CHAPTER 96

MODERN FUNCTIONAL DESIGN OF GROIN SYSTEMS

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ABSTRACT: Coastal zone management policy in the United States and many other countries discourages use of groins for shore protection, even though properly designed groins can maintain beach width, increase longevity of beach fills, and prevent loss of sand into inlets, navigation channels, and submarine canyons. A lack of a systematic approach to groin functional design and a poor image from incorrect applications are probably responsible for the aversion to groins. In this study, a modern approach to groin functional design is demonstrated by applying the shoreline response model GENESIS to simulate the action of single and multiple groins. Groin bypassing and permeability, evolution of the shoreline in a groin field, and groin tapering are discussed. The balance between net and gross sand longshore transport rates emerges as an important factor controlling groin functioning. A criterion is introduced for judging groin success, and an example design diagram is developed based on this criterion to demonstrate the feasibility of developing a general and rational functional design procedure. Predictions are tested in reproducing shoreline change observed at the 15 groins at Westhampton, Long Island, New York.

INTRODUCTION

Coastal zone management policy in the United States and many other countries strongly discourages use of groins for shore protection, despite observations of good performance and their potential for maintaining beach width, increasing longevity of beach fills, and preventing loss of sand into inlets, navigation channels, and submarine canyons. No guidance on groin functional design is available other than rules of thumb, and many examples of poor performance of groins caused by misjudgments in either design or in planning have turned this structure into a cliché representing automatic beach destruction. The result, however, is that society is losing a valuable shore-protection structure that can function effectively and economically under certain conditions, in particular for increasing the longevity of beach fills (e.g., Truitt et al. 1993) and for stabilizing beaches adjacent to inlets. The purpose of the present work is to demonstrate a framework for groin functional design by use of modern coastal engineering predictive tools and knowledge.

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This paper concerns the functional design of groins, specifically their interaction with the beach through interruption of longshore sand transport – the "gating" or valve effect of groins (Hanson & Kraus 1989). Sand bypassing, groin permeability, and the balance between net and gross longshore transport will be shown to be key factors entering groin functional design and are central to this study. The functioning of a groin, which at first sight appears to be a simple structure, is governed by a surprising number of parameters, discussed in the next section. We exploit the shoreline change numerical simulation model GENESIS (Hanson & Kraus 1989) to quantify the influence of several of these parameters. For this study, representation of groins in GENESIS was refined based on qualitative observations in the field and laboratory, numerical testing, and data on groin functioning at Westhampton Beach, Long Island, New York (Nersesian et al. 1992). Although the dependence of groin functioning on longshore sand transport is the main focus, cross-shore transport processes are considered qualitatively.

REVIEW AND SYNTHESIS

Here, groins are defined as shore-perpendicular structures emplaced for the purpose of either (1) maintaining the beach behind them, or (2) controlling the amount of sand moving alongshore. Previous definitions have stated the purpose as "building a beach" or as "trapping littoral drift" (*SPM* 1984), which implies the removal of sand from the littoral system by entrapment. Because modern coastal engineering practice includes a regional perspective that considers the stability of adjacent beaches (Kraus 1989), groin emplacement may involve beach nourishment so that sand bypasses the system. Therefore, we emphasize *maintaining a beach* for Purpose 1. The second purpose primarily refers to terminal structures built to anchor the beach by limiting removal of sand (Dean 1993), as onto an ebb-tidal shoal or into a navigation channel. Here we focus on the first purpose, maintenance of beaches, i.e., providing a certain minimum beach width.

As a shore-normal structure, groins may not function well (a) if there is a large tidal range, allowing sand to bypass the structures at low tide or to overpass at high tide, or (b) if cross-shore sediment transport is dominant, such as is typical in shallow bays and lagoons, and along portions of the U.S. Great Lakes (Hanson & Kraus 1991a) where strong winds and relatively small fetches make steep (erosive) waves predominate over swell. Undesirable updrift buildup and offshore transport of sediment may be promoted if groins extend too far offshore in relation to the wave average breaker line or if they are not sufficiently permeable, potentially causing sand to be jetted seaward.

Groins are a possible component of shore-protection, beach-saving, and sand-management alternatives in the following situations:

1. Where there is a divergent nodal region in longshore transport, such as in the central area of a crenulate pocket beach, in the border region of a diffraction shadow zone of a harbor breakwater or jetty, or where the curvature of the coast changes greatly.

2. Where there is no source of sand, such as on the down-drift side of a large harbor breakwater or jetty.

3. Where intruding sand is to be managed, such as at the updrift side of an inlet entrance, harbor entrance, or navigation channel (for preventing sand intrusion and for stabilizing or anchoring the beach at the groin, or for stockpiling material for bypassing across the inlet).

4. Where sand movement alongshore is to be controlled or gated, such as to prevent undue loss of beach fill, while providing material to downdrift beaches.

5. Where an entire littoral reach is to be stabilized, such as along a spit, near a submarine canyon, or along a barrier island, for which sand is lost without return in an engineering time frame.

6. Where stabilization of the shoreline is required in the face of extreme sand-transporting conditions, such as on the banks of inlets, where the current alongshore is strong.

Synthesis of Present Knowledge

Reviews of groin functional design have been given by Bruun (1952, 1972), Balsillie and Berg (1972), Balsillie and Bruno (1972), Nayak (1976), Fleming (1990), and the U.S. Army Corps of Engineers (USACE 1992). These reviews provide some rules of thumb but no method for systematic functional design under a wide range wave, structure, and beach conditions. Although the literature on groins appears to be substantial, most papers describing the functioning of groins tend to restate conclusions from other studies with and without quoting sources. To the unwary reader, the literature may appear to assign validity to certain concepts and conclusions by weight of repetition and not by independent confirmation. Many laboratory tests appear to suffer so severely from scale distortions that the results are questionable or misleading. Some laboratory studies contain interpretations that confuse cross-shore processes with longshore processes. For example, change in wave steepness may change the breaking wave angle and longshore transport while causing either shoreline advance or recession by cross-shore transport. Almost no well-documented field case studies exist that involve shoreline evolution at groins.

The response of the shoreline to groins can be expressed schematically as an unknown functional relation *Response = F[groin(s); beach; waves, wind, & tide]* that involves at least 27 parameters (Table 1), more than the number found for shoreline response to detached breakwaters (Hanson & Kraus 1990). The engineer can control parameters related to the structure(s), such as groin length, spacing, and permeability (elevation, porosity). Grain size may also be controlled somewhat by selection of beach nourishment material.

Major properties that can be attributed to groins and the authors' reasoning behind accepting or questioning the validity of those properties are summarized in Table 2. Laboratory studies and field performance suggest that groins on sandy beaches function best if their spacing is two to four times the groin length (the *SPM* suggests a spacing ratio of two to three). Optimal spacing and groin functioning depend upon: groin length (depth at the groin tip, which controls sand bypassing); groin permeability or porosity (controlling sand throughpassing); groin elevation and tidal range (controlling sand overpassing); predominant wave direction and height; net and gross longshore transport; and sediment grain size (mode of transport as suspended load or bed load).

Field observations reveal that single groins, groin fields, and jetties that function as groins rarely fill to capacity (to their seaward tips). Typically, the updrift shoreline reaches only a modest distance to the tip, indicating that sand bypassing and permeability, as well as variability in wave direction, play an important role in determining transport around the groin and resultant local and regional shoreline change. In a study of a groin field that has been active for almost three decades, Nersesian et al. (1992) found that the 14 groin compartments were still slowly filling in the predominant direction of the littoral drift. Such behavior can be explained by the process of bypassing, whereby each compartment deprives sand to neighboring downdrift compartments until it is filled to the point that bypassing can occur to the adjacent downdrift compartments or beach. If bypassing is not complete, a groin will act as a headland and impound sand far updrift, reducing the supply of sand downdrift along the remaining portion of the littoral cell.

Table 1. Parameters governing beach response to groins.

Groin(s)	Beach and Sediment	Waves[1], Wind, & Tide
Length	Depth at Tip of Groin	Wave Height & SD[2]
Spacing (for groin fields)	Beach Morphology (depth contours, berm height, etc.)	Wave Period & SD
Elevation	Depth of Closure[3]	Wave Angle & SD
Porosity	Sediment Availability	Wind Speed & SD
Tapering	Median Grain Size & SD	Wind Direction & SD
Angle to Shoreline	Sediment Density	Wind Duration & SD
Shape (as straight, angled, T-head, spurred, etc.)		Tidal Range

1) Long-term wave statistics or time series, and storms.
2) Standard deviation (representing variability in the given quantity).
3) Can be obtained by beach profile survey or estimated from wave information.

Judging Success

How should groins be judged successful in performing their intended function of preserving the position of the (local) shoreline? The criterion imposed here is preservation of shoreline position in a groin compartment or next to a groin such that the shoreline never recedes landward of half the effective groin length. This definition is arbitrary and simply addresses the aim to provide a certain minimum width of beach – others might choose, say, one-fourth the effective length. The effective length of a groin is the distance (on either side) from its seaward tip to the design shoreline, which would normally be formed by beach fill at the time the groins were constructed.

GROIN BOUNDARY CONDITION

Groins have been represented in GENESIS throughout its development (Hanson 1989, Hanson & Kraus 1989), and shoreline change has been successfully simulated numerically for jetties and groins in the field (e.g., Kraus & Harikai 1983, Hanson & Kraus 1991a) and in physical models (Hanson & Kraus 1991b). However, predicted shoreline response adjacent to groins has been regarded by its developers as needing improvement (Gravens & Kraus 1989), particularly for groins that are permeable as well as diffract waves. The groin boundary condition was revised in this study based upon the following three requirements:

1. Bypassing should be represented such that the shoreline response to a groin, including evolution of the shoreline in time and its equilibrium plan form, depend on groin length (depth at tip of groin), with an increase in length increasing the impact of the structure on the shoreline.

2. Different groin permeabilities should produce different equilibrium plan forms, with increasing permeability decreasing the impact of the structure on the shoreline.

3. A permeability of 100% should result in longshore sand transport and shoreline evolution identical to that with no groin present.

Table 2. Functional properties attributed to groins and critical evaluation.

Property	Comment
1. Wave angle and wave height are leading parameters (longshore transport).	Accepted. For fixed groin length, these parameters determine bypassing and the net and gross longshore transport rates
2. Groin length is a leading parameter for single groins. (Length controls depth at tip of groin.)	Accepted, with groin length defined relative to surfzone width.
3. Groin length to spacing ratio is a leading parameter for groin fields.	Accepted. See previous item.
4. Groins should be permeable.	Accepted. Permeable groins allow water and sand to move alongshore, and reduce rip current formation and cell circulation.
5. Groins function best on beaches with a predominant longshore transport direction.	Accepted. Groins act as rectifiers of transport. As the ratio of gross to net transport increases, the retention functioning decreases.
6. The updrift shoreline at a groin seldom reaches the seaward end of the groin. (This observation was not found in the literature review and appears to be original to the present paper.)	Accepted. Because of sand bypassing, groin permeability, and reversals in transport, the updrift shoreline cannot reach the end of a groin by longshore transport processes alone. On-shore transport is required for the shoreline to reach a groin tip, for a groin to be buried, or for a groin compartment to fill naturally.
7. Groin fields should be filled (and/or feeder beaches emplaced on the downdrift side).	Accepted. Filling promotes bypassing and mitigates downdrift erosion.
8. Groin fields should be tapered if located adjacent to an unprotected beach.	Accepted. Tapering decreases the impoundment and acts as a transition from regions of erosion to regions of stability.
9. Groin fields should be built from the downdrift to updrift direction.	Accepted, but with the caution that the construction schedule should be coordinated with expected changes in seasonal drift direction.
10. Groins cause impoundment to the farthest point of the updrift beach and erosion to the farthest point of the downdriff beach.	Accepted. Filling a groin field does not guarantee 100% sand bypassing. Sand will be impounded along the entire updrift reach, causing erosion downdrift of the groin(s).
11. Groins erode the offshore profile.	Questionable and doubtful. No clear physical mechanism has been proposed.
12. Groins erode the beach by rip-current jetting of sand far offshore.	Questionable. Short groins cannot jet material far offshore, and permeable groins reduce the rip-current effect. However, long impermeable jetties might produce large rips and jet material beyond the average surfzone width.
13. For beaches with a large predominant wave direction, groins should be oriented perpendicular to the breaking wave crests.	Tentatively accepted. Oblique orientation may reduce rip current generation.

In GENESIS, the fraction F of sand that passes a groin by being transported over and through it is represented by a permeability factor P, and the amount passing around the seaward end is represented by a bypassing factor B (Hanson & Kraus 1989), such that

$$F = P(1 - B) + B \quad (1)$$

where $0 \leq P \leq 1$, and $0 \leq B \leq 1$. In the new version of GENESIS, the actual transport rate at the groin Q_G^*, denoted with an asterisk, is related to the calculated potential rate at the groin Q_G as

$$Q_G^* = F \cdot Q_G \quad (2)$$

In the original version of GENESIS, the factor F was applied to the transport rate at the updrift cell, as $Q^*_G = F\, Q_{G\pm 1}$. However, to satisfy Criterion 3, that, in the limit $P \rightarrow 0$, the calculation should give the same result as for "no groin present," Eq. 2. is required. The permeability factor is assigned based on groin elevation, groin porosity, and tide range, and the bypassing factor B is calculated in the model at each time step as (using the present shoreline position to calculate present depth)

$$B = 1 - D_G / D_{LT} \quad (3)$$

where D_G is the depth at the groin at a particular time step, and D_{LT} is the depth of active longshore sand transport, taken to be about 1.6 times the significant breaking wave height (Hanson & Kraus 1989). Eq. 3 shows the importance of depth at the groin tip, a parameter related to but more fundamental than groin length, and the form of Eq. 3 suggests that the parameter D_G / H_o should characterize groin bypassing, where H_o is the deep-water wave height.

The reasoning behind use of this simple formula, Eq. 3, in development of GENESIS was pragmatic: the cross-shore distribution of longshore transport on a natural beach takes many forms not readily predicted, including peaks in the swash zone and near the breaker line (Kraus et al. 1982), and the presence of a groin in the surf zone will also modify the distribution in some, as yet, unpredictable way. Therefore, a rectangular distribution across shore was originally taken as an easily calculated representative shape. In the new version of GENESIS, the depths in Eq. 3 are calculated from the equilibrium profile with $y^{2/3}$ shape, where y is distance offshore.

Single-Groin Tests

Time Dependence of Bypassing. Shoreline change predictions at a single groin were compared for four distributions of transport; rectangular on a plane-sloping profile, triangular with peak at the shore on a plane-sloping profile, and two similar distributions on an equilibrium profile shape. In the test, median grain size was 0.25 mm, used to determine the equilibrium profile shape, the groin was 100 m long on an initially straight shoreline, and waves were constant with deep-water height of I m, period of 8 sec, and angle of 20 deg. The model was run for 15 years, and calculated positions of the shoreline directly updrift of the groin divided by the groin length are plotted in Fig. I. The general trend is for rapid initial buildup followed by a more gradual growth after about two years. The calculated gradual buildup agrees with the qualitative observation that groins seldom fill to capacity, and an influential factor is the increased amount of material bypassing a groin as the shoreline grows. The rectangular distribution based on the equilibrium profile falls between the two extremes and was selected for the new version of GENESIS.

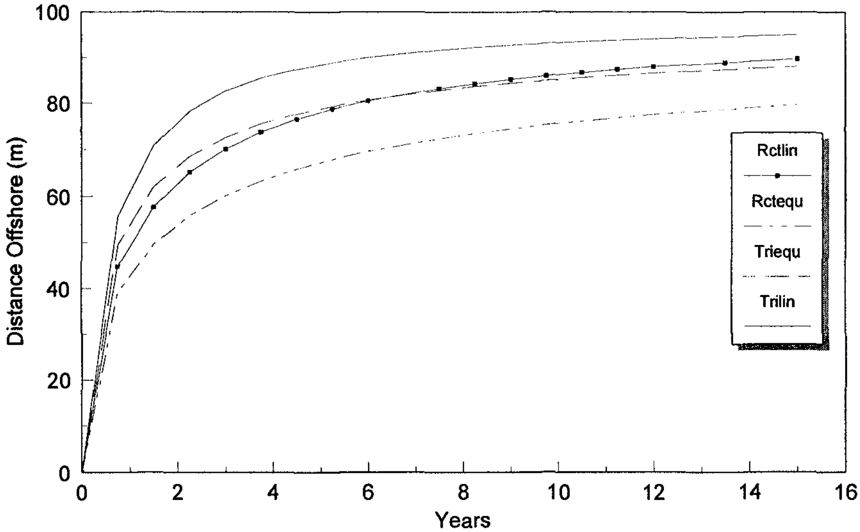

Fig. 1. Shoreline change at groin calculated with different distributions for bypassing.

Influence of Gross Longshore Transport. Shoreline change in the vicinity of disturbances that alter transport alongshore is controlled by the gross transport rate as well as the net (Bodge 1992). A single groin was placed on the beach of the previous example, and the directions of hindcast waves from the Westhampton project, discussed below, were modified to change the ratio of the net transport rate Q_n to the gross Q_g as $Q_n/Q_g = 1, 0.5, 0.33$, and 0.25. The ratio Q_n/Q_g varies between 0 and 1 for the limiting conditions of perfectly balanced transport (no net) and unidirectional transport, respectively. The ratio $Q_n/Q_g = 0.5$, with $Q_n = 300{,}000$ cu m is the design condition for Westhampton. The length of the groin Y_G was also varied in relation to the width of the surfzone (to the breakpoint) Y_B on the initially straight beach $Y_G/Y_B = 0.5, 1$, and 2. Fig. 2 plots calculated shoreline change on the updrift side of the groin for $Y_G/Y_B = 1$. Over the 5-year calculation interval, the shoreline approaches the tip of the groin only if the gross and net rates are equal. As the gross rate exceeds the net, the growth decreases, confirming Property 5 in Table 2. Shoreline change with $Q_n/Q_g = 0.5$ for the three dimensionless groin lengths is plotted in Fig. 3. The updrift shoreline moves seaward more rapidly as the relative groin length increases.

Multiple-Groin Tests

Shoreline change was calculated for a field of seven groins with $P = 10$ % placed on an initially straight beach. The groins were 100 m long with spacing of 400 m. Waves were Raleigh-distributed in height with significant $H_o = 1$ m, period 8 sec, and deep-water direction 10 deg. Grid spacing was 50 m and time step was 6 hr. Fig. 4 shows calculated shoreline change after 5 and 10 years. The groins slowly filled in the direction of transport, but the shoreline did not reach the tip of the most updrift groin. Updrift groins deprived the downdrift compartments and downdrift (unprotected) beach of sand until substantial bypassing occurred. At 10 years, the most downdrift compartment did not yet benefit from the gradual bypassing, and it lost sand because of groin permeability. Tracking of shoreline position through time (Fig. 5) downdrift of the most updrift groin in the first compartment shows that it first retreated because sand could not enter. Over time, bypassing began to occur and the shoreline advanced.

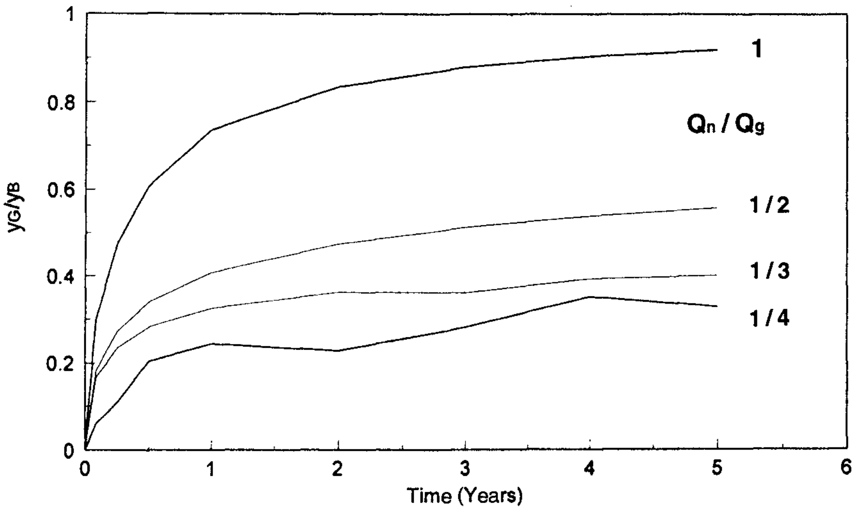

Fig. 2. Shoreline change updrift of groin for different ratios of net to gross transport rate

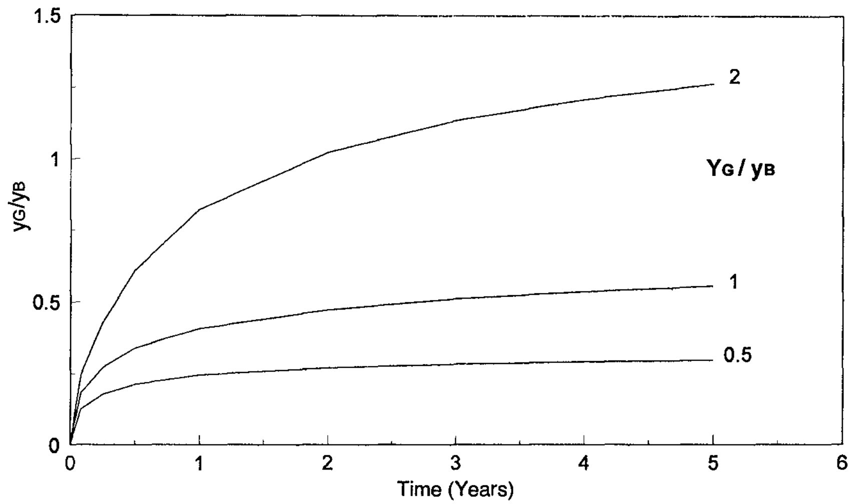

Fig. 3. Shoreline change updrift of groins of different relative length when the net rate equals half the gross rate

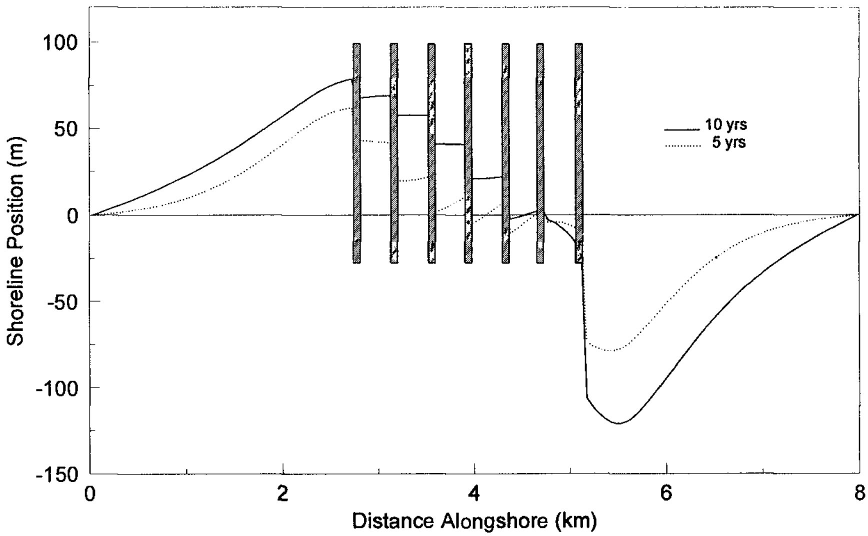

Fig. 4. Shoreline change in a groin field showing gradual filling of compartments in the direction of net drift.

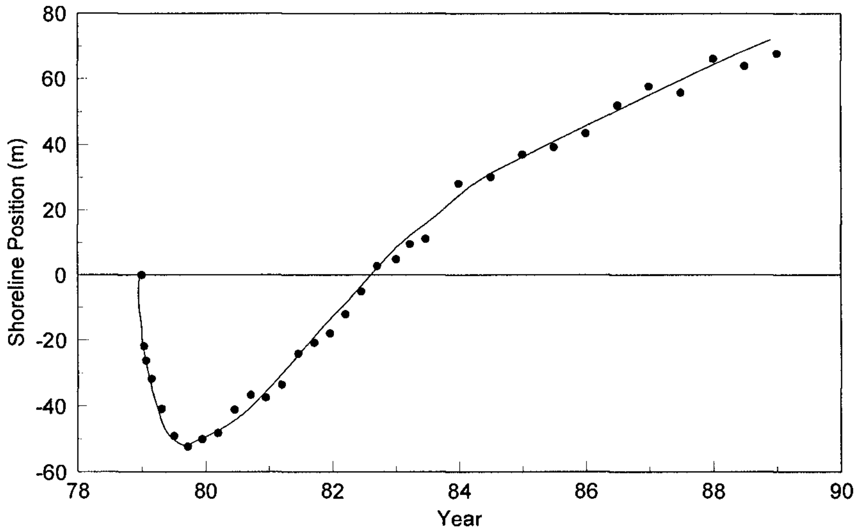

Fig. 5. Evolution of shoreline within most updrift groin compartment.

Example Design Diagram. The final example, which demonstrates numerical modeling capability to develop general functional design guidance, concerns a pair of groins placed on a 0.25-mm sand beach. Waves with constant significant deep-water height, period of 8 sec, and deep-water direction of 30 deg were applied for one year. Initial depth at the groin tip was specified for groin lengths of 50, 75, 100, 150, and 200 m, and simulations were also done for $D_G/H_o = 0.5$ and 1.0 to give groin lengths of 10 and 27 m. The groin spacing X_G divided by groin length Y_G was also changed. The resultant shoreline response was classified as either satisfying or not the criterion that the calculated landward-most shoreline position Y be less than half the effective groin length, where filled circles in Fig. 6 indicate satisfaction of the criterion.

Fig. 6 shows that shorter groins, indicated by smaller D_G/H_o values, satisfy the criterion with a larger relative groin spacing, suggesting that shorter groins will be more cost effective. For the longest groin tested, the criterion was met for all groin spacings, explained by the fact that for a relative groin spacing exceeding about 8, the two groins no longer interact as a system but function independently. Thus, very long groins satisfy the criterion as a single groin. Care must be used in interpreting a plot such as Fig. 6 which involves non-dimensional parameters. The figure implies, by the imposed success criterion, that a spacing of $X_G/Y_G = 1/1$ is satisfactory, but only as far as maximum recession is concerned; maximum *accretion or filling capacity* (by nourishment) for smaller ratios is also much smaller. For example, with longshore spacing of $X_G = 200$ m, the ratio $X_G/Y_G = 1/1$ gives a maximum advance of about 14 m, whereas the ratio 1/11 gives a maximum advance of 106 m. Effectiveness in holding a certain width of beach, reduction of down-drift impacts, and initial and maintenance costs must be kept in mind when developing groin functional designs. Shorter relative groin spacing may also increase cost. In using longer groins, *relative* erosion is limited, whereas *absolute* erosion increases with groin length.

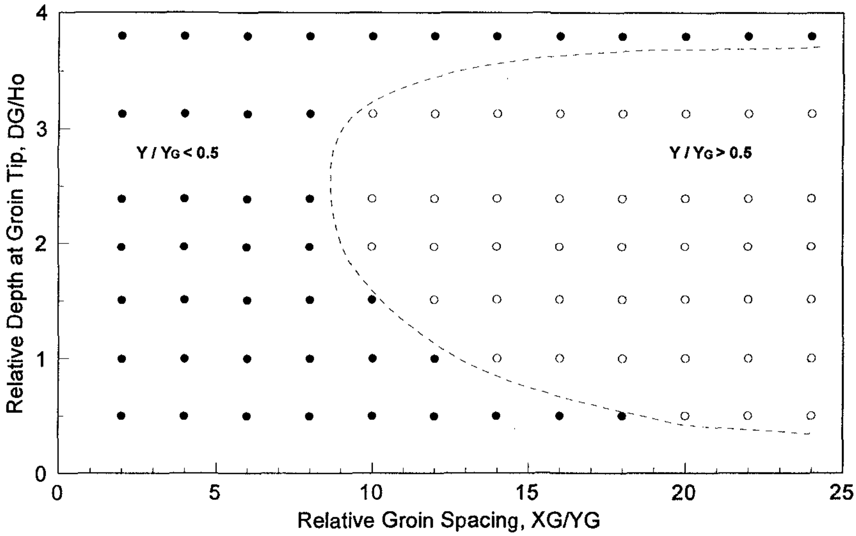

Fig. 6. Example design diagram for a single groin compartment

SIMULATION FOR WESTHAMPTON BEACH

Background

Westhampton Beach faces the Atlantic Ocean and is located on a portion of a 24.6-km long barrier island of the southeast shore of Long Island, New York, between Shinnecock Inlet to the east and Moriches Inlet to the west. This coast was devastated by a hurricane in 1938 and further damaged by at least seven other hurricanes and extra-tropical storms that struck the area from 1944 to 1962. As a result, the U.S. Government authorized storm-protection planning for much of the south shore. Groins were constructed initially at Westhampton Beach because it was the section judged to be most vulnerable to breaching and inlet formation to the Great South Bay. Nersesian et al. (1992) describe the regional setting, history of the Westhampton Beach shore-protection project, and the functioning of the groins there. The work described in this section is a continuation of the paper of Nersesian et al. to modeling of shoreline change at Westhampton.

The original plan developed by the U.S. Army Corps of Engineers (USACE 1958) provided for construction of dunes, fronting protective beaches, together with 23 groins if needed. Owing to political and economic considerations (Heikoff 1976) (with law suits against the three levels of Government (Federal, State, County) by private land owners settled in October, 1994), eleven groins were constructed without placement of the dune and beach fill on the eastern 3.8 km of shore extending westerly from a point 10.6 km east of Moriches Inlet. This work was supplemented in 1970 by construction of four groins extending 1.8 km west of the 11 groins, including beach fill in the four new compartments. The groins are made of large quarry stone, and are 146 m long with average spacing of 400 m. The chronology of fills as implemented in the shoreline change simulation is: 1969-1970, 1.49 million cu m placed in last four compartments during and after completion of construction (USACE 1980); 1974, 31,400 cu m (probably dredged beach-quality material from channel maintenance) placed directly downdrift of Groin 15 (assumed to be a rectangular fill 400 m long); and 1977, 44,700 cu m, placed similarly as the 1974 fill.

Westhampton Beach is composed of fine to medium sands, and the net transport rate has been estimated to be on the order of 300,000 cu m/year to the west (Panuzio 1968). Fig. 7 is an oblique aerial view of the Westhampton groin field, looking east, with Groin 15 in the foreground. Over the years, the groin field has very successfully performed its intended *local* function of reinforcing the historically weak section of barrier beach by building a wide beach at the groin field and to the east (updrift) (Nersesian et al. 1992). However, the beach immediately to the west has eroded significantly and was breached on December 18, 1992, during a strong subtropical storm.

Simulation of Shoreline Change

The shoreline change model was driven with data generated from a recent Corps of Engineers Wave Information Study (WIS) hindcast (Hubertz et al. 1993) that provides wave parameters at 3-hr intervals for the 20-year period 1956-1975. Using representative coefficient values of $K_1 = 0.54$ and $K_2 = 0.27$ in the CERC/GENESIS longshore sand transport rate (LSTR) formula (Kraus et al. 1982, Kraus & Harikai 1983), a shoreline orientation of 70 deg from north, and wave shadowing by land masses to achieve a 20-year average annual net of approximately 300,000 cu m (the WIS hindcast gives waves from all directions), GENESIS produced statistics as shown in Table 3, using both the WIS sea and swell components. With the average annual LSTR constrained to approximate the empirically determined rate (Panuzio 1968), the corresponding gross rate was about twice that amount. In the simulations, the grid spacing was 61 m, and the time step was 3 hr. The lateral boundary conditions were a pinned beach located approximately 4 km east of Groin 1 on the east, and a gated boundary defined by the Moriches Inlet jetty about 4 km to the west of Groin 15.

Fig. 7. Aerial view of Westhampton groin field, looking east, Dec. 1992

Table 3. Variability in annual potential longshore sand transport rates (1,000 cu m) calculated from the 20-year WIS wave hindcast (positive net transport to the west).

Quantity	Net Rate	Gross Rate	Year
Minimum Net	117	471	1967
Maximum Net	685	842	1958
Minimum Gross	189	434	1957
Maximum Gross	685	842	1958
Average	321	610	—
Standard Dev.	130[1]	114	—

1) Note that ratio of std. dev. over average for the net transport is much greater than for the gross.

Variability in Wave Input. Simulations were performed using four different sequences of ten years of record from the 20-year hindcast wave time series. The series were 1956-1965 and 1966-1975, taken in chronological order by year and in reverse chronological order by year. The resultant calculated shoreline positions showed little difference among each other, which may be explained by the groin system having more control (as through bypassing) than do reasonable variations in wave conditions. The only notable difference produced by the wave sequencing was in position of the shoreline directly west of Groin 15 (downdrift of the groin field), depending on whether the most recent waves arrived more out of the south than out of the north.

Model Calibration. Fig. 8 shows measured and calculated shoreline change in December 1989 starting from the February 1966 measured shoreline, which was the pre-construction shoreline. The overall trend in simulated shoreline change follows well that of the actual change. Of particular note is the reproduction in the model of the gradual infilling of the groin compartments from east to west (left to right in the figure). Reproduction of the observed gradual infilling of the groin field in the direction of predominate transport is considered a major success of the model. No attempt was made to adjust the transport coefficient K_1 or otherwise tune the model.

The hump in the measured 1989 shoreline around distance 14 km (east of Groin 1) is anomalous from the perspective of longshore transport processes and may be a result of irregular nearshore bathymetry. The model overpredicts erosion on the west side of Groin 15. Depth soundings made by the first author in reconnaissance of the site in June 1991 indicated that the water adjacent to the west side of Groin 15 was much deeper than at comparable distances offshore of the groin field and the distant unprotected beach. The steeper nearshore profile west of Groin 15 alters wave transformation and sediment transport processes, and it is not accounted for in the shoreline change simulations. Also, occasional strong reversals in direction of longshore transport in the summer, not necessarily accounted for in the hindcast, can create a fillet on the east side of Groin 15. Such fillets are present in autumn/winter 1979 and 1994 aerial photographs. Sand volume in the system increased; we believe the extra volume to be associated with onshore wind-blown sand transport on the wide beach in the groin field, creating lush high dunes and a wide berm.

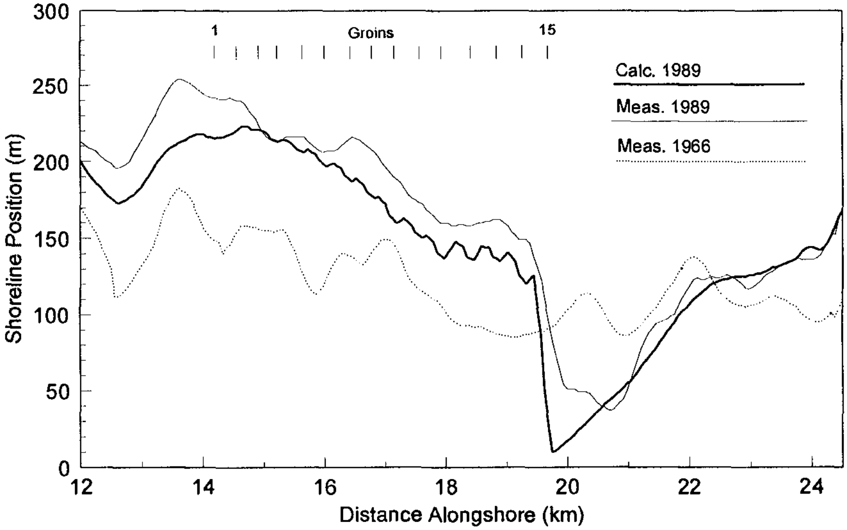

Fig. 8. Calibration of the shoreline change model for Westhampton

Groin Tapering and Shortening - Alternative Designs. Tapering and shortening of groins reduce their gating capacity and promote transport of sand out of the groin field in transition of the groins to the unprotected beach. Tapering of the westward-most groins at Westhampton would increase bypassing and movement of sand to the west. Shortening of the groins would release sand to the system, reduce updrift impoundment, and provide stone for constructing additional groins to the west, if needed. Moderate tapering and shortening of the groins would cause a minor decrease in level of protection to the properties in their lee by decreasing berm width.

As a simple example of the use of a shoreline response model in groin functional design, three alternatives were examined to estimate the shoreline plan form at and west of the groin field 20 years into the future. The simulations started from the measured shoreline of March 1989 and finished in July 2009 (Fig. 9). Alternative 1 simulated the existing condition to provide a baseline for comparison. Alternative 2 involved shortening of Groins 14 and 15 to 129.5 and 85.3 m, respectively (groins shortened by 16.8 m and 61.0 m), with addition of a groin between them of 107.4-m length to maintain groin spacing to length ratio, and placement of 2,500,00 cu m in the westernmost eight compartments (including the intermediate groin). Alternative 3 involved shortening all groins by 30.5 m or to the existing shoreline, with addition of 300,000 cu m west of Groin 15 for a distance of 1,600 m. Each year of the WIS wave hindcast was used in the 20-year simulation.

Fig. 9 shows after 20 years, the groin field will be effectively filled, except for the most westward compartment, because it can receive sand from the east, but not from the west (because of the great effective groin length on the west side) during times of reversal from the predominant direction of transport. Tapering plus fill provides maximum benefit to the downdrift beach; clearly, the model could be used to optimize the preferred alternative design to meet planning objectives.

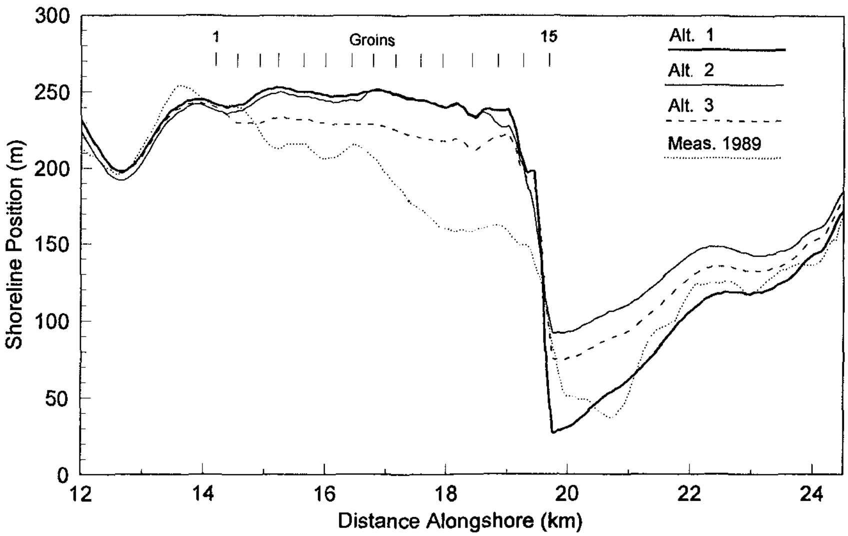

Fig. 9. Comparison of groin shortening and tapering alternatives

CONCLUSIONS AND RECOMMENDATIONS

1. This paper has demonstrated that modern numerical simulation models can reproduce the main features of shoreline change at single groins and at groin fields, and thus are powerful tools for groin functional design.

2. Bypassing (parameterized by the ratio D_G/H_o), structure permeability, and the balance between net and gross longshore transport rates (parameterized by the ratio Q_n/Q_g) are three key factors that determine the functioning of groins. These three factors succinctly incorporate many fundamental parameters, such as wave height, direction, period (and their variability), equilibrium beach slope (or grain size), and groin length. Ratio of groin separation distance to groin length is a key controlling factor for groin systems, as found in previous studies.

3. There is great need for comprehensive project-level monitoring of groin behavior, including periodic shoreline surveys (as through aerial photography), and periodic beaeh profile and sediment surveys together with long-term wave and current monitoring.

4. Field and large-scale laboratory studies are required to quantify groin bypassing, distribution of transport in the presence of a groin, groin permeability, seasonality of waves in inducing both longshore and cross-shore transport, and the offshore jetting effect of groins.

5. Cross-shore sediment transport processes and their intricate and unknown interaction with longshore sediment processes need to be investigated to understand how beach elevation and width can build beyond what can be presently calculated with shoreline change models. It is postulated here that cross-shore transport, such as a strong accretionary event in summer, is a potentially important mechanism for groin filling, because longshore transport alone cannot fill groins to their tips owing to bypassing and variability in direction of transport.

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