Alternative Shore Protection Strategies: Innovative Options and Management Issues

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INTRODUCTION

Accelerated development in the coastal zone has inhibited the natural cycles of the beach and has placed many buildings and infrastructure in jeopardy of erosion. In the United States a study conducted by the Heinz Center (2000) warns that there are an estimated 350,000 buildings located within 500 feet (150 meters) of the open ocean and Great Lakes shorelines in the lower 48 states and Hawaii. Of these, it is estimated that 87,000 homes are likely to erode into the ocean or Great Lakes during the next 60 years. Assuming there is no structural protection or beach nourishment, it is also estimated that 1,500 homes and the land on which they are built will be lost to erosion each year. In the face of such danger, it is not surprising that shoreline developments have turned to shore protection techniques to minimize their loss of property.

The United States is not unique. Global sea level rise and the increasing force and intensity of coastal storms resulting from climate change will likely mean an increasing need for coastal defense to prevent erosion and flooding worldwide. The Heinz Center (2000) reports that global sea level has risen 10 to 25 centimeters in the past 100 years. Although this change may not sound significant, sandy beaches retreat landward in response to sea level rise and can result in shoreline retreat rates that are 50 to 100 times as great (Komar 1998). The Intergovernmental Panel on Climate Change (1995) predicts an additional 15-95 centimeter rise (with a best estimate of 50 cm) by 2100. Based on these predictions, an additional 50 cm sea level rise could result in 75 meters (about 250 feet) of beach erosion. When coupled with regional subsidence, the impacts of sea level rise are further magnified. From a coastal manager's point of view, high tides will become higher, beaches narrower, and wave energy may increase, which will in turn increase the erosion impacts and raise the demand for protection measures.

Coastal management agencies have two types of policy options for erosion hazard reduction: (i) strategies that seek to avoid exposure such as coastal retreat or relocation, setbacks, density restrictions, and building codes; or (ii) those that seek to buttress against natural forces such as structural reinforcement and beach nourishment (Beatley and Schwab 2002). The use of traditional hard reinforcement is in decline as the disadvantages associated with it become more apparent. Although a commonly used approach, beach nourishment is also waning due to the diminishing sources of sand, maintenance requirements, and high costs associated with this approach. Consequently, a wealth of alternative strategies for shore protection is emerging and a growing body of literature about such techniques provides insight into the effectiveness of these measures. The challenge lies in recognizing the strategies that are sound versus those that border on being harebrained.

Despite the fact that much the same physical and sedimentary processes are common to all coasts, their manifestation can be quite site-specific. Given this unique nature, explicit shore protection methods and designs may not translate from one location to another. While literature documenting the design and implementation of the more conventional protection options is available, a concise guide is needed to steer management decisions on the use of emerging shore protection methodologies. Such a guide would also serve as an effective link bridging the science and engineering of coastal erosion and shore protection with the policy and decision-making component of shore protection. Scientific information is needed to make wise decisions about the use of coastal resources, to protect the environment, and to improve the quality of life for coastal residents. The National Research Council (NRC 1995) has called for new means to improve interactions between scientists and policymakers. One possible method may be to present a broad range of scientific literature in a form that is translated and disseminated to the decision-makers. Coastal managers have a diverse range of backgrounds, and may not be specialists in coastal processes.

Manuals for the design and use of traditional "hard" structures and beach nourishment are readily available, but a comparative review of emerging alternatives is not. Bird's (1996) text entitled *Beach Management* begins to introduce emerging technologies by discussing beach dewatering as a means of erosion control. McQuarrie and Pilkey (1998) evaluated alternative or non-traditional shoreline stabilization devices in a brief, generalized overview that focuses on their environmental impacts. The US Army Corps of Engineers Section 227 National Shoreline Erosion Control Development and Demonstration Program have compiled a searchable Internet database of "innovative structures." Neither of these latter sources provides details about experience with their use, but they do offer information about the manufacturers and the marketed devices.

The objective of this study is to compile a concise guide to alternative shore protection options for coastal management, based on theory and experience with their use. Here, selected strategies are reviewed together with their relevant problems and benefits, so the decision making process can proceed to identify the human values against which the alternatives and their costs and benefits may be judged (NRC 1995).

Five strategies have been selected for rigorous review: beach scraping, beach dewatering, cobble berms, artificial dunes, and artificial surfing reefs. Each shore protection option is presented independently, so one need not read this report sequentially from beginning to end. The first three methods can be considered derivatives of beach nourishment. The practice of beach scraping in not new, but interest in this alternative has experienced resurgence as a "soft" solution without the need for an outside sediment source. Beach dewatering and cobble berms are comparatively innovative methods that have not experienced a significant history of documentation. In the context of this paper, sand-filled geotextile containers are used to construct artificial dunes and surfing reefs, and therefore the materials and designs are an emerging technology. One could argue that geotextile containers are "hard" structures, but because they are often permitted when traditional materials are not, they are considered here.

There are inherent consequences when interfering with the natural cycles of the coast, regardless of the method chosen for coastal protection. The problems and benefits associated with a coastal protection scheme should be clearly defined prior to making a decision about its use. Unlike traditional erosion mitigation methods, literature about experiences with these emerging responses is not abundant, and is therefore more difficult to obtain.

This paper aims to present a comprehensive review of the selected coastal protection alternatives in a form most useful for coastal mangers. It is not intended to serve as a technical review of the engineering design of shore protection schemes. The concept, design, and application of each method are reviewed. Management implications are interpreted from the literature, and presented in a discussion. The key problems and benefits are subsequently presented in a bulleted list for clarity. Following each shore protection strategy are cited references along with options for additional research.

Alternatives to scientific literature are used when appropriate, as traditional literature sources were often in short supply. The Internet is an effective tool to locate documentation about emerging shore protection technology; therefore websites and listservs were used and those sources are included in the references.

BACKGROUND

The evolution of the coast is produced by natural processes that occur on a broad time scale ranging from hours to millennia. Beach erosion is one such process that occurs when the losses of beach sediment exceed the gains. As this volume of sediment decreases, the beaches become narrower. When backed by fixed developments, beaches are unable to respond naturally to changes, resulting in a cessation of beach/dune interactions, instability of the fronting beach, and a reduction of sediment inputs into the sediment budget. In the absence of development, coastal erosion is not a hazard. The presence of large and expensive communities in the coastal zone creates the potential for major disasters resulting from erosion.

Erosion is typically episodic, either with the shore recovering afterward or with the episodes being cumulative and leading to a progressive retreat of the shoreline and property losses. The episodes of erosion are generally associated with major storms such as an extratropical storm (Nor'easter) or hurricane, or can be associated with a climate event, such as El Niño. The erosional impact on properties depends on the width of the buffering beach, and on the nature of the beach as defined by the morphodynamics model of Wright and Short (1983).

The presence and width of the surf zone is primarily a function of the beach slope, and secondarily depends on the tidal stage. Beaches of low slope, normally composed of fine sand, are characterized by wide surf zones. Steeply sloping gravel beaches seldom possess a surf zone; the waves instead breaking close to shore and develop directly into an intense swash that runs up and down the beach face. Moderately sloping beaches commonly lack a surf zone at high tide when the waves break close to shore over the steeper beach face, but develop a surf zone at low tide when the wave action is over the flatter portion of the beach profile (Komar 1998). This range of beach types is inherent to the morphodynamics classification scheme developed by Wright and Short (1983). In the simplest terms, beaches can be classified by one of three beach types diagrammed in Figure 1:

i. Dissipative beach – the type having a low-sloping profile, such that waves first break well offshore and continuously loose energy as they travel across the wide surf zone. If a storm generates increased breaker heights, the waves break further offshore with a minimal increase in wave energy at the shoreline.

ii. Reflective beach – the type having a steeply sloping profile in which the incident waves break close to shore with little prior loss of energy.

iii. Intermediate beach – incorporates a range of morphological types that involve complex water-circulation patterns and bar-trough systems within the narrower surf zone. The wave response is neither clearly dissipative nor reflective.

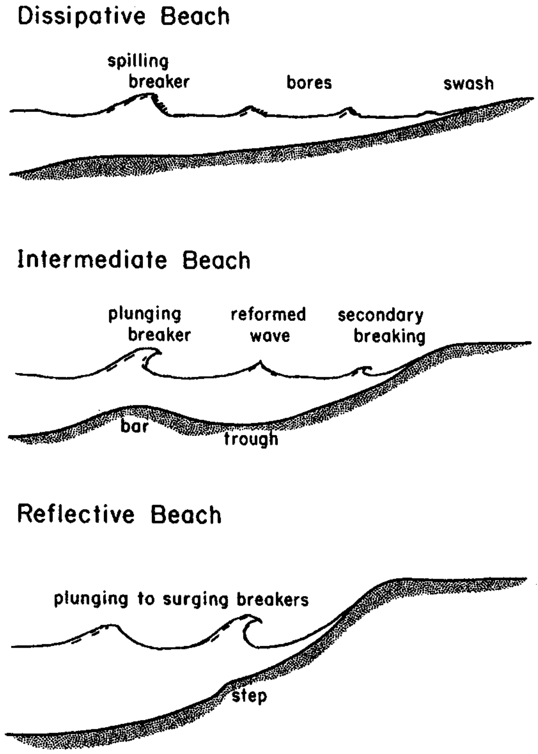

Figure 1. Wright and Short (1983) morphological beach classification scheme (Komar 1998).

In reality, the beach classifications describe a series or continuum, with the dissipative beach at one extreme and the reflective beach at the other. The intermediate beach falls in the middle, and can be further defined by four additional classifications (Wright and Short 1983):

a. Longshore bar-trough – there is more relief in the bar versus trough elevations and the beach face is steeper than a dissipative beach. Most of the wave dissipation occurs by wave breaking over the bar, reforming in the deep trough, and breaking again on the beach face. Weak offshore rip currents can be generated. Beach cusps often develop in response to localized steepening and reflection.

b. Rhythmic bar and beach – similar to the longshore bar-trough state but crescentic bars and large-scale cusps form along the shoreline, resulting in stronger rip currents.

c. Transverse bar and rip – the offshore crescentic bars meet the beachface, forming welded bars with intervening oblique troughs, resulting in strong rip currents.

d. Ridge-runnel or low tide terrace – a swash bar migrates shoreward, creating a narrow and deep longshore trough at the base of the beach face.

When the wave conditions change, as during a storm, the beach state within this sequence changes. During a storm, the beach may shift quickly to a bar type profile with dissipative conditions, but with lower waves following the storm it may successively pass through several intermediate states as it approaches a more reflective condition. The flattening of the beach during a storm should not be confused with erosion, as the sediment has only moved to offshore bars and is not permanently lost to the foreshore. Wright and Short (1983) point out that most beaches will not range through all morphological states, as they are constrained within the limits that depend on the grain size of the beach sediment and the total wave climate. Consequently, grain size largely controls the average beach slope. Coarser sand beaches show greater elevation changes over the seasonal cycle and in response to individual storms. Beaches that are at the extreme, either dissipative or reflective, tend to show the least morphologic variability (Komar 1998).

In the context of the erosional threat to properties, a dissipative sand beach or a reflective cobble beach are most desirable because the profiles are more stable and wave energy is greatly reduced before reaching the shorefront properties. The erosion of properties ultimately depends on the combination of tide height, storm surge and wave swash runup, with their addition reaching the foredune or seacliff backing the beach. The erosion of cliffs is progressive, depending on the frequency and intensity of wave attack, whereas foredunes can rebuild between episodic storm events. The period of recovery, however, may be substantially longer than the episodic erosion. In a study of beaches in southern California following an extreme storm event, Egense (1989) found that while 45 to 65 percent of the sand volume lost to the berm was regained during the first three weeks, or first phase, following the storm, the second phase was a much slower recovery period that continued for more than a year. Morton, Paine, and Gibeaut (1984) conducted a ten-year monitoring program following Hurricane Alicia in 1983 that eroded the beaches of Texas. They identified four time-dependant stages of recovery: (i) rapid forebeach accretion following the storm; (ii) slower backbeach aggradation; (iii) dune formation; and (iv) dune expansion and vegetation recolonization. Beaches backed by developments only reached the backbeach aggradation phase, as dune-sand accumulation was prevented by the presence of houses. Dunes, a natural source of coastal protection, were therefore unable to form, subjecting developments to future erosion hazards.

Shore protection measures are often installed to defend properties from erosion. The choice of an appropriate shore protection strategy must be considered in light of the dynamic responses of the beach, the capacity of the backshore to recover from the erosion, and the extent of progressive shore retreat. Various shore protection approaches are used to reduce the erosion hazard to public and private buildings and infrastructure as well as for the protection of recreational and aesthetic values. Coastal managers may implement regulatory approaches to avoid erosion hazards or may use structural or "soft engineering" techniques to defend against erosion hazards. Structural reinforcement methods are frequently referred to as "hard engineering" and include structures like seawalls, riprap revetments, groins, jetties, and breakwaters. "Soft engineering" methods aim to work with the dynamic nature of the beach, and the most popular and well known method is beach nourishment; however, other emerging soft techniques include beach scraping, beach dewatering, cobble berms, artificial dune building, and multi-purpose offshore reefs. Each of these methods is reviewed individually in the following sections.

REFERENCES CITED

BEATLEY, T. and A.K. SCHWAB. 2002. *An Introduction to Coastal Zone Management.* Washington D.C.: Island Press.

BIRD, E.C.F. 1996. *Beach Management.* New York: John Wiley.

EGENSE, A.K. 1989. Southern California beach changes in response to extraordinary storm. *Shore and Beach.* 57(4):14-17.

HEINZ CENTER. 2000. *Evaluation of Erosion Hazards*. Prepared for the Federal Emergency Management Agency. Document EMW-97-CO-0375.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 1995. *IPCC Second Assessment – Climate Change 1995.* Retrieved on 19 May 2003 from the Intergovernmental Panel on Climate Change website: http://www.ipcc.ch/pub/reports.htm

KOMAR, P.D. 1998. *Beach Processes and Sedimentation.* New Jersey: Prentice Hall.

MCQUARRIE, M.E. and O.H. PILKEY. 1998. Evaluation of alternative or non-traditional shoreline stabilization devices. *Journal of Coastal Research.* Special Issue No.26:269-272.

MORTON, R.A., J.G. PAINE, and J.C. GIBEAUT. 1994. Stages and durations of post-storm beach recovery, southeastern Texas coast, USA. *Journal of Coastal Research.* 10:884-908.

NATIONAL RESEARCH COUNCIL (NRC). 1990. Managing Coastal Erosion. Washington, D.C.: National Academy Press.

WRIGHT, L.D. and A.D. SHORT. 1983. Morphodynamics of beaches and surf zones in Australia. In *Handbook of Coastal Processes and Erosion,* P.D. Komar, ed. Pp. 35-64. Florida: CRC Press.

ADDITIONAL REFERENCES

PILARCZYK, K.W., ed. 1990. Coastal Protection. Proceedings of the Short Course on Coastal Protection, Deleft University of Technology. Rotterdam, Netherlands: A.A. Balkema Publishers.

SILVESTER, R. and J.R.C. HSU. 1997. Coastal Stabilization. Singapore: World Scientific.

GOOD, J.W. and S.S. RIDLINGTON, eds.1992. Coastal Natural Hazards: Science, Engineering, and Public Policy. Oregon Sea Grant ORESU-B-001.

CHARLIER, R.H. and C.P. DEMEYER. 1998. Coastal Erosion Response and Management. Berlin: Springer-Verlag.

CICIN-SAIN, B. and R.R. KNECHT. 1998. Integrated Coastal and Ocean Management Concepts and Practices. Washington, D.C.: Island Press.

BUSH, D.M., O.H. PILKEY, JR., and W.J. NEAl. 1996. Living by the Rules of the Sea. North Carolina: Duke University Press.

FRENCH, P.W. 2001. Coastal Defences: Processes, Problems, and Solutions. New York: Routledge Inc.

BEACH SCRAPING

Concept

The beach profile responds dynamically to changing wave conditions, and periodically results in sediment drawdown at the back of the beach in front of coastal properties. While the lower energy wave conditions, such as those common in the summer, build a wide sandy berm, the stormy winter conditions transport sediment into an offshore bar. Beach scraping manipulates the beach profile by removing "surplus" material from the lower part of the beach and transferring it to the upper part of the beach or to the dune toe, where it may better serve coastal protection (Figure 2). The material is in "surplus" when ridges build up from swell activity following a storm or during the spring and summer seasons (Bruun 1983). The technique is also thought to encourage additional sand to accrete on the lower beach, which can then be scraped in the future, leading to a net gain of sediment on the beach. Beach scraping is quite simple - sediment is pushed up onto the beach using heavy equipment such as a bulldozer.

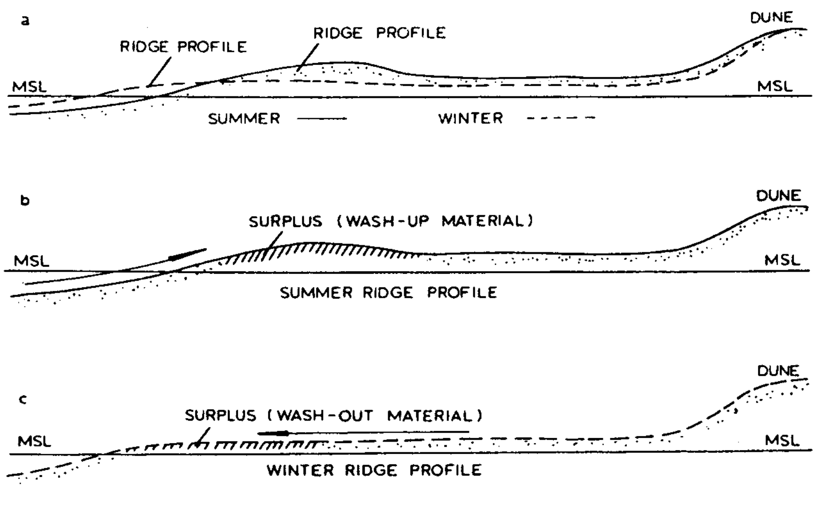

Figure 2. (a) Summer (berm) profile and winter (bar) profile. Source areas used for scraping, (b) and (c), are indicated with 'surplus' (Bruun 1983).

The reasons for scraping include the temporary prevention or relief of erosion, protection of existing dunes and beachfront structures from overwash, and to provide a wider recreational beach at high tide. Most frequently, it is performed on a small scale as a preventative measure for protection from winter storms, or as an emergency measure to restore the backbeach after erosion has occurred. Although the goals are similar, this method differs from beach nourishment because it does not add new sediment to the beach, but rather redistributes it within a limited region of the littoral system.

Applications

Beach scraping has been practiced extensively on the East Coast of the United States, perhaps in reaction to the ban on the use of hard structures to protect property in states such as North and South Carolina. In spite of its common use, a lack of research on beach scraping has resulted in considerable controversy over its effectiveness for erosion control and its overall impact on the beach (McNinch and Wells 1992). When scraping has been monitored, research appears to indicate that the techniques used to scrape the beach may ultimately determine its degree of success.

One major criticism is that beach scraping adversely steepens the beach profile, making subsequent erosion more likely and severe (Kana and Svetlichny 1982). In Ocean City, Maryland, scraping lowered the foreshore, which in turn altered the summer profile readjustment process. The development of a steeper profile gradient was noted and backshore erosion followed at a greater rate than previously observed (Kerhin and Halka 1981). Similarly, following emergency scraping in response to Hurricane David, the mechanical steepening of the beach profile at Folly Beach, South Carolina resulted in a net offshore transport of sediment. This was attributed to a change from spilling to plunging breakers on the steepened profile (Tye 1983). In either case, the detrimental result may not have occurred had more concern been given to the volume and extent of the scraping.

Another criticism is that beach scraping will have an adverse effect on the natural nourishment of downdrift beaches. If sand is brought to the lower beach by longshore transport and removed to the upper beach by scraping, the longshore transport is cut-off, depriving downdrift beaches of sediment. Like a steeper beach profile, minimizing longshore sediment transport accelerates beach erosion. Unlike trapping behind a groin however, the sediment will eventually be returned to the longshore system with the first significant storm that reaches the fill (McNinch and Wells 1992). Each if these concerns may be ameliorated by controlling the location and size of the borrow and fill sites. Bruun (1983) suggests that adverse impacts can be eliminated if beach scraping is "done correctly." By skimming only the uppermost 0.2 to 0.5 meters of the beach, longshore drift will not change and the profile will not adversely steepen. Areas of surplus and deficit on the foreshore must be clearly identified to prevent the removal of excessive sediment.

Practicing conservative scraping measures does lend itself to success. A scraping project at Myrtle Beach, South Carolina limited the scraping depth to 0.3 to 0.5 meters and focused on broad sections of the low tide beach where relatively more sand was available (Kana and Svetlinchny 1982). Although the success of this type of project is subjective, a wider high tide beach was provided for a period of several weeks to almost a year at different locations. The project also delayed the reactivation of erosional scarps on the dunes, and by creating a gently sloping fill in front of shore protection structures, reduced wave impact forces on them for the brief period that the fill remained. The benefit of the scraping at Myrtle Beach was least valuable in front of vertical walls, where it was needed most (Kana and Svetlichny 1982). The presence of shore protection structures such as sea walls severely reduces the longevity of the fill.

Unlike many scraping projects that commence hastily in response to emergency conditions, a scraping project at Topsail Beach in North Carolina occurred gradually over a prolonged period. The success of this project is attributed to the method of scraping (McNinch and Wells 1992). The beach was scraped gradually, rather than episodically, by a single piece of machinery from a very narrow borrow zone of 15 to 20 cm thickness. Because this project was monitored, it provided a rare look at the effectiveness of preventative scraping in storm events. According to McNinch and Wells (1992), beach scraping afforded a greater degree of erosion protection than non-scraped beaches during an extratropical storm. The non-scraped control section lost almost twice as much sediment from the combined beach and dune zones as did the scraped section. On the other hand, the scraped beach lost more sediment than the control during Hurricane Hugo, but the greater losses were attributed to the fact that the scraped sections were already more susceptible to erosion, hence the need for scraping. Regardless of the volume lost, the loss to the primary dune would have been even greater if the scraping fill had not been present. It was concluded that scraping could not be expected to yield sufficient shoreline protection during extreme events like hurricanes.

An emerging concern about scraping is the ecological impact of this disturbance to the beach. The sand beach ecosystem is characterized by dense populations of burrowing macro-invertebrates that serve as the prey base for shorebirds and commercially important surf fishes. Although the sediment volume and area may play a role in the level of impact, very little research has investigated this issue so the consequences are essentially unknown. Other animals, such as turtles and birds, use the beach for nesting habitat. Physical changes on beaches, such as the formation of steepened berms or scarps can prevent female turtles from reaching preferred nesting sites. The presence of equipment on the beach can also deter turtles from suitable nesting sites (Greene 2002). Birds, like the endangered piping plover and snowy plover, can be physically displaced or nests and eggs destroyed by scraping equipment. Further study is needed to understand how physical modifications might have biological impacts and to allow for the development of means to mitigate the ecological affects of beach scraping (Peterson, Hickerson, and Johnson 2000).

Management Considerations

While scraping may have a positive effect on preventing erosion in the short-term, it will not halt the long-term erosion of beaches. Scraping is likely to work best on equilibrated or mildly erosive beaches. Placement of the scraped material on the beach profile will contribute to its longevity. Beaches with a flatter profile will allow the scraped sediment to be reworked by waves and tides more slowly than a narrower, steepened beach. Longevity may be inconsequential when coastal regulations limit the placement of the scraped material. For example, North Carolina limits placement to landward of the vegetation line, where it is rapidly reworked to the beach in small storms (Rogers 2003).

The location of the borrow area is of particular importance. Recent designs have called for the removal of sand from the crest of offshore bars for placement on the beach face (Schmid 2003). The bar crest initiates offshore wave breaking, so removal of the bar will move the storm or even daily break point closer to shore and likely increase offshore transport from the upper beach (Rogers 2003). On steeper beaches, the removal of bars would be apt to cause a quick reduction of the dry beach that one is trying to protect. By caring only about the visible beach profile and ignoring the underwater offshore profile, a false sense of security may pervade. The borrow location should be selected from an area that will be naturally replenished over a rather short duration and that will not negatively affect the local sand transport system.

In most cases, the degree of human manipulation from beach scraping is relatively minor with respect to natural cycles, and when performed correctly it will not likely cause any permanent shoreline change. With careful planning, the technique does not impede the dynamics of the coastal zone and emulates the natural behavior of a post-storm beach, which is characterized by an onshore movement of sediment in an attempt to readjust to an equilibrium profile (McNinch and Wells 1992). Based on the success or failure of previously documented beach scraping projects and the monitoring of Topsail Beach, Wells and McNinch (1991) make the following recommendations:

- i. Identify the erosion problem and limitations of scraping
- ii. Assess the feasibility of scraping with respect to wave energy and available fill space
- iii. Determine whether sufficient fill can be obtained without adversely affecting the beach
- iv. Initiate and maintain a monitoring program during and after scraping

Consideration should also be given to avoid critical nesting and migration seasons for birds and turtles that depend on the beach habitat. By shifting the scraping period, ecological damage may be reduced.

Benefits:

- ✓ Widens the dry beach for recreational use
- ✓ Increased beach width provides improved temporary coastal protection
- ✓ Aesthetically unobtrusive
- ✓ Provides an emergency response option without permanence
- ✓ Natural and compatible sediment supply
- ✓ May not inhibit the natural cycles of the coast
- ✓ Increased defense without the expense of importing volumes of sand

Problems:

- ✓ Serves only a temporary solution that may need to be repeated frequently
- ✓ Temporarily interrupts sediment supply which could result in downdrift erosion
- ✓ Least effective in front of sea walls, where protection may be most needed
- ✓ Modification or destruction of habitat
- ✓ Offshore borrow areas may increase erosion rates
- ✓ Size of borrow area may adversely steepen beach profile

Table 1. Beach scraping studies with follow-up monitoring (Adapted from Wells and McNinch 1991)

Location	Method	Scraping Duration	Scraping Length	Results	Reference
Jupiter Island, FL	Sauerman Drag	Two 1-month periods, 1967	0.2 km	Moderately Successful	Univ. of FL 1969
Myrtle Beach, SC	Bulldozer	Three 1-month periods 1981-1982	15 km	Moderately Successful	Kana and Svetlichny 1982
Ocean City, MD	Bulldozer	Periodically over 18 mos. 1976-1977	13 km	Detrimental	Kerhin and Halka 1981
Folly Beach, SC	Not Specified	Two week period Summer 1977	5 km	Detrimental	Tye 1983
Topsail Beach, NC	Front End Loader	Periodically over 6 mo. Every year	1 km	Moderately Successful	McNinch 1989

REFERENCES CITED

BRUUN, P. (1983) Beach scraping – is it damaging to beach stability? *Coastal Engineering*. 7:167-173.

GREENE, K. 2002. *Beach Nourishment: A Review of the Biological and Physical Impacts*. ASMFC Habitat Management Series #7. Retrieved on 6 June 2003 from the Atlantic States Marine Fisheries Commission website: http://www.asmfc.org/PUB/Habitat/HMS&BeachNourishment.pdf

KANA, T.W. and M. SVETCLICHNY. 1982. Artificial manipulation of beach profiles. *Proceedings of the 18th Coastal Engineering Conference*. Cape Town, South Africa, 903-922.

KERHIN, R.T. and J. HALKA. 1981. Beach changes associated with bulldozing of the lower foreshore. *Maryland Geological Survey, Open File Report 7.*

MCNINCH , J.E. and J.T. WELLS. 1992. Effectiveness of beach scraping as a method of erosion control. *Shore and Beach.* 60:13-20.

PETERSON, C.H., D.H.M. HICKERSON, and G.G. JOHNSON. 2000. Short-term consequences of nourishment and bulldozing on the dominant large invertebrates of a sandy beach. *Journal of Coastal Research.* 16(2):368-378.

ROGERS, S. 2003. Re: Beach renourishment via nearshore source. Retrieved on 13 March 2003 from Shoreline-change listserv. shoreline-change@csc.noaa.gov

SCHMID, K. 2003. Re: Beach renourishment via nearshore source. Retrieved on 4 March 2003 from Shoreline-change listserv. shoreline-change@csc.noaa.gov

TYE, R. 1983. Impact of Hurricane David and mechanical dune restoration on Folly Beach, SC. *Shore and Beach.* 51:3-9.

UNIVERSITY OF FLORIDA. 1989. *Final feasibility report and environmental impact statement on hurricane protection and beach erosion control.* Wilmington District, South Atlantic District, in Wells, J.T. and J. McNinch 1991.

WELLS, J.T. and J. MCNINCH. 1991. Beach scraping in North Carolina with special reference to its effectiveness during Hurricane Hugo. *Journal of Coastal Research.* Special Issue No.8:249-261.

BEACH DEWATERING

Concept

Beach dewatering is based on the principle that a lowered water table within the beach contributes to the accretion of sand. As swash runs up on the beach, water from the wave is quickly drained through the dry beach, leaving its suspended sand load as a deposit on the beachface. In short, beach dewatering continuously removes water from the beach, in the expectation that a higher and wider beach will develop. Interest in this technology stems from the prospect that raising and widening the beach will in turn serve as a source of coastal protection and recreation.

Several theories have been proposed to explain the mechanism of beach stabilization through dewatering (Mulvaney 2001). In a detailed literature review, Turner and Leatherman (1997) suggest that the origin of this concept lies in Bagnold's (1940) laboratory research in which it was determined that the ratio of swash to backwash energies determines the slope and elevations of the beach profile. In particular, the velocity of the swash up the beach depends on the wave height and water depth, the slope of the beach, and the sediment surface roughness (Grant 1948). The velocity of the swash will decrease if water is lost to infiltration, and as the velocity decreases, suspended sediment deposition can occur. During the backwash period, the velocity increases and the deposited sediments can again be eroded. The velocity with which the backwash returns is dependant upon the slope of the beach and the amount of infiltration that has occurred. A reduction of backwash compared with the onshore swash due to water infiltration results in an enhanced net onshore transport of sand, relative to a less permeable beach face.

Grant (1948) linked the elevation of groundwater within the beach to its erosional and accretional trends on sandy coasts. He concluded that a permeable beach with a lower water table reduces backwash flow and thereby facilitates sedimentation and stability. Conversely, backwash flow velocity increases if groundwater is actively seeping out of the beach. Another theory used to define the mechanism of beach stabilization through drainage is based on the stability that is imparted on sediment particles when pore water is reduced. In addition to a reduction in particle buoyancy, intergranular stresses are increased through drainage, resulting in a more stable sedimentary environment (Lenz 1994). Seepage of groundwater out of the beach face can contribute to sediment liquefaction and slumping, so lowering the water table should act to reduce such seepage. In either case, a beach drainage system removes water from the beach face, which in turn increases the opportunity for infiltration that promotes backwash energy loss and sand accumulation.

Applications

Experimental Installations

Although laboratory studies and modeling have concurred with the beach drainage theories, Turner and Leatherman (1997) caution that the experiments depict the beaches as a thin layer of unconsolidated material over an impermeable surface, which does not behave like many natural beaches that overlay an unconfined aquifer. In order to test the hypothesis relating sediment balance to water table position, water tables were first regulated by pumping in natural beaches in New South Wales, Australia (Chappell et al. 1979). From this study, it was recommended that beach conservation only be assisted by water table pumping at *appropriate* times in order to achieve measurable results. The suggested times include during "storms when beach face slumping can be minimized and during prolonged periods of moderate swell, when sand accretion may be accelerated" (Chappell et al. 1979). Despite this recommendation, subsequent field experiments have operated the pumps either on a continual basis, emptying the sump every time it filled, or even through direct and continuous pumping. It is important to note that continuous pumping would not be appropriate for commercial operations because of the increased cost of operation and maintenance (Sato et al. 2001). The effectiveness of a beach dewatering system during a storm is also questionable, and an important limitation that is addressed below.

In lieu of using a pump, several field experiments have been based on the assertion that a water table can be lowered without pumps by enhancing a beach's own drainage capacity or hydraulic conductivity using drains (Figures 3 and 4) (Davis et al. 1992). At Dee Why Beach in New South Wales, Australia, a drain commonly used to draw off groundwater from roads, parks, and playing fields was installed beneath the beach. The drains immediately lowered the water table and reduced asymmetry of the tidal response. The beach face morphology was considered to be stabilized, but accretion was not noted (Davis et al. 1992). A gravity drainage system was also installed at the Hazaki Oceanographic Research Station in Japan, a site that is fully exposed to the wave energy of the Pacific Ocean. Seawater infiltration was considered to be enhanced in the drained area because the percolation resulted in air bubbles actively coming to the surface of the beach. While areas of the natural beach remained wet from wave run-up, the drained beach surface was dry. From this experiment, it was concluded that the permeable layer could drain the groundwater gravitationally through the drainage pipe into the surf zone, even during a storm (Katoh and Yanagishima 1996).

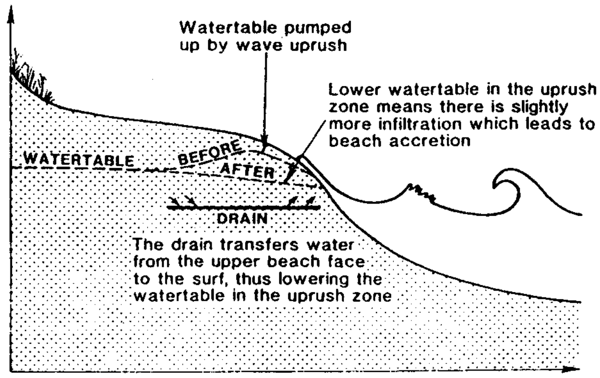

Figure 3. Effect of gravity drain on the water table (Davis et al. 1992)

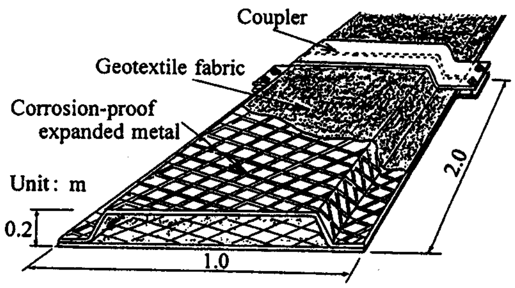

Figure 4. Permeable layer buried beneath the beach surface as a gravity drain (Katoh and Yanagishima 1996).

A highly questionable non-pumping mechanism has been marketed in which a system of vertical pipes connect the beach groundwater with the atmosphere. This method is based on the premise that the groundwater hangs on a vacuum beneath the beach surface. If this were true, the pipes would have the same effect as opening up a valve, but the beach water table is not under a vacuum, so there is no physical reason why the pipes should affect the water table level and produce beach accretion (Nielson 2002).

Prototypical pumping systems (Figure 5) have successfully lowered the water table level and have resulted in morphological responses ranging from no change to stabilization to accretion. A dewatering system installed at Kashiwabaru Beach in Kagoshima, Japan was used to experiment with drainage pipe placement. Despite the multiple pipe locations and the use of direct and continuous pumping, no definitive differences between the dewatered beach and control beaches were found (Sato et al. 2001). A prototype installation at Holme Beach in Norfolk, England resulted in inconclusive results due to stormy weather (Mulvaney 2001); however, this installation elucidates the "soft" nature of this approach. The beach is part of the Holme Nature Preserve so beach dewatering was chosen as an erosion management tool because minimal visual impact and lower costs were significant considerations. An installation in Hirtshals East in Denmark experienced significant accretion in which the coastline stabilized 25 meters in front of the drain (Vesterby 1994). Well sorted, medium-grained sediment of moderate permeability is found at this site. The success there lead to an installation at Hirtshals West, where fine-grained, silty sand and low permeability are characteristic. In addition, there is no nearshore drift at this site due to harbor construction. It was reported that the beach in front of the pump still experienced accretion, while the reference areas eroded (Vesterby 1994).

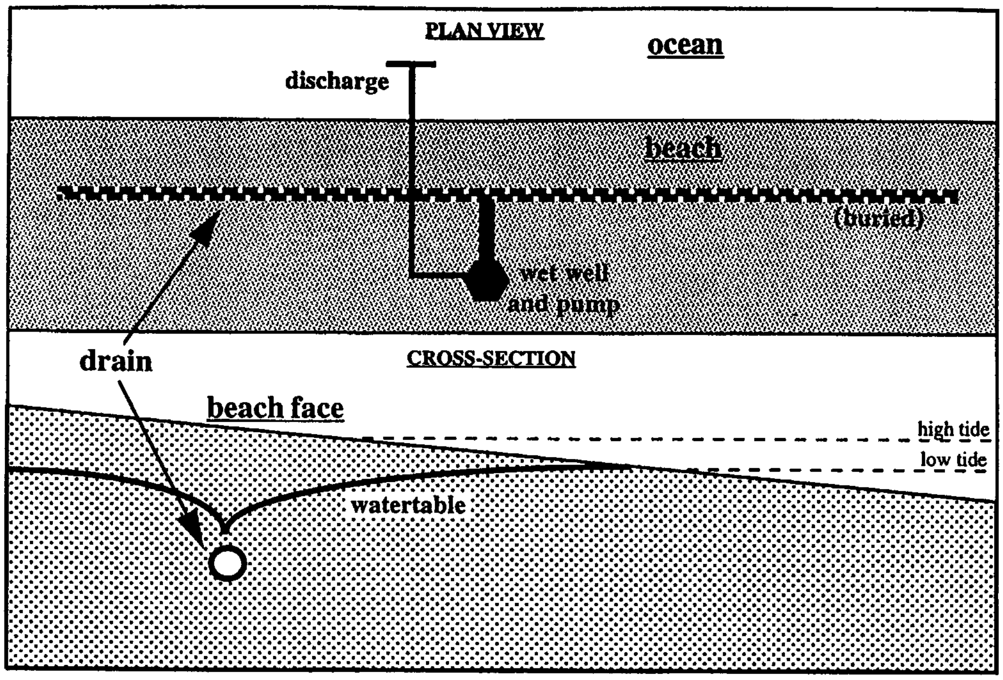

Figure 5. Diagram of a beach dewatering system using a pumping mechanism (Turner and Leatherman 1997).

Commercial Installations

The performance of the experimental beach dewatering systems has lead to commercial interest in the technology. The Danish Geotechnical Institute (Formerly DGI, now GEO) holds the U.S. patent and is commercializing the technology as the Beach Management System™. In the United States, the patent is licensed to Coastal Stabilization, Inc. (CSI) and the technology is marketed as STABEACH™. Commercial installations have been located in England, Denmark, and the United States, and like the experimental installations, have experienced mixed success. A commercial installation at Towan Beach in England was chosen because a deteriorating seawall backs the intertidal beach. The expense of repairing or replacing the seawall was unfeasible, so a dewatering system was selected. The beach posed a unique situation for drainage because it has a macrotidal regime, unlike any other Beach Management System installation location

(Mulvaney 2001). During six years of monitoring, a trend of accretion was found and the system withstood the effects of storms that were magnified due to reflection from the seawall. Additionally, the beach dried out during successive high waters where it had previously remained wet, increasing the recreational use of the beach (Mulvaney 2001). In the United States, Nantucket Island, Massachusetts was the site of a commercial installation of the STABEACH™ system. Like other systems, the groundwater level was measurably influenced by dewatering and the greatest amount of drawdown occurred at high tide. Although the anticipated response of the lowered groundwater level was the development of a higher, wider berm and steeper foreshore slope when compared to undrained beaches, such a change was not clearly apparent in the monitoring data. According to Curtis and Davis (1998), "It was difficult to discern the overall effectiveness of the systems when compared to untreated regions of the shoreline by looking at shoreline change or beach volume change observations in relation to periods of full operation." They have specifically noted the periods of full operation because the systems were unable to operate continuously due to frequent storm-related power failures and equipment damage. Delays of weeks to months resulted from equipment damage as the failure was discovered, identified, and repaired.

Storm Response

Notwithstanding the beach response to storm events, the dewatering mechanisms are not likely to withstand frequent or severe storms. Several field studies have indicated repeated storm damage to both the pumping mechanisms and the drains. In the Englewood Beach, Florida installation, a series of storms rendered the system inoperable after a limited operational period (Curtis and Davis, 1998). Despite a horizontal placement below the sand surface to minimize risk of exposure during storms, storms damaged the seaward end of the drains placed on Dee Why Beach, Australia, reducing their efficiency (Davis et al. 1992). At Branksome Chine in England, the dewatering system's effectiveness varied and performance was inhibited by repeated storm damage (Mulvaney 2001). On several occasions, the sump was rendered inoperable as it was completely filled with sand. In addition, storms exposed the sump outlet as well as leaving pipes visible on the dry beach (Figure 6). The exposure of equipment is a safety hazard to people using the beach, and the cost of maintaining a dewatering system can never be truly predicted.

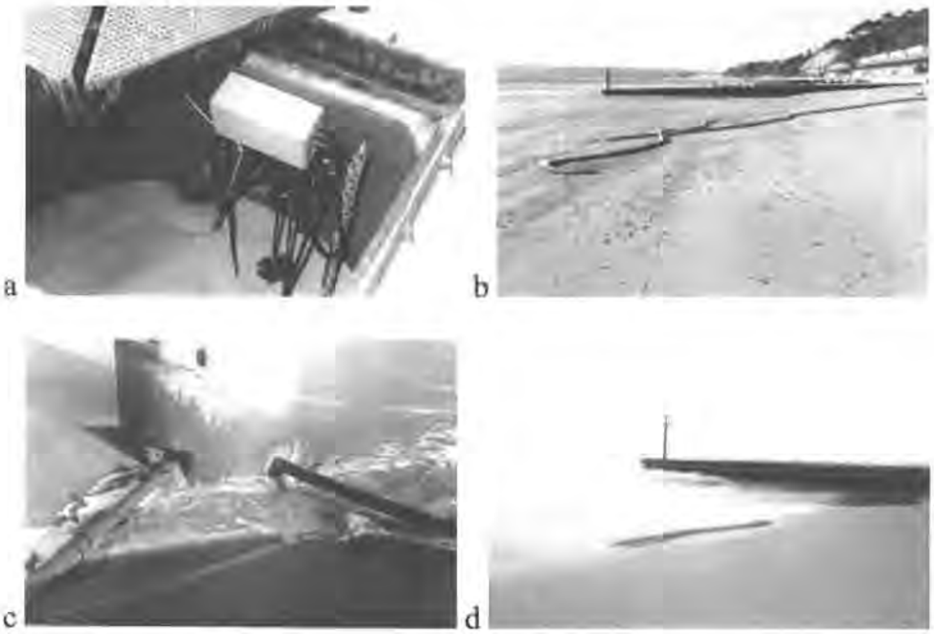

Figure 6. Damage experienced at Branksome Chine, England: (a) sump pump filled with sand; (b) damaged drainage pipes on the beach; (c) low beach levels exposing sump outlet; and (d) uncovered pipe (Mulvaney 2001)

The effectiveness of beach dewatering systems in erosive storm events has varied between field tests. In general, however, a dewatered beach cannot be depended upon to provide protection from storm erosion. In fact, Bruun (1989) suggested that beach dewatering could be expected to be successful for erosion reduction only under gentle wave conditions, and would be unlikely to prevent erosion by storm waves. It is probable that erosion will occur despite the dewatering system, but some studies have indicated that the drained beach will either erode more slowly or recover more quickly than non-drained neighboring beaches. At the Hirtshals East site in Denmark, a storm struck while the pumps were inactive, resulting in significant erosion; however, the beach returned to its former size in a historically eroding coastline. Likewise, at Thorsminde, Denmark, episodes of storm retreat were restored at the drained beach sites (Vesterby 1994). Vesterby (1994) justifies loss during a storm by suggesting that although erosion in front of the system will occur, "due to the wave activity, much sand will be in suspension nearshore and this sand will be added in excess to the beachfront by the end of the storm." He does not provide justification for this theory. At the gravity-drained system at Hazaki Oceanographic Research Station, severe storm conditions eroded the berm of the drained beach to the same constant slope as the natural beach, however the permeable layer decreased the speed of beach erosion during the storm. The rate of accumulation following the storm was considered a "quick recovery" on the drained beach (Katoh and Yanagishima 1996).

Most of the field studies seem to demonstrate successfully that beach drains can lower the groundwater level; however, the use of dewatering systems to significantly accrete beach sand and minimize erosion is still questionable. The underlying physical mechanisms that may contribute to the success of beach dewatering have yet to be completely revealed, despite the impression that commercial interests present in marketing brochures and literature (Turner and Leatherman 1997). Even the president of

CSI has stated that, "We do not believe it is possible to predict the quantitative results of draining a beachface until there is a sufficient backlog of completed projects which can be categorized with respect to the many elements which affect erosion and accretion on any specific beach" (Lenz 1994). He also suggests that the beach drainage process does not eliminate erosion, and severe erosion conditions will cause erosion on a drained beachface. One should consider this method of shoreline stabilization with caution, and only after a great deal of consideration has been given to the site-specific conditions.

Management Considerations

Despite the documented field and laboratory tests, it is impossible to determine precisely which beach settings will experience success with this method. Evidently, there are some situations where dewatering is more effective than at other sites, but the factors determining the successes are not clear. It is apparent that dewatering produces some beneficial effects in fair weather conditions, and likely on calm, mildly erosive coasts. A limited sand supply is also likely to affect the performance of a beach dewatering system, since a supply of material is necessary for accretion to occur, although a benefit to this technique is that the sand will automatically be suitable for the site. Installations on exposed or stormy coasts are more likely to fail, particularly on coasts that experience erosive rip currents, but causes of some of the scheme's failures remain unknown.

The link between a drop in the water table and a change in the beach profile and accretion rate is understood, but the exact nature of this link is less clear. Factors such as time lags, changes in response to the tidal stage, and short-term changes in response to swash and backwash have not been defined in the context of the beach dewatering scheme. Thus, engineering recommendations and guidelines have yet to be developed.

Factors such as the placement within the beach profile, depth of burial, pumping time, and the extent needed to cover a beach have been suggested by the commercial manufacturers, but are based on a limited number of installations. Installation will therefore be an experiment that must be preceded by an assessment of local conditions. Like all coastal protection measures, an examination of the coastal processes and causes of erosion that shape the location of concern should lead any installation. Geotechnical and hydrological investigations must be carried out to make preliminary determinations about the effectiveness of a drain system on any given beach. A dewatering system is likely to be more effective in a beach where a high water table is already contributing to erosion. The permeability of the sand, subsurface stratification, and groundwater discharge level must also be considered. Another consideration of all coastal protection techniques is the potential for detrimental impacts on neighboring beaches. While considered a "soft" engineering solution to coastal erosion, beach dewatering is not a complete alternative to beach nourishment because new sand volume is not produced. Because beach growth is encouraged without a net increase in sediment availability, there are potential implications for the sediment supply to adjacent beaches.

Additional evaluation of laboratory and full-scale demonstrations is necessary to document engineering design criteria and to quantitatively predict system performance (Curtis and Davis 1998). The field tests have concluded with questionable results, so any installation should be approached with the recognition that the outcome is unpredictable. There are many complex variables that affect the outcome of beach dewatering, and it should only advance with an experimental status.

Benefits:

- ✓ Unobtrusive in natural setting
- ✓ Fairly low initial and maintenance costs when compared to nourishment
- ✓ Increased beach width provides improved coastal protection
- ✓ More dry beach for recreational use
- ✓ Increased socio-economic stability for coastal tourism dependent towns
- ✓ Coastal protection without alteration of wave dynamics

Problems:

- ✓ Unlikely to prevent erosion by storm waves
- ✓ Minimal durability of mechanism against major storm events
- ✓ Multiple drainage networks may be needed to cover an entire beach profile
- ✓ Addition of sand that may have been intended for downdrift beaches can result in neighboring erosion issues
- ✓ Increased beach width may create a false sense of security and promote further development
- ✓ Significant down time when non-functioning, especially during storms

Table 2. Major Beach Dewatering Installations

Installation Date	Location	Mechanism	Results	Reference
1979	Durras Beach, New South Wales, Australia	Pump	• Unable to detect impacts on morphology	Chappell, et al. 1979
1981	Hirtshals West, Denmark	Pump	• Significant accretion noted	Vesterby 1994
1983	Hirtshals East, Denmark	Pump	• Unable to prevent storm-induced erosion • Material accreted while reference areas eroded	Vesterby 1994
1985	Thorsminde, Denmark	Pump	• Test beach accreted while control eroded • Effective length greater than drain pipe length • Episodes of storm retreat restored	Vesterby 1994
1988	Sailfish Point, Stuart, FL	Pump	• Inconclusive in initial monitoring period • Later moderate accretion	Dean 1990 in Curtis and Davis 1998
1992	Dee Why Beach, Australia	Gravity	• Dewatered shoreline showed greater stability	Davis et al. 1992
1993	Englewood Beach, FL	Pump	• Inoperable due to storms	Curtis and Davis 1998
1994	Enoe Strand, Denmark	Pump	• Measurable accretion	DGI in Turner and Leatherman 1997
1994	Towan Beach, England	Pump	• Rapid accretion did not survive storm • Beach dried out where surface previously remained wet • Proved effective in macrotidal regime	Mulvaney 2001
1994	Hazaki Research Station, Japan	Gravity	• Erosion reduced during storm event • Enhanced post storm recovery	Katoh and Yanagishima 1996
1994	Nantucket Island, MA	Pump	• Drained beach showed no significant difference from undrained beach	Curtis and Dean 1998
1997	Holme Beach, Norfolk, England	Pump	• Positive effect compared to undrained beaches • Overall results considered inconclusive	Mulvaney 2001
1998	Branksome Chine, Dorset, England	Pump	• Storm damage not as severe on drained beach	Mulvaney 2001
1998	Kashiwabaru Beach, Japan	Pump	• No definite difference between dewatered beach and control profiles	Sato et al 2001

REFERENCES CITED

BAGNOLD, R.A. 1940. Beach formation by waves: some model experiments in a wave tank. *Journal of the Institute of Civil Engineers.* 15:27-54.

BRUUN, P. 1989. The coastal drain: what can it do or not do? *Journal of Coastal Research.* 5(1):123-125.

CHAPPELL, J., I.G. Eliot, M.P. Bradshaw, and E. Lonsdale. 1979. Experimental control of beach face dynamics by water table pumping. *Engineering Geology.* 14:29-41.

CURTIS, W.R. and J.E. DAVIS. 1998. Field Evaluation/Demonstration of a multisegmented dewatering system for accreting beach sand in a high-wave-energy environment. *US Army Corps of Engineers Waterways Experiment Station Construction Productivity Advancement Research Program Final Report.* CPAR-CHL-98-1.

CURTIS, W.R., J.E. DAVIS, and I.L. TURNER. 1996. Evaluation of a beach dewatering system: Nantucket, USA. *Proceedings of the 25th Coastal Engineering Conference.* American Society of Civil Engineers, New York, 2677-2690.

DAVIS, G.A., D.J. HANSLOW, K. HIBBERT, and P. NIELSEN. 1992. Gravity drainage: a new method of beach stabilization through drainage of the water table. *Proceedings of the 23rd Coastal Engineering Conference.* American Society of Civil Engineers, New York, 1129-1141.

GRANT, U.S. 1948. Influence of the water table on beach aggradation and degradation. *Journal of Marine Research..* 7:655-660.

KATOH, K. and S. YANAGISHIMA. 1996. Field experiment on the effect of gravity drainage system on beach stabilization. *Proceedings of the 25th Coastal Engineering Conference.* American Society of Civil Engineers, New York, 2654-2665.

LENZ, R.G. 1994. Beachface drainage – a tool for coastal stabilization. *Proceedings of the Seventh National Conference on Beach Preservation Technology.* Tampa, Florida, February 1994, 27-52.

MULVANEY, H.S. 2001. Beach Drainage Network. Retrieved on 12 April 2003, from http://www.beachdrainage.com

NIELSEN, P. 2002. Trouble with magical pipes. Retrieved 13 April 2003, from The University of Queensland, Coastal Engineering Research Centre website: http://www.uq.edu.au/coastal/downloads/nielsen/drainage.pdf

TURNER, I.L. and S.P. LEATHERMAN. 1997. Beach dewatering as a 'soft' engineering solution to coastal erosion – a history and critical review. *Journal of Coastal Research.* 13(4):1050-1063.

VESTERBY, H. 1991. Beach face dewatering – the European experience. *Proceedings of the Seventh National Conference on Beach Preservation Technology.* Tampa, Florida, February 1994, 53-68.

ADDITIONAL REFERENCES

ADAMS, J.W. 1989. The fourth alternative – beach stabilization by beachface dewatering. *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* Charleston, South Carolina, July 1989, 3959-3974.

BIRD, E.C.F. 1996. *Beach Management.* New York: John Wiley.

KANAZAWA, H., F. MATSUKAWA, K. KATOH, and I. HASEGAWA. 1996. Experimental study on the effect of gravity drainage system on beach stabilization. *Proceedings of the 25th Coastal Engineering Conference.* American Society of Civil Engineers, New York, 2640-2653.

NIELSEN, P., S. ROBERT, B. MOLLER-CHRISTIANSEN, and P. OLIVA. 2001. Infiltration effects on sediment mobility under waves. *Coastal Engineering.* 42:105-114.

TERCHURNIAN, A.V. 1990. Performance of beachface dewatering. The STABEACH system at Sailfish Point (Stuart), Florida. *Proceedings of the Third Annual National Beach Preservation Technology Conference.* St Petersburg, Florida, February 1994, 185-202.

COBBLE BERMS/DYNAMIC REVETMENTS

Concept

A strategy for shore protection of relatively recent origin is the use of what has been variously termed "dynamic revetments", "cobble berms", or "rubble beaches". The approach involves the construction of a gravel (shingle) or cobble beach at the shore, in front of the property to be protected. In this respect, a constructed cobble berm represents a transitional strategy between a conventional riprap revetment of large stones and a beach nourishment project. The name "dynamic revetment" reflects this transition in that by consisting of gravel and cobbles, the material is expected to be moved by waves and nearshore currents – it is "dynamic", contrasting with a conventional "static" riprap revetment where the boulder-sized quarry stone is designed not to move under the expected forces of waves during extreme storms. The cobble berm is constructed to provide protection to coastal developments while remaining more flexible than a conventional riprap revetment, not failing when movement occurs.

In application, the constructed cobble berm either fronts directly into the water or is back of a sandy beach that is providing inadequate buffer protection for the properties from the forces of waves and currents. Such morphologies are common on coasts, so the placement of a cobble berm constitutes a more natural and aesthetic solution than a conventional revetment or seawall. Indeed, the objective is to construct the cobble berm to be as close as possible to the form of natural cobble beaches in order to be compatible with the natural environment and to insure its stability wherein it responds to ocean processes like a natural cobble beach.

The origin of the use of a cobble berm for shore protection is unclear. There are early papers on the artificial nourishment of gravel (shingle) beaches (e.g., Muir Wood 1970), and aspects of their design can be similar to those for a cobble berm. The concept of a structure having a dynamic response to wave attack has also been applied to rubble-mound breakwaters, but of a much larger scale (Bruun and Johannesson 1976, Willis et al. 1988). The earliest published paper that clearly considers the design of an artificial gravel beach is that of van Hijm (1974), the application having been along the bank of the entrance to Rotterdam Harbor in the Netherlands, needed to dissipate wave energy rather than serving for shore protection. A similar engineering application is that of Ahrens (1990), who undertook research into the use of a constructed cobble berm to protect a bulkhead located in shallow water. The use of cobble berms for shore protection has been particularly advanced by the observation that natural cobble beaches often protect the backshore from erosion. Such occurrences are common along the Oregon coast, where natural cobble beaches served as the basis for the design of a cobble berm to protect a State park (Allan and Komar 2002; Komar, Allan, and Winz 2003).

Whatever the origin of the concept, the basic strategy has evolved into one of building a gravel or cobble beach for shore protection. The dynamic structure is effective in defending properties because the sloping, porous cobble beach is able to disrupt and dissipate the wave energy, even during intense storms. There are a number of practical advantages in using a cobble berm for property protection (Ahrens 1990). Stone size is smaller than the large armor stone used in a riprap revetment, and placement does not require special care so its construction is also simpler. Although more material may be needed in a cobble berm, its construction is generally less expensive than conventional structures. However, the primary motivation for using a cobble berm rather than a riprap revetment is its natural appearance, so that it conforms to the setting of the coast in being indistinguishable from natural cobble beaches. This may make its construction more acceptable by management authorities, even on coasts that do not permit the use of conventional "hard" structures.

It cannot be expected that a cobble berm will provide the same level of protection as a conventional riprap revetment or seawall. Since the gravel and cobbles can be moved by the waves, the placed material may be transported alongshore or offshore by extreme waves, so that maintenance requirements can be expected to be more frequent than in the use of "static" structures. The cobble berm itself may become a hazard to shorefront properties if the cobbles become projectiles during a storm, flung by the waves against houses.

Design

The design of cobble berms/dynamic revetments has been variously based on experiments undertaken by engineers in laboratory wave basins, and on observations and measurements made by coastal geologists during many years of studying natural gravel and cobble beaches. The results of laboratory studies (e.g. van Hijm 1974; van der Meer and Pilarczyk 1987; van der Meer, et al. 1996; Ahrens 1990; Ward and Ahrens 1991) provide guidance on the quantity of stone needed to provide adequate protection from wave attack. A shortcoming of the experimental studies undertaken by engineers is that they have not included the condition where a sand beach fronts the cobble berm, the more common setting for their use in protecting shorefront properties.

There is an extensive literature derived from the study of natural gravel and cobble beaches. Of relevance to the design of cobble berms are documentations of cobble movement by waves and how the clasts are sorted by size and shape across the beach profile, or are transported alongshore at different rates. A particularly relevant field study of natural cobble beaches is that of Everts, Eldon, and Moore (2002) in Southern California, in that it was undertaken with the purpose of providing improved design criteria for constructed cobble berms. At the study sites, natural cobble accumulations are found at the back of an otherwise sandy beach that dissipates much of the energy of the waves. Repeated profiles established that the cobble deposits accrete in the winter and lose volume in the summer, opposite to the fronting sand beach and what is normally found in beaches. The explanation involved the movement and dispersal of cobbles into the sand portion of the beach during the summer, and their return to the cobble accumulation by winter waves. At times of storms, the cobble beaches are steepened, again opposite to the general response of sand beaches that generally decrease in average slope as sand is moved offshore. This response has also been observed by Komar, Allan, and Winz (2003) in both natural cobble beaches and a constructed cobble berm on the Oregon coast, a response that is important to their stability.

Applications

Until recently, most of the construction of cobble berms for shore protection has occurred in relatively low wave-energy environments. Downie and Saaltink (1983) describe an installation on the shore of Vancouver, Canada, within the fetch-restricted Strait of Georgia. The site is a pocket beach adjacent to the campus of the University of British Columbia where a conventional structure for shore protection was undesirable;

the use of a cobble berm was a compromise between the engineers, who wanted to protect the University's engineering building from the threat of bluff erosion, and users of the beach, this being a favored nudist beach. Johnson (1987) documents several examples in the Great Lakes of North America where cobble berms proved to be cost effective solutions for shore protection. Initially their creation was inadvertent, where gravel beaches formed from copper mine tailings that had been disposed of on the beach, or where a beach nourishment project used a mixture of sand and gravel, with the sand subsequently being lost while the waves concentrated the gravel into a revetment-like deposit at the back of the beach. Based on these serendipitous examples demonstrating their potential for shore protection, cobble berms have been intentionally constructed at Great Lakes sites. Lorang (1991) reports on the construction of a perched gravel beach used for shore protection in Flathead Lake, Montana.

An interesting extension of this approach for shore protection is a gravel beach accumulation at the Port of Timaru, on the east coast of the South Island of New Zealand (Kirk 1992). The breakwater of the port had suffered degradation due to direct attack by high-energy waves, so a protective beach was established along the length of the breakwater by constructing a short groin at its end, which partially blocked the longshore gravel transport that previously had bypassed the breakwater. The accumulated gravel beach has been so successful in dissipating wave energy, that large rocks of the breakwater have been "mined" for use in structures elsewhere.

Only recently have large-scale cobble berms been constructed on the ocean shore of the United States for erosion control. A 300-meter long cobble berm, backed by an artificial dune containing sand-filled geotextile bags, was constructed in 1999 in Cape

Lookout State Park, Oregon (Figure 7), following several years of extreme erosion (Allan and Komar 2002; Komar, Allan, and Winz 2003). The selection of a cobble berm to prevent further erosion and flooding of the park's campground was based primarily on the desire to maintain the park in as natural a condition as possible, not wanting a large-scale "hard" structure separating the park from its main attraction, the beach. An extensive monitoring program is underway, including monthly profiles, measurements of cobble movement and the progressive development of particle sorting patterns, and video data collection of swash runup on the berm. Comparisons are being made with similar measurements on natural cobble beaches found along the Oregon coast. Another US West Coast installation is a test section located at Surfers Point, Ventura, California, designed and constructed in 2000 by Coastal Frontiers Corporation to protect eroding parklands and a bicycle path. The choice of a cobble berm rather than a conventional structure was in part influenced by this stretch of shore being an important surfing site.

Figure 7. Construction of a cobble berm at Cape Lookout State Park, Oregon (courtesy of Oregon State Parks).

Management Considerations

The negative effects that are associated with conventional "hard" structures are not usually attributed to cobble or gravel beaches. However, because an artificial cobble berm represents a transitional strategy between a traditional riprap revetment and beach nourishment, coastal management regulations for hard structures or beach nourishment may determine their extent of use, depending on the locality. Furthermore, the few existing oceanfront applications of cobble berms make it difficult to evaluate their potential performance in a full range of settings. In Cape Lookout State Park, Oregon, the cobble berm has served to maintain the artificial dune, constructed concurrently, and has taken on a natural appearance, responding to the storms in the same manner as nearby natural cobble beaches (Komar, Allan, and Winz 2003). As noted, storm waves can turn cobbles into projectiles, resulting in significant property damage. Because of this potential, the use of cobble berms is safest if backed by a bluff or substantial dune, or if developments are sufficiently set back beyond the reach of wave-flung cobbles.

Figure 8. Comparison of the constructed cobble berm (a) at Cape Lookout State Park, OR with a natural cobble deposit (b) at Oceanside, OR (courtesy of P. Komar).

Cobble and gravel beaches are not natural features along all coastlines. Coastal tourists and homeowners alike often expect a wide flat sandy beach that offers unimpeded ocean views, and not so much as a broken shell or piece of seaweed along the water's edge. Accordingly, although this approach is considered natural in appearance on a coast that has cobble deposits, it may not be environmentally compatible and acceptable on others.

Benefits:

- ✓ Works with the dynamic nature of the coastal environment
- ✓ Placement and construction are simple and less expensive than traditional "hard" structures
- ✓ Natural in appearance
- ✓ Generally inexpensive to construct
- ✓ Protects upland properties from wave attack
- ✓ Flexible under the attack of waves, and therefore doesn't fail as do static revetments
- ✓ Small gravel or cobbles are less of an obstacle to beach access than large armor stone
- ✓ Often become buried by sand during the summer

Problems

- ✓ Provides less protection than a revetment or seawall
- ✓ Frequent maintenance may be required as material can be expected to move in large storms
- ✓ Cobbles become projectiles during a storm, potentially damaging backing properties
- ✓ Cobbles and gravel do not provide the same recreational opportunities as a sand beach

REFERENCES CITED

AHRENS, J.P. 1990. Dynamic Revetments. *Proceedings of the 22nd International Conference on Coastal Engineering.* American Society of Civil Engineers, New York, 1837-1850.

ALLAN, J.C. and P.D. KOMAR. 2002. A dynamic revetment and artificial dune for shore protection. *International Conference on Coastal Engineering.* American Society of Civil Engineers, New York.

BRUUN, P. and P. JOHANNESSON. 1976. Parameters affecting stability of rubble mounds. *Journal of Waterways, Harbors, and Coastal Engineering.* American Society of Civil Engineers, New York, 102(WW2).

DOWNIE, K.A. and H. SAALTINK. 1983. An artificial cobble beach for erosion control. *Coastal Structures '83.* American Society of Civil Engineers, New York, 846-859.

EVERTS, C.H. C.D. ELDON, and J. MOORE. 2002. Performance of cobble berms in Southern California. *Shore and Beach.* 70(4):5-14.

JOHNSON, C.N. 1987. Rubble beaches versus revetments. *Proceedings, Coastal Sediments '87.* American Society of Civil Engineers, New York, 1217-1231.

KIRK, R.M. 1975. Aspects of surf runup processes on mixed sand and gravel beaches. *Geografiska Annaler.* 57A:117-133.

KIRK, R.M. 1992. Artificial beach growth for breakwater protection at the Port of Timaru, East Coast, South Island, New Zealand. *Coastal Engineering.* 17:227-251.

KOMAR, P.D., J. ALLAN and R. WINZ. 2003. Cobble beaches – the "Design with Nature" approach for shore protection. *Coastal Sediments '03.* American Society of Civil Engineers, New York.

LORANG, M.S. 1991. An artificial perched-gravel beach as a shore protection structure. *Proceedings, Coastal Sediments '91.* American Society of Civil Engineers, New York, 1916-1925.

LORANG, M.S. 1994. Predicting threshold entrainment mass for a boulder beach. *Journal of Coastal Research.* 16:432-445.

MUIR WOOD, A.M. 1970. Characteristics of shingle beaches: the solution to some practical problems. *Proceedings of the 12th Coastal Engineering Conference.* American Society of Civil Engineers, New York, 1059-1075.

van der MEER, J.W. and K.W. PILARCZYK. 1986. Dynamic Stability of rock slopes and gravel beaches. *Proceedings of the 20th International Conference on Coastal Engineering.* American Society of Civil Engineers, New York, 1713-1726.

van der MEER, J.W., W.H. TUTUARIMA and G. BURGER. 1996. Influence of rock shape and grading stability on low-crested structures. *Proceedings of the 25th International Conference on Coastal Engineering.* American Society of Civil Engineers, New York, 1957-1970.

van HIJM, E. 1974. Equilibrium profiles of coarse material under wave attack. *Proceedings of the 14th International Conference on Coastal Engineering.* American Society of Civil Engineers, New York, 939-957.

WARD, D.L. and J.P. AHRENS. 1991. *Laboratory study of a dynamic berm revetment.* Coastal Engineering Research Center, Waterways Experiment Station, US Army Corp of Engineers.

WILLIS, D.H., W.F. BAIRD and O.T. MAGOON. 1988. *Berm breakwaters.* American Society of Civil Engineers, New York, 284.

ADDITIONAL REFERENCES

BLUCK, B.J. 1967. Sedimentation of beach gravels: examples from South Wales. *Journal of Sedimentary Petrology.* 37:128-156.

BRADBURY, A.P. and K.A. POWELL. 1992. The short term response of shingle spits to storm wave action. *Coastal Engineering.* 16:2695-2702.

CARR, A.P. 1969. Size grading along a pebble beach: Chesil Beach, England. *Journal of Sedimentary Petrology.* 39:297-311.

CARR, A.P. 1974. Differential movement of coarse sediment particles. *Proceedings of the 14th Coastal Engineering Conference.* American Society of Civil Engineers, New York, 2249-3362.

DEGUCHI, I., M. ONO and T. SAWARAGI. 1996. Wave on pebble beach and deformation of pebble beach. *Proceedings of the 25th Coastal Engineering Conference.* American Society of Civil Engineers. 851-870.

NICHOLLS, R.J. and N.B. WEBBER. 1987. Aluminum pebble tracer experiments on Hurst Castel Spit. *Coastal Sediments '89.* American Society of Civil Engineers. 1562-1577.

NICHOLLS, R.J. and N.B. WEBBER. 1991. Longshore transport of pebbles: experimental estimates of K. *Coastal Sediments '91.* American Society of Civil Engineers. 920-933.

ORFORD, J.D. 1975. Discrimination of particle zonation on a pebble beach. *Sedimentology.* 22:441-463.

POWELL, K.A. 1988. The dynamic response of shingle beaches to random waves. *Proceedings of the 21st Coastal Engineering Conference.* American Society of Civil Engineers. 1763-1773.

SHERMAN, D.J. 1991. Gravel beaches. *National Geographic Research.* 7:442-452.

van der MEER, J.W. 1992. Stability of the seaward slope of berm breakwaters. *Coastal Engineering.* 16:205-134.

WILLIAMS, A.T. and N. CALDWELL. 1988. Particle Size and shape in pebble-beach sedimentation. *Marine Geology.* 82:199-215.

ARTIFICIAL DUNES

Concept

The design and construction of shore protection structures using sand-filled geotextile containers has increased in recent years (Harris 1989). Interest in their use stems from the ability to deploy them quickly and their relatively inexpensive cost when compared to the traditional structures such as seawalls. The range of applications in which geotextile bags and tubes are being used is growing, with their primarily use having been for groins, berms, sills, bulkheads and revetments. Unlike traditional construction materials such as rock, steel or concrete, geotubes are more easily removed and have a finite lifespan. Thus, they potentially have a less permanent impact on the environment. A newly emerging use of sand filled bags and tubes is as a core of artificially constructed dunes.

Coastal sand dunes serve as a source of protection for upland properties by sheltering them from storm surges and waves, and indirectly as an erodible supply of sand for the fronting beach. Although sand dunes are naturally created by the wind, waves and tides play important roles in shaping the dunes. In particular, storm waves may reach the dune, drawing from the sediment store and transferring it to the fronting beach. Like most coastal features, sand dunes are naturally dynamic and the extent of dune development is a function of the fronting beach profile and sediment type. Dunes tend to migrate landward in response to sea level rise, but are unable to do so when backed by developments and infrastructure. Accordingly, the extent of dune development is also largely dependant upon human use. Dunes have been built upon or removed for development, which disables the buffering role they play. In addition, construction and human foot traffic result in the loss of vegetation, reducing a dune's ability to trap windblown sand that would naturally replenish the sand that is eroded by wave activity. As the protective role of dunes is recognized, the desire to preserve or construct dunes is increasing. In heavily degraded areas, the complete reconstruction of dunes may be necessary.

The construction of artificial dunes is frequently a component of beach nourishment projects. Many artificial nourishment projects include the placement of sand in the upper beach, above the zone of tidal influence to enhance the protection of shore-front properties. The Dutch have long used large dunes as a source of coastal protection. Most dunes along the Dutch coast are manmade and are designed to withstand the 1 in 10,000-year condition of wave intensity and storm surge (Komar 1998). This extreme level of protection is justified because entire cities are present behind the dunes, sometimes lying below mean sea level. Nevertheless, dune building requires a large volume of sand that may not be available. The erosion of dunes is a naturally occurring process, but when the absence or degradation of a dune can result in property damage, waiting for the dune to rebuild is often not an option.

The concept of placing a resistant body within a constructed dune may have evolved from the natural burial of seawalls or revetments. When beaches backed by a seawall or revetment undergo a period of accretion, the structure may become buried in the sand at the back of the beach or beneath the re-formed dune. Subsequent storm conditions may erode the beach, exposing the structure, at which time it again serves its initial purpose, protecting the upland property. The deliberate placement of sand-filled geotextile bags or tubes at the core of an artificial dune is a logical extension of this concept. The technique has not been widely used, although sand-filled containers have been used to protect upland structures and to stabilize dunes since the early 1980's (Zadikoff et al. 1998). There is an apparent paucity of scientific literature documenting the implementation or monitoring of geotextile containers at the cores of artificial dunes. As a result, there is limited guidance for designing and predicting the stability of tube structures (Davis and Landin 1998). For direction, one must turn to earlier applications of sand-filled containers. The marketing materials of the geotextile manufacturers and consulting engineers are also available, but are unlikely to provide full disclosure. Auspiciously, the Texas Bureau of Economic Geology has initiated a monitoring program following the use of geotube-cored dunes, and has made the data available on the Internet (http://www.beg.utexas.edu/coastal/geotube.htm). Their monitoring and evaluation reports can be downloaded, and geographic data viewed with an internet mapping server (ArcIMS), which provide the most complete available information about the use of this method.

Design

Design typically includes placing the geotextile containers in a shore parallel orientation between upland features and mean high water, as illustrated in Figure 9 (Zadikoff et al. 1998). The bags or tubes fortify the dune system, and act much as a seawall or revetment would if the dune system is eroded by waves. The geotubes are adaptable for each project and the design specifications are determined by site characteristics. Originally, it was thought that small sand bags were limited to slope stabilization applications on inland waterways and land uses, while larger geotextile containers were to be used on the open coast. In application, configurations range from very large singular tubes to tiered stacks of various size tubes or bags. The greater mass of larger tubes imparts an element of stability, but their susceptibility to damage, an important limitation discussed below, suggests that a single incident could damage an entire installation. In contrast, when exposed, smaller tubes or bags may be more easily displaced, but are simpler to replace. Depending on the size and location of the geotubes, sand for filling the tubes can be pumped from the nearshore, trucked to the site, taken from nearby beaches, or obtained from dredging activity.

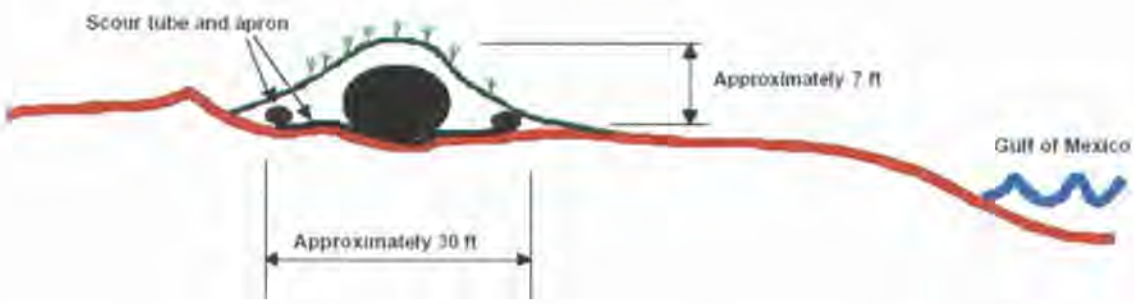

Figure 9. Cross section of typical geotube installation in Galveston County, Texas (Gibeaut et al. 2001).

The crest height of the tubes or bags within a dune is an important consideration - wave overtopping can lead to the loss of sand cover and the erosion and flooding of upland properties. The artificial dune is designed to minimize overtopping and to resist erosion at the elevated water levels of the predicted storm surge. At the same time, the geotube needs to be buried to a depth below the expected beach elevation to minimize undercutting. A workshop was held in 1995 by the US Army Corps of Engineers Waterways Experiment Station (WES) to evaluate recent experiences with geotextile tubes. Although the focus was broad in scope, the limitations and criteria for applications that were identified can be translated to their use as the core of a sand dune. From a synthesis of the conference (Davis and Landin 1998) and from concerns raised by Pilarczyk (1995), the following generalized limitations are identified:

- Geotube resistance to punctures and abrasion is low;
- In almost any area where the public has easy access, the tubes have been vandalized;
- Debris that is forced against the tubes by waves or currents may puncture or abrade the tubes;
- Tubes have been damaged by equipment during construction;
- Tubes can be weakened by ultraviolet radiation from sunlight;
- No method has been documented as the best way to deploy and fill tubes;
- If fill material consolidates over time, the height of the tube will decrease, rendering it insufficient for its intended purpose;
- If the tube is not placed on a level bed, there will be variations in the tube crest elevation;
- A tube may twist or roll to one side while filling, leaving the filling port on the side of the tube;
- Low spots may occur near filling ports;
- Based on conclusions from the workshop, a tube of any size cannot be expected to reach more than 5 feet in height.

Like many innovative schemes, improvements have been made to material and designs based on lessons learned from early installations, resulting in increasing effectiveness, stability, and longevity. Strap systems have been designed to hold units with multiple tubes together, allowing for greater stability at elevations that could not be achieved previously, and to prevent the displacement of individual containers. Fabric bedding is used to prevent differential settling of the containers, and the filter cloth can be extended seaward to form a toe-scour protection apron. The seaward "apron" can be sewn back on itself forming a tube that is filled with sand, which will drop down as the beach erodes seaward of the containers, intending to minimize undercutting (Harris 1989). Protection from vandalism, debris, and UV damage can be achieved by covering the geotextile tubes with compatible sand and planting with dune grass. Covering the tube also serves to create an aesthetically acceptable, natural looking feature on the beach – in essence, a dune.

Applications

Criteria for geotextile tube applications were identified at the WES workshop, based on the experience of the participants (Davis and Landin 1998). Of fundamental importance is the temporary nature of geotextile tubes. The term "temporary" holds several meanings in the context of artificial dunes. A geotube can be used as a temporary measure until a more permanent solution is employed or where structures are not permitted, as they are easily removed. It could be recognized that a temporary tube is one that has scheduled maintenance of repair or replacement upon damage. A geotube could also be considered temporary in that it only becomes effective during certain conditions, such as when exposed by erosion, requiring maintenance to repair and rebury it.

The State of New Jersey has had extensive experience in the use of geotubes in artificial dunes, with installations in Sea Isle City, Avalon, and Atlantic City (Mauriello, personal communication 2003). In the past, artificial dunes were created with a resistant core of clay and gravel. The effect was similar to a sand-filled container, but residents and tourists complained about the orange beach that resulted from the eroding clay core, when exposed. Sand-filled geotextile tubes have served as a suitable replacement. They are used primarily as a temporary solution to localized erosion problems, until alternatives can be implemented. In particular, the City of Sea Isle wanted to build a sea wall to protect the threatened beachfront road after storms in 1998. Instead, an artificial dune was created while a beach nourishment project underwent planning and design. The length of the constructed dune was at least 1 mile, consisting of two tubes in a trench, topped with a single tube. The geotubes were covered with beach sand and planted with dune grass. Perhaps due to the flat profile of the Sea Isle beach, the geotube did not experience undercutting. Although only deemed marginally successful because the tube was quickly exposed as the covering sand was eroded, it did provide a resistant material that withstood erosion until the commencement of nourishment. Following nourishment, however, the dunes were left in place, to provide back-up protection if the nourished beach erodes. The boardwalk in Atlantic City was also threatened by erosion and was awaiting renourishment. The interim response was the construction of an artificial dune. However, the beaches of Atlantic City are very narrow and steeper than the beaches of Sea Isle City. While remaining completely covered in some areas, the tubes locally experienced scouring at the toe, which resulted in their slumping and rolling seaward on the beach. Vandalism was particularly a problem in this urban area. Homeless people cut the tube, and removed sand to create a temporary shelter. Despite such problems, the State of New Jersey considers that these applications have been a success - coastal infrastructure was protected and towns were steered away from armor by this temporary, interim solution.

Although other projects have transpired in the United States and Europe, three major installations have undergone documentation by follow-up monitoring programs - Longboat Key, Florida; Galveston County, Texas; and Cape Lookout State Park, Oregon. The need for protection on Longboat Key resulted from years of continuing shoreline recession that threatened upland properties during relatively minor, high frequency storm events (Barber 1993). In 1988 a series of two ProTechTube II™ geotextile containers were installed landward of the high water level, in front of an existing vertical dune face, to a total length of 182 meters. ProTechTube II™ containers are hollow, flexible tubes with a three-cell cross section (Figure 10). They are designed to be filled with sand and placed shore parallel along a dune face, eroding escarpment, or at the toe of a fill section to retain upland sediment and to reduce erosion during relatively low energy events (Barber 1993). The wedge shape is specifically designed to improve the structure's rotational stability compared to circular containers. To further protect against the effects of scour, the device is constructed with a scour apron and a sand filled tube that can settle should severe profile lowering occur.

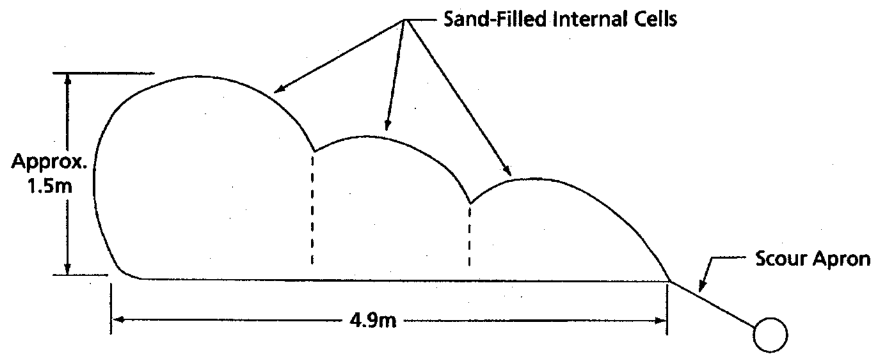

Figure 10. Cross section of three-cell geotextile container (Sample 2002).

Florida Department of Natural Resources permitted the project with the condition that it be covered with beach-compatible upland fill. The structure normally remained completely covered with the exception of exposure during typical winter storms. The device was not intended to serve as the primary shore protection measure during infrequent high-energy storm events, but such storms occurred during the monitoring period. Wave runup overtopped the structure and eroded sand landward of the containers, but no settlement, displacement, or damage to the containers was observed. From four years of follow-up monitoring, the basic conclusion that can be drawn is that: "the tube has been successful in stabilizing the profile landward of the installation while the remaining sections of the property have continued to receive sporadic erosion damage resulting in documented net retreat" (Barber 1993). It was also noted that "the shoreline within the structure limits did not achieve its apparent stability as a result of an artificial cross section protruding seaward and 'fixing' the waterline" (Barber 1993).

Perhaps the most extensive geotextile tube shore protection project is that of the upper Texas coast on the Gulf of Mexico with 7.3 miles (11.7 kilometers) of tube-protected shoreline as of 2001. Installation was in response to the severe erosion initiated by Tropical Storm Frances in 1998. Individual geotubes with an oval cross section of approximately 12 feet (3.5 meters) rest on a fabric scour apron, placed in a shore parallel trench along the backbeach or foredunes, with designs calling for sand and natural beach vegetation to cover them. The geotubes are intended to serve as temporary storm surge protection and erosion control, but "their effectiveness in protecting against storm surge is untested and as erosion structures is questionable" (Gibeaut et al. 2002).

Monitoring has revealed that once the beach erodes to the base of the geotubes, they become undermined and slump seaward. In addition, direct wave attack at some locations quickly removed the sand cover, damaged the UV shroud, and caused punctures (Figure 11). According to Gibeaut et al. (2002), if the beach becomes narrow such that the tubes are seaward of the swash zone, it is expected that they will be destroyed by conditions of less intensity than tropical storms, particularly in settings with hard debris in the surf zone. Monitoring has also revealed that keeping the geotubes repaired, sand covered, and vegetated requires significant effort. Complications such as these are likely a reflection of the geotube placement on the beach profile. More specifically, the geotubes were installed farther seaward than the natural boundaries represented by the line of vegetation, foredunes or bluffs, and some segments were routed seaward of houses, causing a departure from the planned shore-parallel orientation. In such cases, the fronting beach was narrower than adjacent beaches, permitting frequent wave attack against the geotube structures and creating impassable beach segments during times of moderately elevated water levels. A concern at the onset of these projects was that the geotextile tube would cause the adjacent shorelines to retreat at higher rates than they would in the absence of the geotubes, but as of 2002 there was no indication that the geotubes had increased the rate of retreat of adjacent beaches. Gibeaut et al. (2002) concluded that sand supply to adjacent beaches would be reduced and erosion increased if the beaches in front of the geotubes completely eroded and the geotubes prevented erosion behind them; however, the geotubes would likely be destroyed before significantly altering the adjacent beaches.

Figure 11. Uncovering and damage to geotubes due to direct wave attack (Texas Bureau of Economic Geology 2002).

The experience of using geotextile bags within an artificial dune at Cape Lookout State Park, Oregon has been more positive. Cape Lookout State Park had experienced significant erosion during the El Niños of 1982-83 and 1997-98, eliminating the high dunes that had protected the park. The extreme storms of 1998-99 were able to inundate the park facilities, and the loss of the protective dunes suggested that additional damage could be expected during subsequent winters. In response, the aforementioned cobble berm was selected as a protective measure, but for additional defense and in an attempt to restore the park to its former appearance, an artificial dune with a core of sand-filled geotextile bags was constructed immediately landward from the cobble berm (Allan and Komar 2002).

The core of the dune consists of 2,750 geotextile bags, each filled with approximately 1 m^3 of sand (Figure 12). A scour blanket was placed on the ground, the geotextile containers piled on top, then buried under sand, covered with a biodegradable jute-coconut fiber mat, covered by another layer of loose sand, and planted with a native dune grass. Growth of the planted vegetation quickly covered the dune. The completed project did not achieve the recommended design specifications in terms of the expected runup elevations of storm waves combined with high tides. As such, the line of artificial dunes yielded a variable level of defense with the expectation of fairly frequent overtopping (Allan and Komar 2002). Little change in the structures occurred during the first winter due to low wave conditions, but the subsequent winters have brought significant storm events and frequent dune overtopping. Although the wave overtopping carried drift logs and cobbles over the dunes, the general impact to the constructed dune has been small. The cumulative overtopping events have resulted in the loss of some sand and grass from the crest of the constructed dunes, so there is concern about the long-term stability of the artificial dune, particularly once the coconut fiber cloth has biodegraded (Allan and Komar 2002).

Figure 12. Artificial dune core of geotextile bags, overlain with sand at Cape Lookout State Park, OR. The coconut fiber cloth is visible in the foreground (courtesy of Oregon State Parks).

Figure 13. A log on top of the artificial dune as evidence of wave overtopping at Cape Lookout State Park, OR (courtesy of P. Komar).

The level of bag exposure at this installation has been significantly less than for the other monitored projects, perhaps attributable to the fronting cobble berm and the sand-stabilizing coconut fiber cloth. It is also possible that the design using smaller sand-filled containers resulted in a more naturally shaped feature that better resists the forces of the waves. The site continues to undergo monitoring, which will provide additional information about the longevity of the artificial dune.

Management Considerations

The inclusion of geotextile tubes or bags as the core of an artificially constructed dune is intended to provide protection that is greater than a natural dune and to protect the base of the dune during moderate wave attack (First Coastal 2003). In general, it is not intended for protection during intense storms, as undermining, rolling, or overtopping will likely occur with a storm surge and severe wave attack. Due to the uncertain durability of geotextile tubes, depending on them to provide protection for extended periods without maintenance is not recommended (Davis and Landin 1998).

Opponents of this approach suggest that dunes are, by definition, piles of loose sand. By placing a structural component within the dune, is it still a dune? One may logically suggest that cored dunes are just shoreline hardening with sand fill to cover the structure, given that the physical effects of exposed geotubes are essentially the same as seawalls and other traditional hard structures. The system only works without impact to adjacent beaches so long as the dune remains intact. There really is no mechanism to insure that sand is maintained in front of the structure (Anders, personal communication 2003). In fact, in the State of New York there has been considerable controversy surrounding the use of geotubes and debate about the potential negative impacts of long-term use. A geotube was buried in a dune in Southampton, New York, but during a small extratropical storm, the entire structure collapsed after the tubes were torn apart, damaging the house they were designed to protect (Anders, personal communication

2003). Despite the fact that this method has been touted as a "soft" shore protection technique, New York does not differentiate between "hard" structures and "soft" structures and generally does not approve their use.

Although the impacts of an exposed geotube may be similar to traditional hard structures serving the same purpose, unlike traditional hard materials geotubes are easy to remove should site conditions or project objectives change. Artificial dunes with sand-filled geotextile containers should be considered as an aesthetic alternative to revetments or seawalls. They also serve as a quick, temporary solution for emergency erosion response, to be removed after the crisis has passed.

Specific design recommendations cannot be gleaned from the monitored installments as each project has had unique site conditions and geotextile container configurations. As with all shore protection schemes, site-specific conditions should guide design. In general, the location of the artificial dune on the beach profile is a critical consideration. As illustrated by installations in Texas, the placement of the geotubes created landward boundaries to the public beach and subjected the dunes to direct wave attack. If the device is intended as toe protection for an upland dune or bluff, the existing profile should serve as guidance for horizontal placement. Barber (1993) suggests that the success of an artificial dune is most likely when the tubes are not in direct contact with the waterline during average conditions, and function only to reduce the effects of moderately elevated wave energy. If the structure creates wave reflection and scour during prolonged wave attack, a steepened profile will occur, contributing to increased beach erosion rates at the expense of upland protection.

Finally, although sand-filled geotextile containers are generally considered less expensive than traditional construction materials, the cost will vary depending on the source of sand used to fill the tubes (Barber 1993). Whenever sand-filled geotextile containers are used, care should be taken not to deplete sand from the area to be protected. This may necessitate the purchase of sand from an inland or offshore mining source (Armstrong and Kureth 1979). The size of the tubes plays an important role in determining sand sources. In Oregon, the relatively small geotextile containers were simply filled by shovel, while large tubes, like those used in Texas, require a pump or dredge.

Benefits:

- ✓ Can be deployed relatively quickly in an emergency
- ✓ They are not permanent features and hence can be removed should undesirable effects occur
- ✓ Geotextile tubes are typically less expensive than traditional construction materials
- ✓ At the core of a dune, sand-filled geotextile containers serve as a secondary line of protection, should the dune experience erosion
- ✓ When covered by sand and vegetation, the geotextile tubes appear natural

Problems:

- ✓ Maintenance to repair damage to the geotextile material can be extensive
- ✓ Maintaining a sand and vegetation cover is often challenging and requires frequent maintenance
- ✓ Unpredictable longevity
- ✓ Susceptible to vandalism
- ✓ Flexibility of the material makes it difficult to maintain a consistent crest elevation
- ✓ When exposed, the impacts are similar to those of revetments or seawalls
- ✓ May be considered to be a hard structure by coastal management regulations

REFERENCES CITED

ALLAN, J.C. and P.D. KOMAR. 2002. A dynamic revetment and artificial dune for shore protection. *International Conference on Coastal Engineering.* American Society of Civil Engineers, New York.

ARMSTRONG, J.M. and C.L. KURETH. 1979. Some observations on the Longard tube as a coastal erosion protection structure. *Proceedings, Coastal Structures '79.* American Society of Civil Engineers, New York, 250-269.

ANDERS, F. 2003. *Geotubes.* Personal e-mail, 12 June 2003.

BARBER, P.D. 1993. *Review of recent geotextile coastal erosion control technology.* US Army Corps of Engineers. Technical Letter No. 1110-2-353.

DAVIS, J.E. and M.C. LANDIN. 1998. Geotextile tube structures for wetlands restoration and protection: an overview of information from the national workshop on geotextile tube applications. *US Army Corps of Engineers Waterways Experiment Station WRP Technical Note.* HS-RS-3.2. Retrieved on 4 May 2003 from http://www.wes.army.mil/el/wrtc/wrp/tnotes/hsrs3-2.pdf

FIRST COASTAL CORPORATION. 2003. Sand tube and restoration project. Retrieved on 6 June 2003 from the First Coastal Corporation website: http://firstcoastal.net/Geotube/Geotube.htm

GIBEAUT, J.C., T.L. HEPNER, R. WALDINGER, J.R. ANDREWS, R.C. SMYTH, and R. GUTIERREZ. 2002. Geotubes along the Gulf Shoreline of the upper Texas coast. Retrieved on 5 May 2003 from the Texas Bureau of Economic Geology website: http://www.beg.utexas.edu/coastal/2001%20final%20report.pdf

HARRIS, L.E. 1988. Design of sand-filled container structures. *Proceedings of Beach Technology '88.* Shore and Beach Preservation Association, Tallahassee, Florida. 357-364.

HARRIS, L.E. 1989. Developments in sand-filled container systems for coastal erosion control in Florida. *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* Charleston, South Carolina, July 1989, 2225-2232.

KOMAR, P.D. 1998. *Beach Processes and Sedimentation.* New Jersey: Prentice Hall.

MAURIELLO, M. 2003. Personal Communication via telephone re: Geotube use in New Jersey, 10 June 2003.

PILARCZYK, K.W. 1995. *Novel systems in coastal engineering: geotextile systems and other methods, and overview.* HYDROpil Report, Road and Hydraulic Engineering Division of the Rijkswaterstaat, Delft, the Netherlands.

SAMPLE, J. 2002. An evolving method of erosion control. *Geotechnical Fabrics Report.* 20(2):50-52.

ZADIKOFF, G.P.E., D.M. COVELLO, L.E. HARRIS, and E. SKORNICK. 1998. Concrete tetrahedrons and sand-filled geotextile containers: new technologies for shoreline stabilization and other uses. *Journal of Coastal Research.* Special Issue No.26: 261-268.

ADDITIONAL REFERENCES

US ARMY CORPS OF ENGINEERS WATERWAY EXPERIMENT STATION. 1995. *Dredged material-filled geotextile containers.* Environmental Effects of Dredging Technical Notes. EEDP-05-01.

BRUUN, P. 1998. Dunes – their function and design. *Journal of Coastal Research.* Special Issue No.26:26-31.

ARTIFICIAL SURFING REEFS

Concept

Coastal structures specifically designed to improve or maintain surfing conditions while providing shoreline erosion protection are known as multi-functional artificial surfing breaks or ASBs (Ranasinghe, Hacking, and Evans 2001). Offshore coastal protection structures and artificial surfing reefs have been independently constructed in the past; however, the design of a multi-purpose structure is a very new science, which has required extensive research. The concept is based on a fusion of the benefits of artificial reefs for erosion protection and artificial reefs for surfing amelioration. In recent years, interest in creating artificial surf breaks has increased as surfing popularity has grown, generating greater demand on existing breaks (Mead and Black 2001). Pitt (1997) estimates that there are at least ten million active surfers worldwide, supporting a multi-million dollar industry. Surfing skill has also been increasing, adding pressure to the use of world-class breaks and generating a stronger demand for quality waves (Mead and Black 2001). All the while, traditional means of coastal protection can reduce or even destroy surfing waves and create hazardous conditions for surfers (Jackson, Tomlinson, and D'Agata 2002). ASBs enhance coastal amenity value by incorporating the multiple-use opportunity. By including surfing amenity in reef design, much more sophistication is required than demanded by coastal protection alone.

An informative way to envision the complexity of ASB design is through Black's (2000) "Lever Principle." He equates coastal protection structures with machines that have levers to provide adjustment capacity – the sophistication of the machine is related to the number of levers. The designer of a shoreline structure must adjust the levers to suit the local environment. For example, a shore-normal groin is a machine with two levers; the length and orientation of the groin are adjusted by the designer. Black (2000) argues that a single emerged offshore breakwater also has two levers, the breakwater length and distance offshore. Although height will vary, in this case it is always designed to prevent overtopping. In contrast, a single offshore, submerged reef for multiple uses has many levers. For coastal protection, Black (2002) specifies at least eight: (i) distance offshore, (ii) depth of the reef crest below the surface, (iii) placement in relation to natural water depth at the reef site, (iv) longshore reef length, (v) cross-shore reef width, (vi) length/width ratio, (vii) orientation, and (viii) wave refraction/diffraction characteristics. Surfing amenity creates more levers including surfing wave difficulty, take-off design, section size and number, and paddling access. Other water sports such as windsurfing, bodysurfing, or swimming require different adjustments on these levers. Marine habitat quality varies with wave size, wave exposure, suspended sediment concentration, and complexity of the substrate. All of these factors are dependent on reef design and can also be adjusted. Other positive benefits such as fishing, development of tourism, and association of the reef with land-based facilities can also be adjusted and incorporated into the reef design. Accordingly, the sophistication of the offshore submerged reef allows for many adjustment factors.

Two courses of study are necessary to define the emerging technology of multi-purpose reefs -that of the coastal protection effects of offshore reefs and of the dynamics of both surf breaks and surfers. As such, some of the research to date has generated baseline data about surfing, surf breaks, and the formation of coastal features in response to submerged breakwaters that had not been examined before. Extensive additional research is needed at the local scale to design the reef to meet the specific requirements of the community and the environment.

Design

Coastal Protection Aspects

Offshore structures for erosion control are designed to reduce the offshore loss of beach sand during storm events by reducing incident wave energy. In application, offshore protection structures can be submerged, emerged, or intertidal. The depth of the structure dictates the level of coastal protection. Fundamentally, most existing artificial reefs are submerged breakwaters by design, and often the terms are used interchangeably. Breakwaters are typically constructed in shallow water, close to the shore, causing waves to break and dissipate their energy away from the beach. Submerged breakwaters do not provide the same level of protection as emergent breakwaters because waves are able to pass over them, but they are often preferred as they are below the surface of the water and thus nearly invisible to the beachgoer. By altering the impact of the waves and currents in the lee of the breakwater or artificial reef, reduced erosion or sediment accretion in the form of a tombolo or salient may result. Considerable research has been undertaken on shoreline responses to emergent offshore breakwaters, but very little quantitative work has been done on the effect of submerged offshore breakwaters beyond laboratory wave basin studies (Black and Mead 2000). Existing manmade submerged reefs have been crudely rectangular, with a longshore orientation to maximize the protection value (Figure 14). Thus, extensive research was needed to establish the design of artificial reefs that provide additional amenities as well as providing the required degree of shore protection.

Figure 14. Submerged reef for habitat enhancement and shoreline erosion control in the Dominican Republic (Harris 2001).

In nature, coral reefs and offshore sediment bars have been shown to have wave-dissipation effects comparable to constructed breakwaters. Black and Andrews (2001) have likened coral reefs to "nature's way" of offshore protection, and cite examples where tropical islands having fringing reefs require no coastal protection. They also point out that the natural reef often provides a world-class surfing break together with fishing and swimming amenities. To better understand offshore reefs and islands in the natural environment, aerial photographs were examined and analyzed (Andrews 1997; Black and Andrews 2001). From those analyses, formulae for the prediction of salient and tombolo growth in the lee of multi-purpose surfing and coastal protection reefs were established to be used for numerical modeling exercises in the design of artificial reefs (Black and Andrews 2001).

Surfing Aspects

Preceding the construction of an artificial reef for surfing, the general characteristics of natural surf breaks need to be understood. A surfable wave is one in which a surfer can maintain a mean speed equal to or greater than the peel rate (Walker 1974, Ranasinghe et al. 2001). Surf breaks occur as the result of the interaction of waves and the local bathymetry. Incoming deep-water waves shoal and break when they reach shallow water. Wave breaking continues along the wave crest in a peeling action, producing a surfable wave, when the incident waves arrive at an angle to the bottom contours (Walker 1974).

In order to construct a reef for world-class surfing, understanding the natural bathymetry, wave breaking characteristics, and peel angles of high-quality breaks is required. Mead and Black (2001a) conducted field studies that lead to the bathymetric classification of world-class surf breaks in Indonesia, Hawaii, California, Brazil, New Zealand, and Australia. Several recurring meso-scale morphologies were identified from the bathymetries. These components control wave refraction and allow waves to peel at surfable speeds. They are described based on the components' shape and isobath orientation, and the alignment to the "favored orthogonal direction" of incoming waves. Mead and Black (2001a) have defined the favored orthogonal direction as the wave alignment that produces the best quality surfing waves at each break. If out of alignment, waves peel too fast or too slow for high performance surfing. In addition, several common configurations of large-scale reef components were identified, and numerical modeling was used to investigate how the common configurations function (Mead and Black 2001b). It was determined that the reef component combinations act holistically to determine the overall quality and length of the surfing break. Thus, artificial reef designs must apply the holistic principles in order to optimize the surfability of specific sites.

Understanding wave driven currents over reefs is another important consideration for reef design, as surfers commonly have trouble with wave-driven currents. Symonds and

Black (2001) undertook field investigations and numerical modeling, which show that surfing reefs may experience strong wave-driven flows when the reef crest is narrow, detached from the shoreline, fully submerged, and smooth with low frictional resistance.

Studies to determine the maximum sustainable speed of surfers (Dally 2001a, 2001b), to establish a method to quantitatively predict tube shape (Mead and Black 2001c), and to find a classification of surf breaks in relation to surfing skill (Hutt et al. 2001) are all incorporated into artificial surfing reef design. For a summary of these design considerations, one can turn to the *Journal of Coastal Research* Special Issue No. 29, dedicated to the research leading to the development of artificial reefs for coastal protection.

Applications

The inaugural multi-purpose artificial reef, completed in 2000, is located at Narrowneck, on the northern beaches of Surfers Paradise on the Gold Coast of Australia. Designed to complement a beach nourishment project, the two primary goals for the artificial reef were to provide a control for the widened beaches and dunes at Surfers Point and to improve the surfing conditions. The artificial reef was selected because the Gold Coast City Council specified that the amenity value of the beaches be retained and that the panoramic view not be obscured. Moreover, the Gold Coast region is known to experience up to 500,000 m^3yr^{-1} of net longshore transport. Any structure that blocked this flow of sand could have serious downcoast impacts (Black and Mead 2001). The city of Gold Coast was able to maintain 80,000 m^3 of downcoast nourishment, so the structure was designed to allow free passage of 80 percent of the total littoral drift, while still providing coastal control for the nourished profile, and providing enhanced surfability.

A series of design studies was undertaken, some of them mentioned above, to determine the ideal design for this site. On-site field measurements (Hutt et al. 1998), surfing reef design using numerical modeling (Turner et al. 2001), and sediment transport modeling (Black 1999) were conducted. Because the reef had to meet potentially exclusive surfing and sediment transport design criteria, the site-specific wave and sediment modeling were performed concurrently and iteratively (Black and Mead 2001). Armed with the results from the studies of worldwide surf breaks and surfing waves, as well as hydrodynamic, refraction, beach circulation and sediment transport models, a range of different designs was numerically simulated to determine optimal reef design to meet the criteria (Black and Mead 2001). Upon selection of the ideal reef design, physical modeling was undertaken (Turner et al. 2001) to confirm the numerical results prior to construction.

The result, as illustrated by Figure 15, is a submerged, V-shaped, double sided reef. The overall structure is oriented 5° south of the shore normal, facing swells that were assumed to be best for surfing. The reef has a northern arm extending over 400 meters offshore with a beginner's surfing segment at the inshore end, and a shorter southern arm (Black 2000). The northern arm of the structure provides a right-hand break, while the southern arm provides a left-hand break, with a paddle channel running between the arms, perpendicular to the coastline. The two arms are separated, and according to Black (2000): "this is designed: (i) to eliminate wave interference on the take-off zones and main part of the wave; (ii) to provide the space needed to create the peak at the take-off and (iii) as a paddling channel to give surfers access during moderate and large wave conditions when the adjacent beaches are closing out". At the toe of the reef, the depth at installation is 10.4 meters and the inshore extremity is at 2 meters. The crest height is set to be as shallow as possible without emerging, and is designed to allow sand to pass over. The gap between the structure and the shoreline allow passage 80 percent of the expected littoral drift.

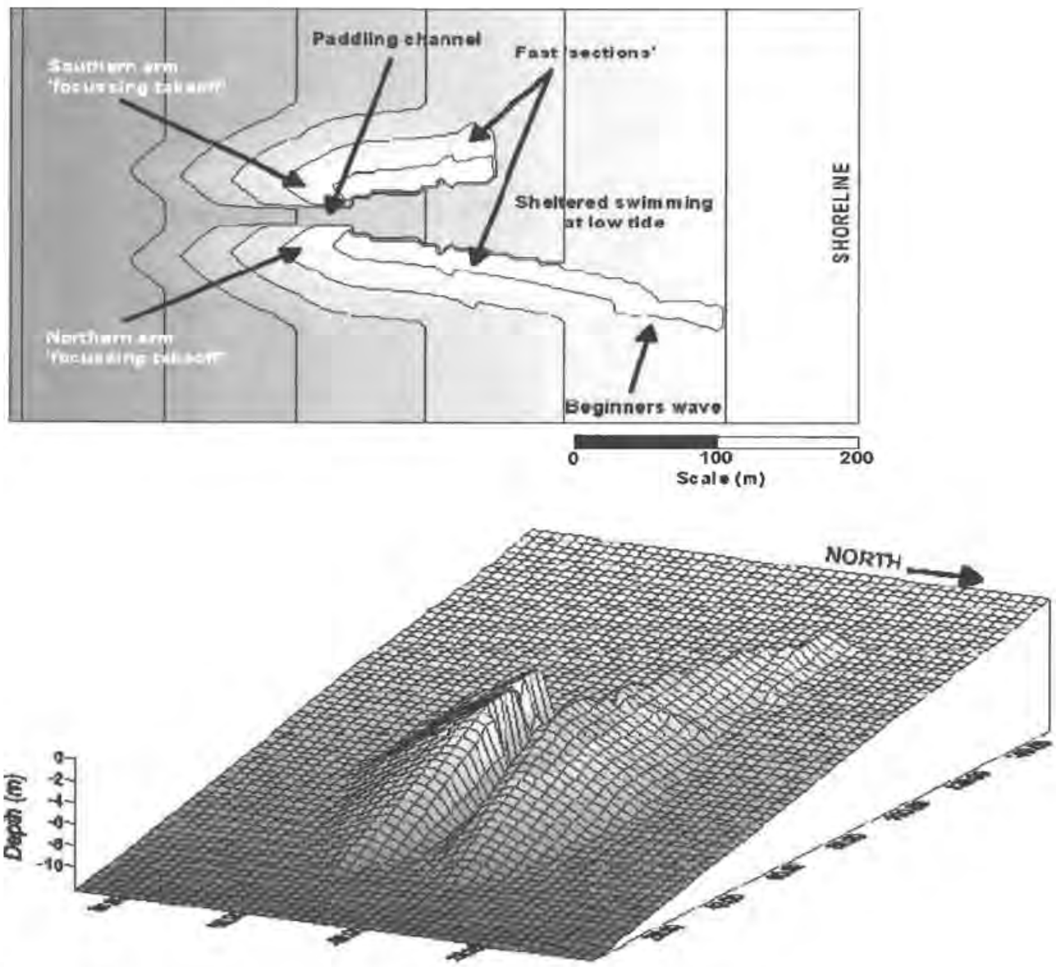

Figure 15. The Narrowneck artificial reef in plan view (a), showing areas designed for surfing amenity, and relief of bathymetry (b) (Black 2000).

Surfing reefs need to be constructed with a relatively smooth surface, avoiding sudden changes in bathymetry, to ensure that waves peel progressively (Jackson, Tomlinson, and D'Agata 2001). They also suggests that the slopes be relatively flat so that the desired shoaling, refraction, and peel characteristics can be achieved, to avoid slumping or surging of the wave face. Design considerations must also consider safety. Surfers are found to be key stakeholders and the choice to construct a "soft" reef is heavily influenced by improved safety (Lenze et al. 2002). Traditional construction materials such as quarry stone and cement may provide good surfing conditions, but their roughness and shape can be dangerous. Sand-filled geotextile containers were selected for these reasons. Geotubes also proved to be 50 percent less costly than a similar rock structure (Jackson and Hornsey 2002). One more important benefit is their ease of removal. As the use of an ASB was untested, the structure represents a full-scale model. Permit conditions required that the structure be easily removed or modified should it create unexpected adverse impacts.

Concern for the use of geotextile containers was expressed by the Gold Coastal City Council because of the potential for damage from surfboard fins. The tubes were also placed in an active wave environment so durability was of paramount concern. A composite geotextile was designed for the project, providing a secondary layer for protection from abrasion and UV degradation. Ultimately, 300 geotextile containers filled with about 75,000 m^3 of sand were placed in the reef formation by a hopper dredge (Figure 16). The design team and the geotextile container supplier regularly dove on the reef to assess durability and stability of the containers. Monitoring has confirmed that the containers are not deforming beyond the design limits, but have deformed slightly. A 20 percent reduction in reef height was allowed for in the design, but the actual reduction has been closer to 15 percent (Jackson and Hornsey 2002).

Figure 16. Geotextile tubes forming the artificial reef at Narrowneck (Jackson and Hornsey 2002).

The ASB at Narrowneck has undergone extensive monitoring via video ARGUS imaging, hydrographic beach surveys, dive inspections, aerial oblique photography, surf parameter observations, and pressure sensors in and on individual units. While monitoring reports are anticipated in the future, a brief summary of monitoring to date is provided by Jackson and Hornsey (2002), indicating that the reef has proven to be very robust in protecting the beach and improving the surf. A number of storms have occurred, but very little erosion has been observed around the reef. The beach has maintained an additional 40 meters width relative to pre-nourishment conditions. A strong trend toward increased wave breaking on the reef has also been found (Jackson and Hornsey 2002) - from 20 percent during construction to 60 – 80 percent in the year and half following construction. Although the analysis did not consider the quality of the waves for surfing, the reef is observed to be popular with surfers (Jackson and Hornsey 2002).

Although not a primary objective, the ASB was installed in the hope of creating new habitat and providing recreational amenities such as scuba diving and snorkeling. Prior to construction, the seabed consisted of loose sand with a limited diversity of marine organisms. According to Black (2000), a biodiverse marine ecosystem has developed with the overgrowth of marine organisms and plants beginning as soon as two weeks after construction. After several months, a complete ecosystem had developed including sightings of sharks feeding on fish.

Prior to the construction of the Narrowneck reef, an artificial surf break of stone was constructed at Cable Station Beach south of Cottesloe on the Perth Metropolitan Coast of western Australia. Unlike the multi-purpose reef at Narrowneck, it was not intended as a shore protection structure and was required only to produce surfable waves. In the United States, following the construction of the ASB at Narrowneck, Pratte's Reef in El Segundo, California was designed solely for producing surfable waves as a mitigation response to the loss of surfing areas following the construction of a groin. This reef was constructed with 200 geotextile bags in two installations. Observations showed that the first installation of geotubes had minimal impact, if any, on the wave breaking characteristics (Borrero and Nelson 2003). The second installation created better surfing waves, but only for a few months. At present, Pratte's reef is no longer affecting incoming swells as the reef bags are mostly level with the sand. Borrero and Nelson (2003) attribute its underperformance as a surfing reef to deficiencies in the design rather than local conditions. Primarily deficient due to its small size, the volume and size of Pratte's Reef was limited by funding; therefore, it was unable to significantly alter wave breaking and nearshore coastal processes in the area. The reef at Narrowneck is 70 times greater in volume and extends 150 meters offshore while Pratte's extends only 30 meters (Figure 17). Multi-purpose artificial reefs like the one at Narrowneck have been proposed and designed for Bournemouth, England; Noosa and Palm Beach, Australia; and Mount Wanganuai, Gisbourne; and New Plymouth, New Zealand.

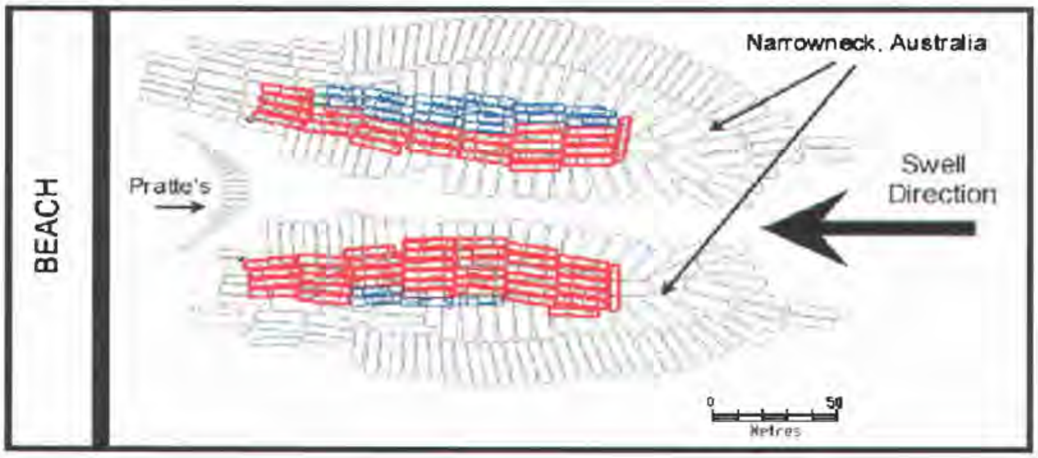

Figure 17. Plan view of the Narrowneck Reef in Australia in comparison to Pratte's Reef in California (Borrero and Nelson 2003).

Management Considerations

Offshore submerged reefs minimize the need for obtrusive shore protection structures on the beach, and can be used when hard structures and planned retreat are not options. As such, artificial surfing reefs:

- unify coastal protection and amenity benefits into a single offshore structure;
- enhance coastal amenity value by incorporating multiple use options of surfing, diving, marine habitat, water games, and sheltered swimming; and
- preserve existing beach amenity (Black and Mead 2000).

Other coastal protection schemes do not offer substantial overall value to the community, and artificial surfing reefs address the growing demand for coastal amenity development and environmentally conscious solutions to coastal erosion (Black and Mead 2000).

Offshore reefs will not entirely halt beach erosion, so they must be considered to modify and control shoreline change, not to act as a total barricade (Black 2000). This concession is particularly important when maintaining the natural character of the coast as a priority. By building an artificial reef with plans for beach nourishment, nourishment frequency and volume may be decreased, reducing the cost and maintenance of sustaining a wide, protective beach.

The inclusion of surfing amenity to a coastal protection structure significantly complicates the design. The Narrowneck reef has provided considerable data about the design and performance of ASBs, but its design relates to the environmental conditions and surfing criteria for that specific site, so the structure shape will not be the same at other sites. Despite the baseline data provided by studies about the components of natural surf breaks and the surfability of waves, the design phase of an artificial reef must consider the local physical environment. Criteria such as sediment movement, trapping rates, salient size, and amenity criteria such as desired surfing conditions must be predetermined as design criteria. The development of sophisticated computer modeling allows for the optimization of reef designs for coastal protection and surfing (Black 2000). Modeling allows the user to test many designs until the best fit is found, generating results closest to the predetermined criteria.

By using geotextile containers rather than rock or concrete, the artificial reef is more easily adjusted or removed should unwanted effects be detected. Geotextiles also improve the safety of the structure to recreational users. Injuries and deaths have occurred due to surfers' impacts on hard structures, and litigation is a serious consideration when dangerous conditions are created (Jackson, Tomlinson, and D'Agata

2002). Because the conditions found at an artificial reef are highly dynamic and abrasive, consideration needs to be given to the quality and design of the sand-filled geotextile containers, and to their potential hazards.

Geotextiles are less expensive than traditional construction materials, but the feasibility studies needed to incorporate surfing amenity increase the cost if otherwise designed for shore protection only. The Narrowneck Reef cost $2.1 million (Australian) to construct with an additional $700,000 (Australian) for feasibility studies. Baseline data defining the dynamics of surf breaks and surfers will not have to be repeated, potentially reducing the cost of feasibility studies in the future. Extensive site-specific conditions still must be examined for each installation, including environmental conditions and the needs of the community.

Design and monitoring of the Narrowneck reef have primarily focused on coastal protection and enhanced surfing conditions. Other amenities are provided by the reef, but little information about their development is available. Little is currently known about ecological processes at multi-purpose artificial surfing reefs, but a comparison can be drawn to other artificial structures (Ranasinghe, Hacking, and Evans 2000). Biological enhancement due to the construction of a reef may include increased environmental value such as increases in biodiversity and abundance, increased amenity for divers and enhanced fisheries by the incorporation of specific habitat (Black and Mead 2001).

In summary, according to Black and Mead (2000), offshore surfing reefs should be used when:

- a partial blockage to sand is required;
- hard structures on the beach are not suitable or permitted;
- the natural character of the coast is to be preserved; or
- improved recreational and environmental amenity value is required.

In addition, offshore surfing reefs are only appropriate on open ocean coasts where surfing conditions are possible. On-going monitoring of the Narrowneck ASB will provide information concerning their long-term performance and durability, to help guide future installations.

Benefits

- ✓ Low environmental impact
- ✓ Visual amenity is not impaired
- ✓ Reef is constructed offshore with no disturbance to the beach habitat
- ✓ Salient growth in the lee leads to enhanced shoreline stability and protection
- ✓ The natural character of the shoreline is maintained
- ✓ Recreational and public amenities are enhanced
- ✓ Increased economic stability in surfing and coastal tourism dependant towns
- ✓ Marine habitat is enhanced
- ✓ Easily removed or adjusted should unwanted effects be detected
- ✓ Construction takes place offshore so there is minimum impact to beach users
- ✓ Geotextile surface reduces risk of injury to surfers and other recreational water users

Problems

- ✓ Less coastal protection when compared to emergent breakwaters
- ✓ Multiple use criteria complicate the design
- ✓ Sophisticated pre-design modeling is needed
- ✓ Monitoring the reef for multiple objectives requires complex studies
- ✓ Geotextile containers are less resistant to damage than traditional construction materials
- ✓ Increased traffic, crowding and beach use in response to improved amenities
- ✓ Coastal stability and economic stability may encourage development
- ✓ Sharks *and* Surfers?

REFERENCES CITED

ANDREWS, C.J. 1997. Sandy shorelines response to submerged and emerged breakwaters, reefs or islands. Unpublished MSc Thesis, University of Waikato, New Zealand, 137p. in Black and Andrews. 2001.

BLACK, K. 1999. Designing the shape of the Gold Coast Reef: Sediment dynamics. *Proceedings of the Coasts and Ports '99 Conference.* Perth, Australia, 58-63.

BLACK, K. 2000. Artificial surfing reefs for erosion control and amenity: Theory and Application. *International Coastal Symposium, Rotorua, New Zealand.* Retrieved on 17 May 2003 from the ASR Marine and Freshwater Consultants website: www.asrltd.co.nz/reeferosion1.pdf

BLACK, K.P and C.J. ANDREWS. 2001. Sandy shoreline responses to offshore obstacles part 1: salient and tombolo geometry and shape. *Journal of Coastal Research.* Special Issue No.29: 82-93.

BLACK, K. and S. MEAD. 2000. *Submerged structures for coastal protection: A short summary of what they are, why we need them and how they work.* Retrieved on 10 May 2003 from the ASR Marine and Freshwater Consultants website: http://www.asrltd.co.nz/documents.pdf

BLACK, K. and S. MEAD. 2001. Design of the Gold Coast reef for surfing, public amenity and coastal protection: surfing aspects. *Journal of Coastal Research.* Special Issue No.29: 115-130.

BORRERO, J.C. and C. NELSON. 2003. Results of a comprehensive monitoring program at Pratte's Reef. Retrieved on 10 June 2003 from the Surfrider Foundation website: http://www.surfrider.org/artificialreef/results.pdf

DALLY, W.R. 2001a. The maximum speed of surfers. *Journal of Coastal Research.* Special Issue No.29: 33-40.

DALLY, W.R. 2001b. Improved stochastic models for surfing climate. *Journal of Coastal Research.* Special Issue No.29: 33-40.

HARRIS, L.E. 2001. *Submerged reef structures for habitat enhancement and shoreline erosion abatement.* US Army Core of Engineers Coastal and Hydraulic Technical Note (CHETN). Retrieved on 12 May 2003 from: http://ocean.marine.fit.edu/breakwaters/GrandDominicus/CHETN_RBBW.pdf

HUTT, J.A., K.P. BLACK and S.T. MEAD. 2001. Classification of surf breaks in relation to surfing skill. *Journal of Coastal Research.* Special Issue No.29: 66-81.

MEAD, S. and K. BLACK. 2001a. Field studies leading to the bathymetric classification of world-class surfing breaks. *Journal of Coastal Research*. Special Issue No.29: 5-20.

MEAD, S. and K. BLACK. 2001b. Functional component combinations controlling surfing wave quality at world-class surfing breaks. *Journal of Coastal Research*. Special Issue No.29: 21-32.

MEAD, S. and K. BLACK. 2001c. Predicting the breaking intensity of surfing waves. *Journal of Coastal Research*. Special Issue No.29: 51-65.

JACKSON, L.A., R.B. TOMLINSON, and M. D'AGATA. 2002. The challenge of combining coastal protection and improved surfing amenity. *Littoral 2002*. Retrieved on 17 May 2003 from: http://www.io-warnemuende.de/homepages/schernewski/Littoral2000/docs/vol1/Littoral2002_30.pdf

JACKSON, L.A. and W.P. HORNSEY. 2002. An artificial reef to protect Surfers Paradise Beach, developing and implementing the science. *Geotechnical Fabrics Report*. 20(4) retrieved on 6 June 2003 via personal e-mail from W.P. Hornsey.

LENZE, B., G. HEERTEN, F. SAATHOFF, and K. STELLJES. 2002. Geotextile sand containers – Successful solutions against beach erosion at sandy coasts & scour problems under hydrodynamic loads. *Littoral 2002*. Retrieved on 17 May 2003 from: http://www.io-warnemuende.de/homepages/schernewski/Littoral2000/docs/vol2/Littoral2002_46.pdf

MEAD, S. and K. BLACK. 1999. A multi-purpose, artificial reef at Mount Maunaganui Beach, New Zealand. *Coastal Management Journal*. 27(4):355-365.

PITT, A. 1997. Surfing into the 21st century – Harbord Reef. *Proceedings of the 1st International Surfing Reef Symposium*. Sydney Australia, March, 1997.

RANASINGHE, R., N. HACKING, and P. EVANS. 2001. *Multi-functional artificial surf breaks: A review*. Retrieved on 12 May 2003 from the New South Wales Department of Land and Water Conservation website: http://www.dlwc.nsw.gov.au/care/coast/asbreview/asb_pt1.pdf and http://www.dlwc.nsw.gov.au/care/coast/asbreview/asb_pt2.pdf

SYMONDS, G. and K. BLACK. 2001. Predicting wave-driven currents on surfing reefs. *Journal of Coastal Research*. Special Issue No.29: 102-114.

TURNER, I.L. V.M. LEYDEN, R.J. COX, L.A. JACKSON, and J.E. MCGRATH. 2001. Physical model study of the Gold Coast artificial reef. *Journal of Coastal Research*. Special Issue No.29: 131-146.

WALKER, J.R. 1974 *Recreational surf parameters*. Technical Report, University of Hawaii, James K.K. Look Laboratory of Oceanographic Engineering, 73-30. 311p.

ADDITIONAL REFERENCES

BLACK, K.P and C.J. ANDREWS. 2001. Sandy shoreline responses to offshore obstacles part 2: discussion of formative mechanisms. *Journal of Coastal Research*. Special Issue No.29: 94-101.

BLACK, K. and S. MEAD. 2001. Wave Rotation for Coastal Protection. *Proceedings of Coasts and Ports 2001*. Retrieved 12 May 2003 from the ASR Ltd. website: http://www.asrltd.co.nz/waverotation.pdf

RESTALL, S.J., L.A. JACKSON, G. HEERTEN, and W.P. HORNSEY. 2002. Case studies showing the growth and development of geotextile sand containers, an Australian perspective. *Geotextiles and Geomembranes.* 20(5) retrieved on 6 June 2003 via personal e-mail from W.P. Hornsey.

TOURISM RESOURCE CONSULTANTS. 2002. *Proposed artificial surf reef: Opunake, South Taranaki.* Prepared for Opunaki Artificial Surf Reef Committee, South Taranaki District Council. Retrieved on 12 May 2003 from: http://www.taranaki.info/reports/opun_reef_eco.pdf

DISCUSSION AND CONCLUSION

Non-traditional, patented schemes for coastal protection often claim beach rehabilitation using "soft engineering." Manufacturers make claims that their devices work with the natural beach, are "animal friendly", aesthetically pleasing or "all-natural", but neglect to explain how their mechanism works to minimize coastal erosion. By making small changes to the design of a traditionally "hard" protection structure, claims of "soft" engineering may be misleading. In the evaluation of alternative or non-traditional shoreline stabilization devices by McQuarrie and Pilkey (1998), 40 different devices were examined. Of these, 31 percent actually perform as breakwaters, 12 percent as groins, and 12 percent as seawalls, and no device represented a novel solution to coastal erosion. McQuarrie and Pilkey (1998) point out that the lessons learned from traditional hard structures have been ignored by many alternatives, and the same negative impacts are likely. Differences between traditional structures and the alternatives they reviewed are that the alternative devices are less expensive and largely removable in the event of failure. Duke University's Program for the Study of Developed Shorelines provides a description of the 40 alternative devices; available on-line at http://www.env.duke.edu/psds/Stabilization/Categories.htm, the devices are classified according to structure type and function, and associated problems are defined. The marketed name of each device is also provided with manufacturer's claims and installations, if any.

As with any new erosion protection method, it is difficult to generalize with respect to its applicability to the wide variety of potential sites where it may be used. Before selecting any coastal protection strategy, an accurate understanding of the erosion problem and characteristics of the site are needed. Engineering approaches of any type have the potential to modify the dynamic system of the coast. Often a solution solves one problem while creating others by affecting wave conditions, currents, or sediment supply. Thus, a holistic approach to coastal erosion management is best, considering a particular erosion problem in the context of an overall system. A well-developed, interdisciplinary, regional approach rather than a series of unrelated localized fixes is better suited for a coastal management plan (Pope 1997). Effective Integrated Coastal Management (ICM) should consider environmental, social, and economic issues to ensure that any coastal protection works are sustainable and provide amenity for users of the area that is to be protected (Jackson, Tomlinson, and D'Agata 2002). It is now less acceptable to protect properties at the expense of the beach. Public access and amenities are important considerations.

No protection scheme can be generalized as good or bad. An informed approach requires an understanding of the regional system and must include sound, pre-determined goals and objectives. The success of a shore protection technique is very subjective and can only be determined when the goals of the project are well defined. Mechanisms for evaluating performance need to be developed, and when necessary, mitigation strategies employed when unwanted impacts are detected.

Pope (1997) has proposed ten key concluding "truisms" regarding the philosophy of shore protection:

i. There is no such thing as permanent shore protection in the dynamic coastal environment;
ii. no one type of shore protection is best for all locations;
iii. no shore protection approach will work equally well in all conditions;
iv. there are no shore protection bargains;
v. there are approaches that can protect an area for an effective economic life;

vi. there are engineering practices that can work with coastal processes in a predictable way;
vii. there are areas where the degree of human commitment rules out doing nothing;
viii. there are areas where hard structures are appropriate;
ix. there are areas where soft approaches are appropriate; and
x. there are areas where no shore protection should be undertaken.

All emerging protection methods are not harebrained approaches, though one must proceed with caution when selecting an emerging coastal protection alternative. Upon reviewing this paper, one should be able to make a more informed decision about the use of an innovative shore protection method. Managers that choose to implement an alternative shore protection technique are encouraged to conduct and document follow-up monitoring programs. By contributing to the existing literature about innovative methods of shore protection, future decisions will be better informed. Barber (1993) reminds us: "even reinforced concrete was considered an innovative and somewhat controversial construction material early in its history. Modern coastal engineering practice requires demonstration and testing of today's innovative materials and approaches in order to continue a positive evolution in the profession."

REFERENCES CITED

MCQUARRIE, M.E. and O.H. PILKEY. 1998. Evaluation of alternative or non-traditional shoreline stabilization devices. *Journal of Coastal Research.* Special Issue 26:269-272.

POPE, J. 1997. Responding to coastal erosion and flooding damages. *Journal of Coastal Research.* 13(3):704-710.

JACKSON, L.A., R.B. TOMLINSON, and M. D'AGATA. 2002. The challenge of combining coastal protection and improved surfing amenity. *Littoral 2002.* Retrieved on 17 May 2003 from: http://www.io-warnemuende.de/homepages/schernewski/Littoral2000/docs/vol1/Littoral2002_30.pdf

BARBER, P.D. 1993. *Review of recent geotextile coastal erosion control technology.* US Army Corps of Engineers Technical Letter No. 1110-2-353.