arm that extends in the offshore direction forms a ridge and interacts with the incident waves via refraction and diffraction processes, amplifying the wave height incident to the reef and essentially guiding the waves toward the inboard area of the reef. The waves then break on the left and right side of the V-shaped inner reef structure. The sloping and angled shape of the inboard reef results in extensive wave dissipation through an extended distance of breaking along each leg of the reef. When waves approach from a direction straight on to the reef, the amplified section of wave over the offshore arm becomes a breaking wave "peak" with a progressive breaking zone "peeling" to the left and right along the inboard, V-shaped reef section. When waves arrive at an angle, the amplified wave crest propagating along the offshore arm interferes constructively with the wave crest approaching from inboard portion of the reef, resulting in wave breaking over the inboard section. Therefore, for a broad range of sea states, the inshore wave energy is reduced, encouraging formation of a shoreline salient and a wider sand beach.

Second, the proposed materials and construction of the reef are unique. In contrast to a more traditional sand bag artificial reef design, the pipe matrix can be deployed and anchored with a high level of precision. In addition, the low specific gravity pipe material and pipe matrix anchoring system prevent the reef from settling into the sand over time, as has been observed with sand bag reefs. Finally, the pipe matrix design can be removed, if necessary, and such removal is accomplished easier than removal of the buried fabric of the sand bags or geo tubes.

Design Development

Cost effective beach protection devices must include in their design, a trigger for sand accretion and offshore wave shoaling. Also critical to this requirement is the ability to manufacture these devices in a modular fashion offsite in order to minimize environmental disturbance in the near-shore environment. Stanley's Reef Foundation (SRF) has addressed these issues with the reef design described below.

Porosity. Unlike sand bag, geo tubes or seawall style structures, Stanley's Reef is similar to a basket in structure. An array of High Density Polyethylene (HDPE) pipe is the fundamental structural element to create an open or porous structure.

This "porosity" is a critical design element, in that all wave or current energy is dissipated over surface area much greater than that of a planer surface. The space between the pipes (or “porosity”) allows energy to pass through the structure greatly reducing the loads the structure and anchors must withstand.

Wave and current energies must react against the circular cross section of the pipe. This results in radial deflection of energies around the pipe. These energies are redirected in such a fashion that most energy vectors are, not aligned with respect to the reef’s structural elements. This further reduces aligned loads on the structure and anchor system.

Another advantage to using HDPE pipe is that flow around a cylindrical shape becomes turbulent, slowing the speed of the flow. As sand-laden water slows, the sand falls out of suspension, creating a sand bar within and shoreward of the structure. Sand accretion is one of the designed functions of this structure.

The pilings of a pier have the same effect of reducing wave energy and slowing flow to create sand accretions. In addition a pier is a “porous” structure, which allows wave and current energy to pass through it. This “porosity” is the fundamental element that allows piers to be highly structurally sound in an inter-tidal environment. Stanley’s Reef uses these proven design principals in a horizontal orientation to create a stable, more effective device to trigger sand accretion and wave shoaling.

HDPE Pipe. The use of HDPE pipe has many advantages. Low cost, long life, resilience, ease of construction, neutral buoyancy, environmentally inert properties, lack of corrosion, and wide availability all combine for an ideal structural element for inter-tidal use. The use of this material will allow construction of the reef offsite, which reduces logistics, environmental impacts, cost and complexity.

The nature of this structure can be seen as a manifold that can be filled with air, sand slurry, or concrete for ballast at different times during construction and deployment. When filled with air (immediately after construction) the reef can be towed into position and then “sunk” and anchored to the ocean floor.

Traditional structures such as sand bags, geo tubes, seawalls or rip-rap depend on the sea floor as a foundation for support. These incredibly heavy structures depend on weight to anchor them into position. They also tend to sink into sand substrates due to the extreme weight and planer surfaces (which cause scouring) of these types of structures. This limits their life and effectiveness over time in this environment.

Stanley's Reef is designed to "park" on the semi-fluid sand bed. This feature mitigates the risk of scouring-in and or sinking. In addition, the ability to re-introduce air into the structure allows for position adjustment and low-cost removal of the reef.

The resilient nature of HDPE and its resistance to work hardening insures dispersion of loads, which would be catastrophic to ridged structures of similar design in inter-tidal environments. This resilience also allows for this structure to "move" or adjust to changes in the sea floor due to sand movement. For instance In the event of a storm where littoral currents are dramatically increased and in turn the scouring of sand away from the reef, the reef can settle as sand is removed. In this case a ridged structure would become cantilevered and be subject to catastrophic failure. On the other hand if the sand is deposited around the reef it can adjust to this as well due to its flexibility and buoyancy in the semi-fluid sand environment.

Wave Climate, Sediment Transport, and Shoreline Evolution Modeling

To guide the placement of the reef and to predict the shoreline's response to the new hydrodynamic regime, the hydrodynamic effects of the reef and the resulting impacts to local sediment transport and shoreline morphology will be modeled. The existing waves will be characterized initially using available measured wave data and modeling. Wave refraction-diffraction, shoaling, and breaking are important coastal processes that govern sediment transport and short-term coastal morphology. These physical processes will be modeled using numerical modeling techniques. The wave characterization will serve as input to a shoreline evolution model. Bathymetric and beach surveys charting the evolution of the existing site condition from the pre-existing site condition with the pier in place will be used to verify and calibrate the models. The future wave conditions (post-project) will be modeled, and the future shoreline will be estimated. In addition to providing a basis for design parameters, orientations and geometries, the output of the models will also serve as input to structural design of the mooring and anchoring system.

Beach Nourishment

The SRF team proposes to nourish the beach with sand inshore of the reef (in the expected position of the salient wave directions) in conjunction with the reef placement, thus mitigating impacts on sediment supplies to down coast beaches. The design of the sand placement will involve defining material specifications and sources, calculating overfill and re-nourishment factors, and adjusting placement locations and profiles. These will be based on the recent research and findings. Our cost schedule anticipates this analysis and the actual placement of the sand.

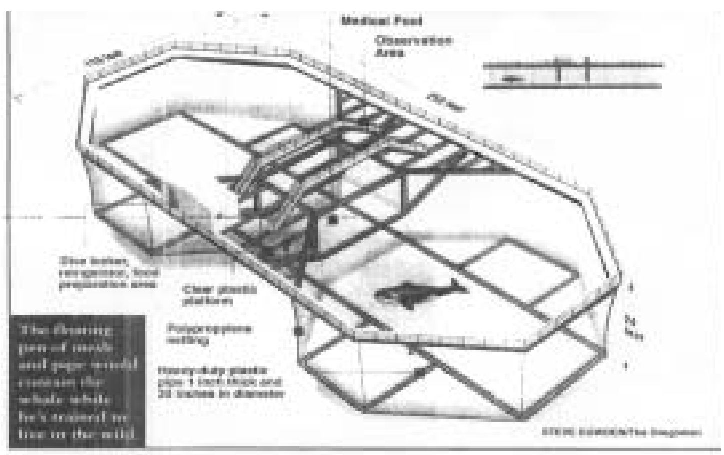
Environmental Loading and Structural Engineering

Because the reef will be installed in a dynamic ocean environment, it must be capable of withstanding the forces experienced at such a site. Historical environmental conditions at the study site will be gathered and reviewed to arrive at a set of site-specific design criteria. The environmental conditions of interest will be wave height, period, and direction; longshore current velocity; wind speeds; bathymetry; and sediment type and stratigraphy. With these data and the size and conceptual shape of reef from the shore processes and wave climatology work, the loads on the reef structure will be calculated. The loads will be calculated using empirical, numerical, or computer-based analysis methods. The anchoring system will be specified based upon the loads applied to the structure. Once the loads are known, they can also be applied to the conceptual structure for sizing and detailed design of the HDPE pipes, connections, and anchoring attachment points.

Advanced suction piles, screw anchors, or a combination of mooring technologies will be assessed as a part of the final engineering effort and directed by all available expertise. The most probable candidate for the anchoring system will be screw anchors. Screw anchors have been proven to be highly reliable in anchoring HDPE outfalls and pipelines in the marine environment. Screw anchors are easily installed in a sand bottom by rotation and result in holding forces of up to 40,000 pounds each.

The final step in structural engineering and anchoring system design will be to produce a complete set of fabrication and assembly drawings of the reef.

The "Free Willy" successful underwater Killer Whale holding pen built in Iceland. Some of the same engineers that developed this are involved in the surf reef technology and design.



Construction, Deployment, and Removal

Construction of the reef structure modules will occur on a beach, wharf, or offshore; the modules can then be deployed to the installation location with some or all assembly taking place at the site. Air is forced from sealed chambers and it is sunk and located in the inter-tidal region where its high point or intersection of the legs will be 2 to 4 feet below mean low water. The anchoring system will utilize screw anchors and other advanced mooring technologies. Anchors will be installed along the perimeter of the structure. After the installation is complete, the reef will be backfilled with sand supplied by a barge or from other sources. The natural wave action will spread the sand in and behind the structure as demonstrated in modeling tests. If ever necessary or desired, the reef can be removed by divers jetting the sand out from around reef and reversing the screw anchors out of the sand bottom. Removal would also involve displacing the seawater from the reef's dedicated flotation pipes by introducing air back into these pipes.

This offshore part of the reef also provides advantages for anchoring and deployment as the end of the leg of the "Y" is out of the surf zone. The offshore portion of the reef will provide the opportunity for attachment and growth of at least two species of large local California kelp (*Egregia menziesii* and *Macrocystis pyrifera*), as well as, unlimited potential for marine invertebrates and inter-tidal fish habitats.

Abalone habitats have been designed and informally tested with success in Proteus Marine Laboratories. Figure 2 shows its the founder of Tom McCormick with one of the modules designed for juvenile abalone. Passive reef pipe will provide unlimited selective habitat for many native species.

Expertise Guiding the Process

Over the course of investigations, in a variety of areas, a large number of outside experts have served and will continue to serve as advisors to help guide the conceptual and detailed development of the project. Such areas include general coastal processes, sand transport, wave shoaling, anchoring, mooring, and structural technology. Materials experts will assist in finding the optimum sizes and structural relationships to meet the design requirements. The results will be coordinated in a dynamic manner with the structural requirements as they relate to the coastal process requirements.

An example of the use of early conceptual advisors on the project is Professor William C. Webster from the University of California at Berkeley, Department of Naval Architecture who advised on the early conceptual work. Over the past decade over two dozen wave tank models were informally tested. A full bathymetric survey of a natural reef and other investigations were also conducted.

Technical assistance has also been obtained from Naval anchoring experts Dr. Paul Palo and Bob Taylor. The sand transport expert from University of California (UCSB), Dr. Steve McLean, has assisted throughout the development and will continue to do so.

The overall design aspects have evolved with the input from a variety of other experts who will oversee all preliminary, intermediate and final designs going forward with acceptance of this project and as needed, throughout the life of the project.

Team Qualifications

The team members for this project and their qualifications are as follows:

Stanley's Reef Foundation (SRF), a federal non-profit foundation. SRF has focused on the Oil Piers Beach site for six years with its mission to preserve the natural and recreational resources of this historic recreational site. SRF helped create awareness of the Oil Piers Beach area. Its public outreach efforts have gained immense local, public and political support for its mission, including the Ventura Board of Supervisors, EDCVC, BEACON, Citizens of Ventura County, Surfrider Foundation, and others. Gary Ross is the President of SRF. Mr. Ross developed and patented the "Y" shaped reef design included in this pre-proposal. He coordinated preliminary design and engineering efforts over the past decade, over half of which was focused at the Oil Piers Site in Ventura; he also implemented wave tank testing of design variations at private tanks, at UCSB and at the Scripps Institute of Oceanography. The offices of SRF are located at 167 Lambert St., Oxnard, CA 93036. The foundation's phone number is (805) 981-1773. The foundation's website is located at www.Stanleysreef.org.

Philip Williams and Associates, Ltd. offers professional consulting services in all aspects of hydrology, hydraulic engineering, geomorphology, and coastal processes and engineering. PWA's expertise in coastal processes includes: (1) numerical modeling of wave refraction, diffraction, and shoaling; (2) coastal geomorphology; (3) sediment transport and sediment budget analysis; (4) erosion control and coastal drainage; (5) dredging and sand bypassing requirements; and (6) mapping of historic shoreline positions and rates of change. The Principal Investigator for the coastal processes and shore protection aspects of the project is Bob Battalio of the engineering and research firm Philip Williams & Associates, Ltd. Mr. Battalio is one of the principals of the firm and is in charge of the project. Philip Williams & Associates, Ltd. offices are located at 720 California St. Suite 600, San Francisco, CA 94108, Phone: (415) 262-2300. Their website is: www.pwa-ltd.com.

Divecon Services LP (formerly the West Coast offices of American Pacific Marine, Stolt-Comex Seaway, and Oceaneering International, Inc.) is well known in the local and regional underwater services and marine construction field with a considerable resume of projects on the West Coast. Divecon removed the Mobil Oil Piers and has first hand knowledge of the offshore area there. Divecon is committed to assist in the development, construction, and deployment of this project. Ken Gluck of Divecon performed the preliminary engineering on the wave-shoaling reef when it was proposed for the Pratte's Reef surf mitigation project. Divecon Services LP will address installation planning, bonding, assembly, and installation tasks on the project. Divecon is located at 741 East Arcturus Ave., Oxnard, CA, 93033. Their phone number and website are (805) 488-6428 and www.divecon.com.

At **Thomas and Beers**, each staff member has over 20 years of experience in the structural design of heavy structures that are used in or around the marine environment.

Thomas and Beers have experience working with marine construction and diving contractors on a number of offshore oil platforms, piers and other marine projects. Thomas and Beers utilize the ANSYS finite element analysis computer program to structurally analyze many of our projects. This is a comprehensive static, dynamic and non-linear program capable of analyzing submersed elements. Additionally, Thomas and Beers prepares fabrication and assembly drawings in AutoCAD and Cadkey**.** The initial and final structural design and drawings of the reef and its anchoring system will be prepared by Thomas and Beers with offices at 572 Poli Street, Ventura, CA 93001. Their phone number is (805) 652-0655.

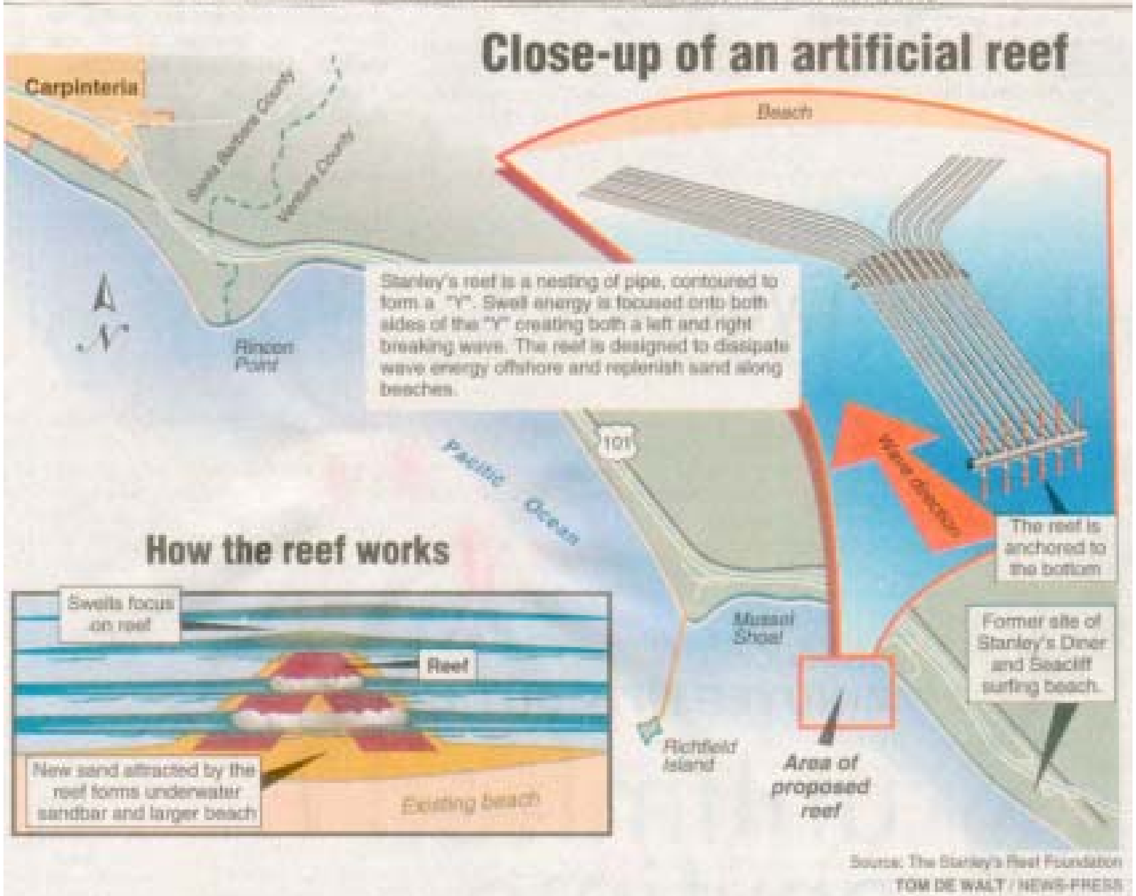
Performance Pipe is the successor to Plexco and Driscopipe in the HDPE pipe and fittings market as a result of a joint venture between the Chevron Corporation and Phillips Petroleum Company. Performance Pipe is now North America's largest producer of polyethylene piping products for gas, industrial, municipal, mining, oilfield, and utility applications. Performance Pipe offers more than forty years of polyethylene piping system experience, with pipe and fitting manufacturing facilities throughout the United States and in Mexico. Performance Pipe of Plano, Texas will be providing materials selection information, constructability and engineering review, and fabrication services. They are located at 5085 West Park Blvd., Suite 500, P.O. Box 269006, Plano, TX 75026-9006. Their phone number and website are (800) 527-0662 and www.cpchem.com.

The Environmental Company, Inc. (TEC) is a full-service environmental and engineering consulting firm with extensive environmental planning and compliance experience in Ventura and San Diego Counties. TEC's experience includes complex projects involving onshore, near shore, and offshore activities. Staff in the Santa Barbara and Solana Beach offices have access to a full range of planning and compliance resources company-wide. Members of TEC were involved with developing environmental planning and permitting strategies for the Pratte's Reef proposal in conjunction with SRF. Environmental compliance for this project will be addressed by The Environmental Company, Inc**.** with California offices in Santa Barbara (1525 State Street Suite 103, 93110) and Solana Beach. Their phone number and website are (805) 564-4940 and www.tecinc.com.

Summary

We have in this report identified the principal premise for the development of a shoaling reef. We have highlighted the unique aspects of its innovative design with some detail to explain the concept and point out other benefits of this new approach. We give a verbal sketch of the actual preliminary design and how it will be constructed and deployed. We also give details of the history of the effort and the members of the development team.

SANTA BARBARA NEWS-PRESS ❖ THURSDAY, NOVEMBER 14, 2002



Artificial reef may restore beach