Shoreline Changes in the Vicinity of a Permeable Groin

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1. Introduction

Groins are known as littoral barriers used on eroding beaches subject to severe longshore transport. Compared to the relatively well known behavior of impermeable groins in the littoral zone, the performance and the underlying sediment transport mechanisms of permeable groins are still not well understood. This study focuses on permeable wood groins and their interaction with the shoreline evolution. 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. A model is introduced based on perturbations in the longshore sediment transport due to wave transformation near the structure and implemented to existing field conditions. Results show that the observed shoreline shapes can be reproduced which otherwise cannot be explained with the existing shoreline evolution models.

2. Field Study

Long-term field data including shoreline and beach profile surveys and aerial photographs are collected along Naples Beaches located on the Gulf Coast of Florida. A total of 53 groins are distributed over 6km of shoreline. Other than the 30 impermeable rock groins, there are a total of 23 permeable wood groins located south of the fill area where a beach nourishment project was

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completed in 1996. Three of the wood groins are pile cluster groins (PCG) and the remaining twenty are timber groins. Although these two groups differ significantly in dimension and in their structural properties, their interaction with the existing wave and sediment transport patterns are similar. The main focus of the field study is based on observations at three pile cluster groins, approximately 36m in length in the shore perpendicular direction, consisting of rows of 30cm diameter wood piles. Significant differences are found between shoreline forms near pile cluster groins and the adjacent rock groins. Although both groin types, permeable or impermeable, are designed as littoral barriers, they perform differently in the littoral zone. Shoreline responses to rock groins follow the typical anti-symmetric formation caused by littoral barriers (dashed line in Figure 1a). On the other hand, interesting observations are made with pile cluster groins which cannot be explained by the same physical processes. The dashed line in Figure 1b shows the symmetric deposition around a pile cluster groin similar to the formation of a salient leeward of a detached breakwater.

Table 1: Description of existing wood groins

Number of Pile Cluster Groins	3
Number of Timber Groins	20
Total Length of Shoreline	1.8 miles
Approximate Groin Spacing	150-600 ft
Department of Environmental Protection (DEP) Monuments Within Groin Field	R-80..R-89

3. Planform and Profile Measurements

Long-term effects of permeable wood groins on adjacent beaches are studied using shoreline measurements including the survey of the MHW-line, bathymetric surveys of DEP-profiles and aerial photographs. Significant differences are found between shoreline shapes near rock groins and shoreline shapes near wood groins (Figure 1). Although both groin types, impermeable or permeable, are designed as littoral barriers their operation is based on different mechanisms. Shoreline response to rock groins confirms the well known anti-symmetric shape as a result of a littoral barrier (Figure 1a). Therefore existing models in general encounter the groin as a boundary condition in the transport rate, Q. In such models, changing groin permeability would only affect the rate of updrift deposition and downdrift erosion. However, the shape of the evolved shoreline remains the same. In contrary to this rather well-known behavior of impermeable groins, interesting observations have been made with pile cluster groins which cannot be explained by the same physical process. Figure 1b shows the symmetric deposition around a pile cluster groin.

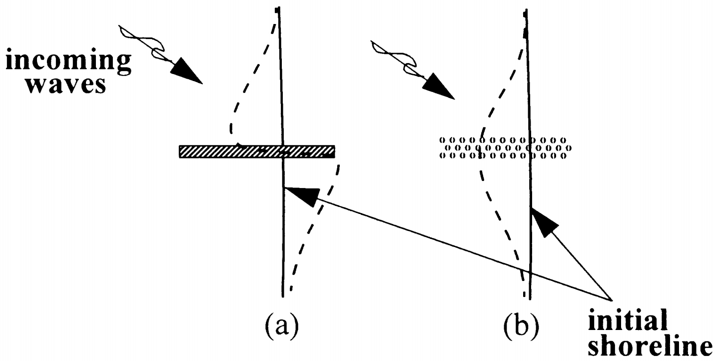

Figure 1: Shoreline response to (a) impermeable and (b) permeable groins.

Measured beach profiles within the groin field indicate some alongshore variation especially in the bar formation. A 2D model grid is generated using the average profile obtained from the three beach profile surveys within the groin field. The nearshore bathymetry is allowed to vary in on/offshore direction only whereas the initial shoreline and the depth contours are assumed straight and parallel.

4. Wave Climate

Input wave parameters for the simulation model are obtained from the Wave Information System (WIS) Station No. 43 in the Gulf of Mexico. Available time series data of 20 years are transformed from their original deepwater location onshore into the model grid at 13 ft water depth. The shallow water time series for sea and swell conditions are analyzed into directional components (northerly and southerly). Table 2 shows the mean wave parameters separately for sea and swell waves.

Table 2:

	Sea	Swell
Mean Significant Wave Height	0.38 m	0.27 m
Mean Wave Period	4.25 s	6.10 s
Mean Wave Angle	265.6 ^{o}N	258.8 ^{o}N

5. Conceptual Model

In shoreline evolution models, groins are generally encountered as a discontinuity in the longshore sediment flux. In such models, changing groin permeability only affects the rate of updrift deposition and downdrift erosion. However, the observations at the Naples Beaches indicate that the evolved shoreline has an anti-symmetric shape.

In the immediate vicinity of the groin, incoming waves start dissipating their energy before they reach the breaking point. This early dissipation occurs due to the interaction of waves with the pile clusters generating a gradient in longshore sediment transport. In the present study, the reduced cross-section of the water column due to pile clusters is modeled as a reduction in water depth along the groin in analogy to the horizontal and vertical permeability of the water column. The introduced shoal causes a focal effect on wave orthogonals which consequently creates a local perturbation in the longshore sediment transport distribution. This perturbation diffuses in time while the shoreline aligns with wave orthogonals (Figure 2).

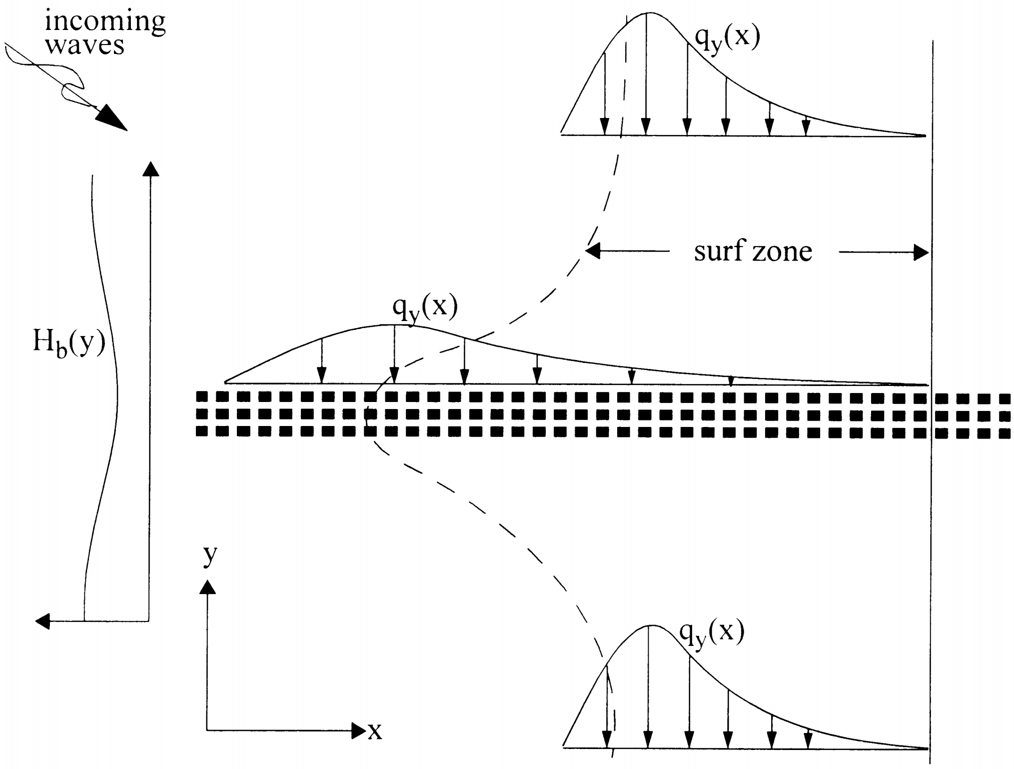

Figure 2: Conceptual model of groin interaction with incoming waves

Interaction of permeable wood groins with hydrodynamic and sediment transport processes are simulated by two numerical models (Figure 3). As a first step, the incoming wave rays are transformed on 2D nearshore bathymetry using REFDIF (Kirby and Dalrymple, 1994). The resultant wave parameters at breaking are used as the input wave conditions to run the sediment transport model to compute shoreline evolution in discrete time steps under computed constant wave forcing.

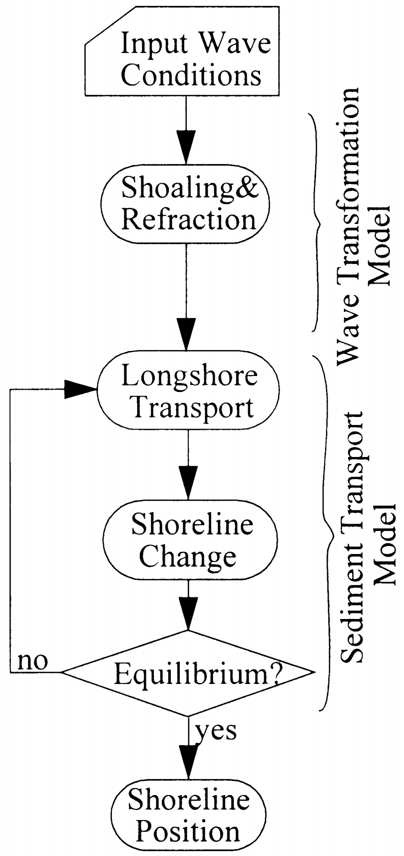

Figure 3: Flow diagram of numerical model

The effect of the wood piles on incoming waves is simulated by a shoal with the same geometric dimensions as the groin. The vertical permeability of the shoal is assumed to be equal to the planform permeability of the groin in analogy to the density refraction and depth differentials (Snell's Law). The altered bathymetry causes a refraction effect on wave orthogonals which consequently create a local perturbation in longshore sediment transport. This perturbation drives the shoreline evolution such that the shoreline tries to align with the wave crests and diffuse the initial perturbation caused by the structure.

Computation of longshore transport rate and shoreline change are based on the CERC transport formula (Shore Protection Manual, 1986) and conservation of mass, respectively.

CERC Transport Formula	$Q = \frac{K}{16(s-1)(1-p)} H_b^2 c_g \sin(2\alpha_b)$
Conservation of Mass	$\frac{\partial Q}{\partial x} + \frac{\partial y}{\partial t} = 0$

where,

Q	= Volumetric rate of longshore sediment transport
K	= Longshore diffusivity constant (0.77)
s	= Specific weight of sediment
p	= Sediment porosity
H_b	= Breaking wave height
c_g	= Wave group velocity
α_b	= Breaking wave angle measured from shore normal
y	= Shoreline position perpendicular to the baseline
x	= Longshore position measured along the baseline
t	= Time

6. Numerical Model Results

The model predicts that the planform disturbance due to the groin increases rapidly at the beginning, but eventually slows down as the shoreline adjusts to the incoming wave direction such that the transport capacity of waves drops to an ambient level. This planform equilibration is similar to bypassing process in rock groins with the difference that in this case, bypassing occurs continuously and overall, the permeable groin causes deposition at adjacent shorelines.

The permeability of the wood groin is modeled with a reduction factor by which the water depth at the groin is reduced. The reduction factor is calibrated such that the resultant wave orthogonals at breaking match the measured shoreline orientation of 7^{o} measured counter-clockwise from the North. The optimum reduction factor is determined as 10%.

Figure 5: Wave refraction around pile cluster groin

Breaking wave parameters including height, angle and group velocity, are computed using existing field conditions as model input. Figure 6 shows the computed longshore distribution of wave heights along the breaker line.

Figure 6: Longshore distribution of wave heights

The sediment transport model which starts with an initially straight shoreline uses the computed wave conditions as a constant forcing on the shoreline. Figure 7 shows the first 30 days of evolution of the longshore sediment transport rate under constant forcing of sea waves. Note the initial perturbation immediately after wave attack (indicated as 0 days) and the relatively rapid equilibration within 30 days. The time scale in this model depends on the probability occurrence of the input wave conditions. Analysis of WIS data indicates that the sea and swell waves used as input in this model make up approximately 27% of the total number of waves encountered during the hindcast. The rest of the waves are either calm or sheltered by geographic constraints and cannot reach the shore. Therefore, one day in model is equivalent to approximately three to four days in reality.

Figure 7: Initial disturbance in littoral drift and its equilibration

An important observation in the shoreline evolution results of the model is the salient-type shore formation near permeable wood groins. In the previous sections it was mentioned that such a symmetric formation cannot be modeled using classic approaches. The present model was able to reproduce similar shoreline shapes as shown in Figure 8. This result is obtained through superposition of sea and swell induced shoreline change.

Figure 8: Computed equilibrium shoreline at a pile cluster groin

The other important outcome of the numerical model is that the disturbance caused by the groin groves rapidly at the beginning but eventually slows down as the shoreline adjusts to the incoming wave direction such that the transport capacity of waves drops to an ambient level. This planform equilibration is similar to bypassing process in rock groins with the difference that here bypassing occurs continuously and therefore the overall effect of the groin on adjacent shoreline is less obvious even before the equilibrium is reached.

The time scale of shoreline evolution is an important parameter in estimating the impact of groins on adjacent beaches. Model results indicate that this time scale is on the order of few months, a relatively short period of time especially when compared to 40+ years for which the wood groins have existed on Naples Beaches.

In addition to the local shoreline disturbance in the immediate vicinity of the groin which has been demonstrated with observations and model simulations, there is also a "group effect" of the groin field. Aerial photographs of the southern section of fill area indicate a convex shaped shoreline on the order of 3 to 4 thousand feet long (Figure 9). This value is comparable to the length of the groin field, and it is too large to be the effect of a single groin. Modeling of this group effect would require a more detailed study with considerably more computation effort due to larger length and time scales.

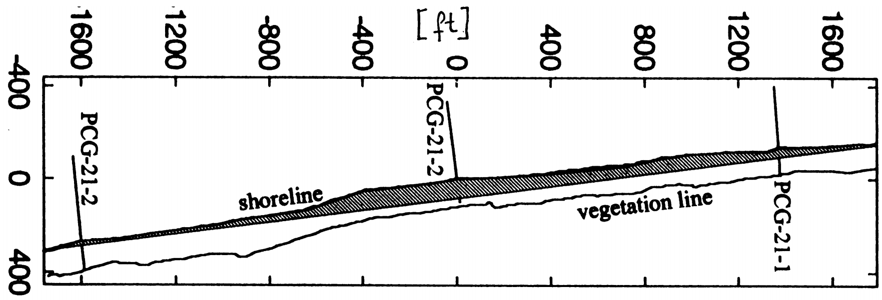

Figure 9: Measured group effect of wood groin field on adjacent shorelines

7. Summary and Conclusions

The study area has a locally unique wave climate with bi-directional wave attack. The shoreline south of the fill area is aligned towards the mean wave direction, more than it does in northern sections of the coast. These two effects have created relatively balanced transport directions with a slight offset to the south.

A numerical model is introduced to simulate shoreline evolution near permeable wood groins. With this model, a salient-type shore formation is reproduced in accordance with field observations. For the existing field conditions, a relatively rapid shoreline evolution is predicted with time scales on the order of few months.

Model results showed that the shoreline evolution around permeable groins has long been equilibrated and therefore no further shoreline adjustment is expected if the existing groin configuration is maintained. On the other hand, substantial shoreline change may occur if existing groin configuration is altered (groins removed or new ones added). Furthermore, if the change in groin permeability does not exceed ±20%, the sediment volume trapped by the groin will remain within ±8%.

8. References

Hubertz, J.M. and Brooks, R.M. [1989]. "Wave Information Studies of US Coastlines: Gulf of Mexico hindcast wave Information," WIS Report 18, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Kirby, J.T. and Dalrymple, R.A. [1994]. Combined Refraction Diffraction Model: REFDIF 1. Center for Applied Coastal Research. Department of Civil Engineering, University of Delaware, Newark, DE.

Shore Protection Manual [1984]. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, Corps of Engineers. Vol. 1, Vicksburg MS.