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Shoreline Stabilization with Experimental Groin Field(s): Modular Adjustable Permeable Groins

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Abstract

This manuscript introduces prospective hard engineering solutions to continuous episodic erosional events on beaches utilized for recreation and tourism. The basis of this paper is information from a modeling study completed in 2011 on a two mile stretch of beach in South Carolina. The study utilized three alternative groin systems and a no groin option. The optimum spacing of the groin applications and the retention rate of a replenished beach at the location was determined based on running a computer model (Genesis) for the environmental conditions (wave climate, littoral transport, etc.) at the demonstration site. It was also determined that the innovative groin alternative presented in this paper would likely develop as the most effective cost/benefit relationship among the more conventional alternatives utilized in the United States. The experimental groin system (modular adjustable permeable groin(s) MAPG) was calculated to save initial construction costs by 25% to 30%as compared to the other alternatives. This was significant when considering that adjacent beach impacts are minimized and the beach berm is better protected over the typical beach re-nourishment cycle. This paper attempts to facilitate further discussion of regional sediment budget and (coastal zone) management by bridging the divide between choosing only sand nourishment vs. engineered structures. We demonstrate that reintroducing engineered structures in combination with beach nourishment can be a cost effective solution to episodic erosional events over time while allowing longshore sediment transport.

Introduction and Approach

Erosion control projects become desirable once developed upland property becomes vulnerable to loss from continued erosion (see: e.g., Denny et al., 2005; Yazdani, et al., 2002; Leatherman et al.,2001; Gable and Edwards, 2001; Houston, 2008 & 2002; Lewis, 1973). This paper reviews a few standard options to reduce the rate of erosion while minimizing costs and decreasing coastal impacts.

Earlier experimental research was partly undertaken to review beach stabilization alternatives for a beach ocean front community in South Carolina. Research continued in this paper to show the effectiveness of a groin based solution option for coastal erosion. The term effective as it is used in this paper means a significant reduction in construction costs, while maintaining a usable recreation beach with minimal effect on adjacent beaches. This paper introduces the concept of a modular adjustable permeable groin (MAPG) as a prospective best practice alternative for increasing sand retention on either renourished or eroding beaches, where engineered structures are allowed with nourishment cycles. This paper is meant as a concept introduction for further consideration and evaluation.

Background and Rationale

An effective solution to reduce the impact of continued erosion is with periodic renourishment. (Houston, 2002; Stapor, et al., 1991; Van Kouwen, et al., 2008)., However, considering project size, location, erosion rates and the availability of a suitable sand source, some erosion problems may be more cost effectively addressed with erosion control structures. (Garrison, 2006; Kraus, et al., 1994). Additionally, depletion of sand resources for nourishment has resulted in an increased level of interest in structural erosion control alternatives. (Kana, et al., 2003). One major consideration when dealing with a beach renourishment project is how long the sand will last on the beach until it is necessary to renourish again. Groins are among the applications used to help retain beach sand for a longer period of time. (Headland, et al., 2007; Perdok, et al., 2004; Deis, et al., 2003; Poff, et al., 2003; Raudkivi, 1996; Eldred, 1976).

In designing a groin solution it is often difficult to develop the most beneficial sand retention ratio. Retaining too much sand may have detrimental effects to the adjacent beaches, while not retaining enough sand will result in an ineffective structure. Additional challenges adding to the design complexity of an offshore beach retention structure is to ensure it will not create adverse impacts. There are four types of negative: (1) those that affect the structure-retained beach so that the post-structure shoreline is unchanged from the original conditions that was to be corrected, (2) those that affect other beaches, primarily starving them of sand, (3) those that affect the structure itself and develop high maintenance costs and (4) those that affect the usability of the beach by developing impediments to pedestrian excursions along the beach during erosion periods. (De Gennaro & Wright, 2007).

Conceptually, an optimum solution might consist of a low maintenance erosion control structure, which interacts with the littoral system to perch a stabilized beach and maintain long shore sediment transport. The structure considered in this study is an experimental permeable groin system comprised of fiberglass (resin) composite (FRC) piles as the seaward component and Articulated Concrete Block Mat (ABM) as the landward component. The system can be designed for modular construction.

Coastal Complexity Is Accounted for in the Design

The vast majority of permeable groins constructed to date, have fixed permeably and are therefore difficult and expensive to modify. (Boczar-Karakiewicz, et al., 2004; Perdok, et al., 2004; Raudkivi, 1996). In researching the design issues for a groin system it became clear that permeable groins have their own particular issues. It is difficult to model the exact conditions that will develop after a groin is constructed. Each slot in a permeable groin acts as a point source of wave energy for the lee side. The superposition of elementary waves radiating from the slots leads to wave fronts parallel to the groin.

(Huygen-principle) Thus, in a field of unbroken waves the groin field has conceptually a four wave systems:

- Incident waves at angle β
- Waves transmitted through the pile groin with crests parallel to it
- Waves reflected from the windward side of the groin
- Waves diffracted by the groin

The setup also creates a gradient for flow seaward. Hence, the flow rate through the pile groin is complex and initially unknown. At the lee side the flow loses energy in the expansion. The situation is further complicated by the erosion of the bed between the piles. In a properly designed pile-groin field the setup against the windward side of the groin is minimal due to its permeability. Seaward currents can arise from the wave setup on the beach but if the groins are adequately permeable no concentrated return currents will develop. (Raudkivi, 1996).

Based on the previous reasoning the primary objective of the design of permeable pile groins is to reduce the littoral current velocity to an extent that rip currents and large-scale circulations in the groin field are minimized. Too low a permeability will lead to conditions as with impervious groins and too high a permeability to loss of velocity reduction required for sand retention. (Raudkivi, 1996; Poff, et al., 2003).

Based on the above discussion it would seem to be an extremely difficult task to model the exact porosity, length and spacing of groin field to develop the maximum benefit with the least impact. Thus permeability in the groin is an important consideration to solve. This is the primary reason to construct an adjustable groin using the best experimental empirical and theoretical models as a starting point. Then make the necessary field adjustments. This system therefor does not heavily rely on the exact results of the hydraulic model which sometimes can be misleading .

The utilization of FRC piles in the groin system under discussion here allows for adjustment of permeability and overall groin length to meet down-drift needs of the beach environment. It also allows for the retention requirements and the needs of the beach community at the local level. Decreased permeability can be achieved by shrouding an existing pile with one of a larger diameter. Increased permeability can be achieved by “tuning” (i.e., pulling/removing) selected piles out of the groin as environmental conditions warrant. The FRC pile is easily handled; compared to a similar diameter wood pile. It weighs one quarter of the same diameter wood pile and has the same strength. The FRC pile has a uniform diameter so shrouding is easy. The design to accurately place the piles to develop selected porosity is easily accomplished. Additional discussion of the benefits of the FRC pile over wood will be presented later.

Study Comparisons

First, before we consider a the modular adjustable permeable groin (MAPG) as a practical innovative option for sand retention it is important to determine if it is indeed the best groin option based on cost savings. If the initial costs and annual savings do not measure up to more traditional designs then this alternative loses much of it appeal. The study was implemented utilizing an approximate two mile recreational beach in Horry County, South Carolina. This study investigated four groin options for recreational beach enhancement and protection. The four options taken into consideration were: Option 1 MAPG – using ABM & FRC piles. Option 2 – sheet pile and rock/stone groin. Option 3 – sheet pile only groin. Option 4 – rock/stone only groin. In addition, beach nourishment only or "soft engineering" was analyzed as a control.

The unpublished study by the lead author and another colleague was completed in 2010 on a two-mile stretch of a beach in South Carolina using the four alternative groin systems and a "no" groin option. (De Gennaro & Mack, 2010). Based on running a computer-based model (Genisis) for the environmental conditions (wave regime, historical storm climate, littoral transport, etc.) at the site, the optimum spacing of the groin was determined along with the retention rate of a replenished beach. Thus, it was initially determined at the demonstration site chosen that MAPG would provide the most effective cost benefit solution compared to the three more conventional engineered devices and design alternatives evaluated in this study A fourth option– stone groin was eliminated early in the study because of its excessive construction costs, $1.5 million more than any of the other three (3) option costs (De Gennaro & Mack, 2010).

The MAPG was calculated to save initial construction costs by approximately 25 to 30 percent as well as future beach sand replenishment volumes between 15 to 30 percent over time. (De Gennaro & Mack, 2010). This is noticeably significant when considering that down-drift cumulative impacts are minimized and the beach berm is better protected over the entire beach replenishment/nourishment cycle. See Table 1

Cost Evaluation

In the experimental modeling study (De Gennaro & Mack 2010), a complete present cost of the each alternate is presented for a 42 year life of the project (seven (7) replenishment cycles) at the clients request. The cost savings is significant after the first cycle and becomes more significant as the price of the sand placed increases for each cycle. As can be seen in Table 1 the initial cost of each alternate is greater than the control over the first 6-8 years. However, after the second replenishment cycle the cost for the proposed MAPG clearly becomes the best cost alternative. The MAPG saves $260,000 in the first 16 years over the no groin (control) alternate (See table 1). An added advantage is the situation that the beach is not fully eroded in between cycles and there is a continuous effective storm berm using the MAPG alternate over the control. The cost savings over the 2nd and 3rd option is nearly $2 million in 16 years and is similar to the savings after the first cycle.. (Note Table 1 only indicates the savings for 3200 feet of the 10,000feet of beach in the study for first 16 years to show the cost savings pattern.)

Advantages and Disadvantages of the Four Groin Field Options

Each of the four groin options has its advantages and disadvantages. In all cases the design of the groin system includes a high profile berm area (high elevations +7.5 Mean Sea Level). This reduces the impact on the dry beach during storm events. It also reduces the impact of land-side breaching (overwash). The effect of the high berm design requirement is to hold a dry beach for a longer period of time. Generally, the disadvantage of a high berm profile is loss of long shore mobility (i.e. access to walking along the dry beach) during times of erosion events. This problem can be mitigated by using the design in the MAPG.

The major advantage of the MPAG is its ease of construction and the fact that it is readily and adaptively adjustable to meet design requirements of any permit condition(s). The construction allows for efficient removal if the experimental design is not functioning as intended as part of the permit condition(s). The removal is facilitated because all the construction materials (i.e. ABM and Gabions) are segregated from the natural environment.

The disadvantage the MPAG is a greater frequency of replenishment because the permeable system does not trap all the sand in the littoral drift/current. Its objective is to slow down the sand in the littoral drift. A further disadvantage may be that while the system is innovative and can be very effective it is not widely understood and has not been constructed and therefore competes with known technologies.

The advantage of the more traditional Option 2 "*sheet pile and rock groin*" is that it is widely utilized in groin construction on recreational beaches throughout the United States. The behavior and impacts of these structures is well documented and studied. The disadvantage rests in the considerable initial capital costs. Also, the rock materials are easily integrated into the sand on the beach. (Boscamazo et al., 2003). The rock groins will be difficult and expensive to remove or adjust if they do not meet the down-drift impact or retention requirement of the permit condition(s). Moreover, during erosion events continuous pedestrian access along the beach is difficult to maintain because of the exposure of the sheet pile wall at the upper berm.

An advantage of the "*sheet pile only groin*", Option 3, is that it is rooted in common groin construction practice (i.e. The Coastal Engineering Manual of the U.S. Army Corps of Engineers). Such groins are a little less expensive (about 10 percent) to construct when compared to the sheet pile and rock groin. Their overall cost when considering the nourishment requirements make it the second least expensive alternative behind the MAPG for the modeled study site. The system can be designed with a notched section in the swash zone to reduce down drift impacts. Such notching, however, has been found to be problematic (Kana, et al., 2003). The disadvantages are the detrimental impacts to down-drift sediment transport and access along the beach and the groin is difficult to adjust for changing coastal conditions once constructed. Removal may be the only option if it does not meet the down drift requirements of the permit condition(s).

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Why a Permeable Groin?

It's been shown that with careful design, permeable groins can have many beneficial qualities for shoreline protection. (Bakker, et al., 1984; Boczar-Karakiewicz, et al., 2002; Poff, et al., 2003). Although both groin types, permeable or impermeable, are designed as littoral barriers, they perform differently in the littoral zone. Shoreline responses to impermeable groins follow the typical anti-symmetric formation caused by littoral barriers. (Kana et al.,2003)

In most cases, groins are implemented as a means of controlling sediment transport in the nearshore. Permeable groins do not impound sand directly, but their influence on the water column causes significant changes in the flowing water's capacity to entrain and transport sediment. Long-term observations along the Gulf Coast of Florida show that shoreline shapes near permeable pile groins differ significantly from the typical anti-symmetric shore formation caused by impermeable groins. The permeable groins develop more symmetrical beaches. (Poff, et al., 2003).

Why a Modular *Adjustable* Permeable Groin (MAPG)?

Much of the government's and the public's disapproval of groins can be attributed to highly publicized cases where the construction of groins had the opposite effect than that for which they were intended. (Poff, et al., 2003). A major reason for these failures is the lack of an understanding of the groin's hydrodynamic interaction with the adjacent beach. (Raudkivi, 1996). As groins are site-specific structures, their implementation requires, among others, a thorough understanding of the local wave climate, sediment transport processes, and site bathymetry.

The use of FRC piles in the groin system allows adjustment of permeability and groin length to meet down-drift and retention requirements. As mentioned eairler decreased permeability can be achieved by shrouding an existing pile with one of a larger diameter. Increased permeability can be achieved by pulling selected piles out of the groin. The use of FRC pile facilitates field adjustment as determined by field measurements after construction. It should be noted that since groins are constructed at the shoreline, from previous studies done by others (*inter alia*, Poff, et al., 2003; Raudkivi, 1996), it was found that a 10 percent groin permeability can result in a 50 percent reduction in the transmitted wave height if waves approach parallel to the groin(s). This reduces the prospective erosion of the beach by storm waves. So adjustments in permeability will have significant effect on the result of longshore energy and thus littoral current and sand movement .

The choice to use FRC piles for the permeable section can be made because the other material choices (wood, steel and concrete) are less desirable from the engineering and cost perspective. Wood can rot and is irregular in shape and can leach toxins into the environment; concrete deteriorates in the marine environment because of cracking, abrasion, and chemical corrosion; and steel rusts even with epoxy coating and is difficult to handle because of high unit weight.

The MAPG Design

The experimental (MAPG) consists of a unique configuration of FRC piles, gabion baskets, and articulated (concrete) block mat (ABM). The FRC pilings are a fiberglass resin composite pile available in lengths up to 40 feet long. They are lightweight and have engineering characteristics that are superior to wood. They can come in diameters between eight and fourteen inches. The gabion baskets used in the upper berm consist of wire mesh containing stone. The basket can be designed to be corrosion resistant. The stone size in the basket can vary depending on the designed permeability and availability of the stone. The ABM which will cover the gabions is comprised of a nine inch thick concrete modular block system that is interconnected by polyester rope to make mats up to eight by sixteen feet (see: Figure 1).

The innovative design will be configured so that landward of the swash zone gabion baskets will be placed as a core of the landward groin. The gabions will be covered by ABM for aesthetics and stability during episodic storm events. Seaside of the swash zone is the FRC pilings which will be driven at a predetermined spacing to allow for the designed permeability of the littoral transport.

Major storms must be addressed in groin design. With storm surge and high energy waves, the landward end of the groin may present problems. If the high waterline extends past the landward end, outflanking can occur. (Bakker, et al., 1984). During outflanking, which can occur with strong storms or continued erosion, the beach protective qualities can be severally reduced. In turn this can add to additional erosion potential. So as part of the MAPG is a robust but still modular section on the land side attachment. It is designed as the land side “root” of the groin which helps perch the beach to protection level.

The ABM and gabion modular components for the landside structure can allow for quick construction (~3 days). The practicality of cost and aesthetics will normally determine the top elevation of the groin. The profile of the ABM allows easy public access along the recreational beach even after storm events. The gabions were chosen so that the rock does not integrate with the beach sand and also allows for quick adaptable adjustment to changing coastal conditions. The additional costs of the gabions are mitigated by the fact that they aid in modular capacity and quick construction of any overall groin system. The design of the landside (beyond the swash zone) groin should allow for energy absorption during erosion events. The more traditional sheet pile groin system reflects wave energy and has the characteristics to increase erosion along the beach during storm events.

Analysis and Discussion (*including relative sea-level rise)*

. The use of fiberglass (resin) composite Pearson pilings in the groin system in option one (1) allows adjustment of permeability and groin length to meet downdrift and retention requirements of any permit issued We realize that a permeable groin's effectiveness as a retention structure is a function of littoral incident wave regime, the design spacing between the pilings, and site bathymetry. Permeable groins don't directly trap and catch sand, they typically decrease the capacity of the littoral longshore current to transport sand. .

Experimental groin(s) and relative sea-level rise affords mentioning. An important element in the groin system is the ABM back-beach berm. The ABM with the gabion core allows a secondary beach berm to lock in additional elevation of dry sand berm. This in turn provides additional protection in the event of relative sea-level rise .Thus, the design of the ABM section will absorb flanking wave energy and will impede flanking of the groin(s) during episodic storm (surge) events that eventually may rush further inland when relative sea-level rise is taken into consideration. In the event of successive erosion events the ABM berm sections unique design will develop the (safe elevation) core that will encourage natural rebuild of the beach. This will reduce the need for beach quick reoccurring renourishment cycles and will allow continuous recreational beach access along the shoreline. It may also impede dramatic erosional "scour" events on ocean facing upland property (see also, Van Kouwen, et al., 2008).

Conclusions

The benefits of permeable groins include relatively low construction and maintenance costs. (Lewis, 1973). Permeable groins reduced both tidal and wave induced currents; decrease littoral (longshore) sediment transport; and develop a more uniform shoreline. This results in decreased intensity of seaward currents along the up drift side of the groin system or structure and reduction in erosion on the leeward side of the groin(s). Basically, regarding the latter, permeable groins may reduce or possibly eliminate the down drift erosion associated with the blockage of sand because they allow a selected amount, through localized "fine tuning" of both water and sediment to sluice through the groin.

The research introduced in this paper demonstrates that the preferred MAPG system can be economically effective and efficient in retaining enough sand to form a usable dry recreational beach between renourishment cycles. The structure can also serve as an effective barrier against upland private or public property damage. The innovative groin design presented in this paper will effectively stabilize the shoreline and can increase the lifespan of renourishment activities without eroding down drift shorelines.

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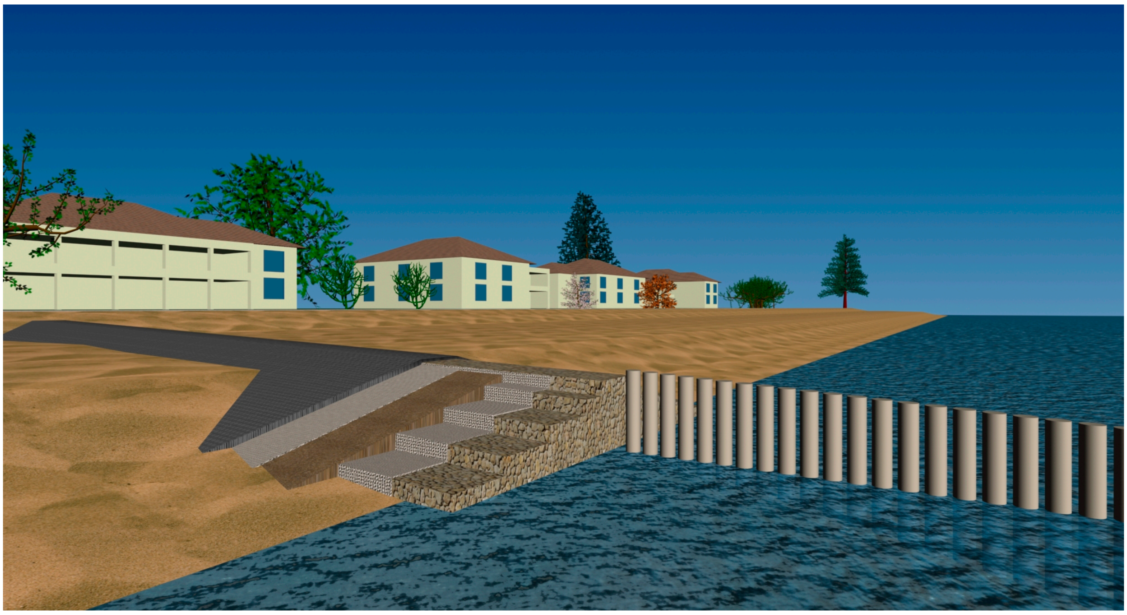

Figure 1 Simplified Cross Section View of the Modular Permeable Adjustable Groin

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Table 1 Groin Alternative Cost Comparisons

Beach Nourishment Costs

Option	fill profile Yd^3/ft	$/CY	length of beach Ft	cycle Years	$/Year
Control - No Groin	55	12	3400	7	$ 320,571
MAPG	25	12	3400	6	$ 170,000
Sheet Pile/Stone	25	12	3400	7	$ 145,714
Sheet Pile/	25	12	3400	8	$ 127,500

Notes—
1)The no groin option allows the beach to erode to bulkhead or dune line accounting for the greater quantity of sand nourishment on each cycle.
2)For Options 1, 2 & 3 beach erodes to storm beach elevation (approx 80 wide and elevation +6.0 NAVD).
3)The number of years in the cycles for each option is different based on computations to allow the beach to erode to the deign berm or bulkhead (no groin option).

Groin Construction

Option	Median Costs	$/Year for 16 years
Option 1 - MAPG	2,150,000	134,375
Option 2 - Sheet Pile/Stone	4,500,000	281,250
Option 3 - Sheet Pile only	4,100,000	227,778

Composite Costs for First Cycle	construction	beach fill	total
No Groin		$ 2,244,000	$ 2,244,000
MAPG	$ 2,150,000.00	$ 1,020,000	$ 3,170,000
Option 2	$ 4,500,000.00	$ 1,020,000	$ 5,520,000
Option 3	$ 4,100,000.00	$ 1,020,000	$ 5,120,000

Composite Costs amortized pre year for 16 years – 2 replenishment cycles

	$/Year
No Groin	$ 320,571
MAPG	$ 304,375
Option 2	$ 426,964
Option 3	$ 355,278