CHAPTER 75

STATE OF GROIN DESIGN AND EFFECTIVENESS

by

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ABSTRACT

An annotated bibliography on groins, compiled by Balsillie and Bruno (1972), has provided the background for this paper. A review of functional design criteria is presented including groin length, height, spacing, permeability-adjustability, and orientation. A discussion of coastal processes and their relationship to groin design and effectiveness is also given.

INTRODUCTION

Groins have been in wide use throughout the world since before the turn of the century. They are possibly the oldest type structure whose specific purpose is to build up a sand or pebble beach where little material existed before, or to maintain an existing beach against further erosion. There are numerous examples where groins have fulfilled these purposes and as many others which have not; indeed some have actually intensified the problems they were intended to solve.

Coastal engineering is a relatively young field of science. Classically established disciplines relegated to the land, the sea, and the atmosphere all meet at the shoreline. Coastal engineers, therefore, need understanding of knowledge in all three of these areas. They must have an understanding of sedimentology, physiography, physics, mathematics, hydraulic and structural engineering, climatology, stratigraphy, to name a few. Their job is made even more difficult, for the many factors that affect the delicate stability of a beach are often impossible to measure in their entirety. As a result, the

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coastal engineer must rely on either his experience as gained from field or laboratory studies, or, lacking this, make judgments based upon documented reports to form the basis of remedial design criteria for a particular problem.

In pursuit of further understanding of the role that documented research plays in groin design, over 450 reports and papers, covering the period from 1900 to 1971, were reviewed during the compilation of an annotated bibliography on groins. It was determined that the majority of articles were introductory in nature, giving in many cases but a cursory glance at groin design and purpose. In other..."instances it is clear that...groins have been attributed magical properties whereby they might conjure beach material out of the sea into their outstretched arms" (Hoyle and King, 1957). Some articles, however, have contributed significant data as a result of experimental endeavors and field observation where groin geometry, spacing, degree of permeability, orientation relative to the shoreline, and materials of construction have been investigated under particular conditions of littoral drift and wave action. Such reports have formed the basis for the development of design criteria for groins. At present it is felt that the criteria as published in the Coastal Engineering Research Center's report "Shore Protection Planning and Design" (U. S. Army Corps of Engineers, 1966) represent the present state-of-the art and provides a logical design approach for groin structures.

Three basic categories form the basis for the design of groins: (1) coastal processes (wind data, wave height, period and angle, beach slopes, textural characteristics of beach sediments, etc.); (2) functional design (spacing, length, height, orientation with the shoreline, permeability, special designs); and (3) structural design (materials of construction and procedures). This paper is primarily concerned with the first two categories, since the selection of materials and construction procedures are of necessity a matter of economics and local practice. Therefore, it is the purpose of this paper to present a review of some of the more prominent criteria used in groin design as revealed by the literature, and to offer general discussion on the effectiveness of groin use.

LITTORAL PROCESSES

In undertaking the functional design of groins, a primary requisite is a comprehensive understanding of the littoral processes predominating in the locality of concern. Too often such knowledge is deficient or totally lacking and the effectiveness of the resulting structure(s) is a matter of chance.

Adequate investigation of the many faceted and interrelated oceanographic and meteorological forces and their effect on the shoreline should be made in order that understanding of the littoral processes is attained. With such understanding, the functional design of a groin(s) can proceed in a manner which best utilizes the littoral processes and yields a structure(s) attuned to the environment producing the desired objectives.

Figure 1 presents the major oceanographic and meteorological forces and their interrelationships with each other and the shoreline. It should be noted that many of these forces vary in magnitude over relatively short periods of time and that determination of specific characteristics suitable for structural design purposes is difficult. This is especially true of those elements concerned with waves and littoral currents. Elements, such as coastal and beach configurations, are relatively stable, therefore, measurable with reasonable accuracy and can easily be used in the functional design of groins. Others, particular littoral drift rates and directions and their influence on the volume of material on a beach, need additional documentation for use in the proper functional design of groins. Although conceptually understood, the means to accurately measure and thus document or predict littoral drift rates are, at present, limited.

When considering the use of groins for shoreline protection or improvement, it should be remembered that each beach is unique due to the combination of forces that are focused at that location, and that the overall configuration of the shore is constantly being reshaped. Thus any structure to be built at the shore must consider and account for these changes. Proponents of proprietary groin designs too often fail to recognize this, and attempt to use a single design as a cure-all device. "There is no such thing as a universal solution to the problem." (Schijf, 1959).

FUNCTIONAL DESIGN

Following are a series of tables, each concerned with a specific functional dimension utilized in the design of groins both singly and in a system. Six criteria are presented. They are: length, height, spacing, permeability-adjustability, orientation with respect to the shoreline, and special design innovations. The tables offer a spectrum of criteria as gained from field observation, experimental results, and personal experience. Specifics of the actual littoral zone and test conditions are not presented since space here will not allow such detailed description. All entries follow as closely as possible the original documentation. Though the list of articles represented is by no means complete, the tables do present some of the more pertinent results concerning functional design criteria for groins.

Length and Height of Groins:

In early shore protection projects, and even to a large extent today, length has remained a question of "trial-and-error". It has been defined in relative terms as short or long; the longer structures collecting larger quantities of littoral drift than shorter structures, though it is argued that shorter structures can be extended, if needed, allowing for greater economy. Many investigators have defined length to be a function of water depth, since the longshore transport rate is also a function of depth. Other investigators have utilized a concept that length is a function of the

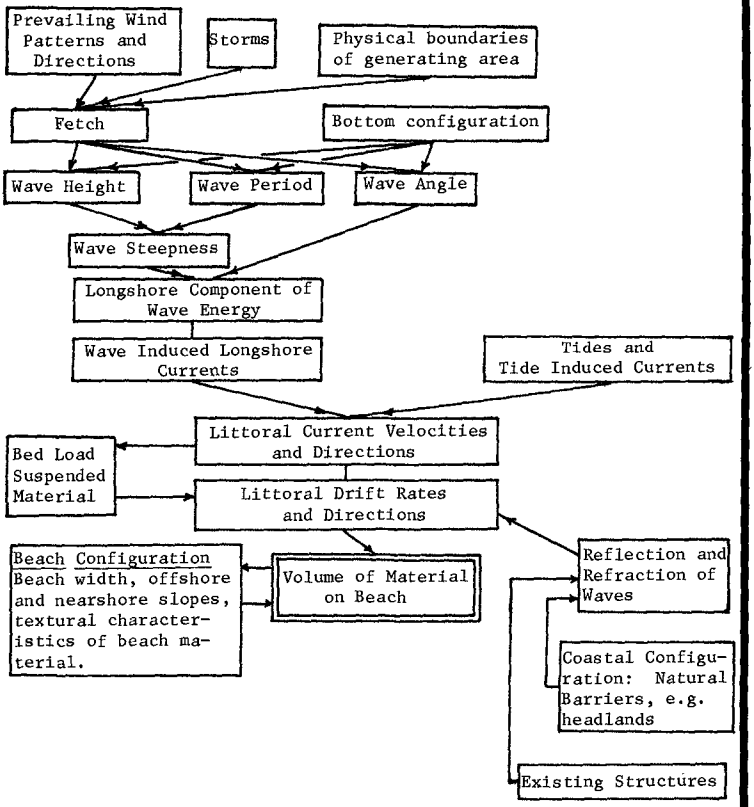


Figure 1. Environmental factors which affect shorelines.

distance from the shoreline to average breaking point of plunging waves. There are design rules that divide a groin into sections, each section of which is prescribed a certain design length. Many designs are contingent upon the amount of littoral drift they are anticipated to entrap. These and other requirements for groin length are presented in Table 1.

The evolution of requirements for the height of groins has followed the same lines as for groin length. Height, as with groin length, has been defined in relative terms, as either high or low. High groins tend to entrap and hold more material than do low groins (depending on length), thereby causing excess erosion of downdrift beaches. Scour along the immediate downdrift sides of high groins has been reported; caused by the spilling effect of water over the structure and subsequent removal of beach material which lead to failure of groins (Evans, O. F., 1943). Low groins, on the other hand, allow littoral drift to pass over the structure so that immediate downdrift scour and overall beach recession should be minimized. Many investigations also reveal that height can be more absolute; and give heights that groins should be built above the beach profile and water level for specific conditions. These results are presented by Table 2.

Height and length are utilized in various combinations to produce various effects. For instance, the use of high, impermeable groins of considerable length to permanently trap sands has been proposed, and the structures thus act as artificial headlands. They may be used at the updrift side of an inlet or submarine canyon. Wicker (1958) and Dunham (1965) have discussed such use.

Spacing of Groins in a System:

Spacing has generally been defined as a function of groin length. A spacing designation of 1:2, for instance, defines a spacing twice the length of a groin to be used in a system, assuming the groins to be of equal length.

Table 3 indicates that spacing ratios commonly fall into a range of 1:1 to 1:4. Spacing requirements are dependent upon such factors as severity of wave climate, size of beach material, steepness of the beach profile, predominant angle of wave incidence with the shoreline, and economic factors.

Permeability-Adjustability of Groins:

Permeability of groins became a design feature when it was observed that such structures could cause deposition in their immediate vicinity, yet allow significant amounts of littoral drift to pass through the structures so that abrupt offsets in shore alignment would not occur between groins, and

TABLE 1. LENGTH OF GROINS

INVESTIGATOR, YEAR	AREA OF INVESTIGATION	TYPE OF INVESTIGATION	LENGTH / REMARKS
Owen, J.S., and Case G.O., 1908	England - General	Theory - Experience	Extend at least to low water line.
Case, G.O., 1915	England, New York, New Jersey	Field - Experience	Long groins recommended - should extend from high to low water, and seaward of low water if possible.
Kressner, B., 1928	Germany	Movable bed, model study	Decreasing length downcoast: proposes principle of shortening groins downcoast at a small angle (4-6°) to insure that downcoast beaches receive littoral drift.
Coen-Cagli, M.E., 1932	General	Theory - Experience	Pebble beaches: 40-50 meters seaward from shoreline should be sufficient length. Sandy beaches: extend to 2 or 3 meter depth; will interrupt most of littoral drift.
Brown, E.I., 1939, 1940	General	Experience	Should extend at least to 6 foot depth below mean sea level. Under normal conditions, 80% of sand movement takes place at depths of less than 6 feet.
Duvivier, Jack, 1947	England	Experience	Utilize shortest length possible to stabilize the beach. Has used short groins between sets of longer groins.
Frech, F.F., 1948	New Jersey	Field	Extend to 6 feet depth of water.
Nagai, Shositiro, 1956	Japan	Movable bed, model study	Optimum distance groins extend from shore line seaward 40% of distance from shoreline to breaking point of plunging breakers where wave steepness is δ_0 = 0.01 0.02. Tests showed this gave greatest amount of deposition downdrift of groins, least updrift scour at groin sides and ends.
Horikawa, Kiyoshi, 1958; Horikawa, K., and Sonu, C., 1958	Japan	Movable bed, model study	Should extend seaward from shoreline 40-60% of distance from shoreline to breaking points of plunging waves.
Hiranandini, M.G., and Gole, C.V., 1961	Cochin, India	Field Study - prototype conditions, model study	200 foot minimum length preferred. Short groins defined as less than 150 feet.
Lee, C.E., 1961	Great Lakes	Field study	64% 100 ft. 21%: 100-150 ft. 15% 150 ft. } of 841 groins examined, these percentages reported for Great Lakes; a predominance of short groins
Rayner, A.C., and Rector, R.L., 1961	Great Lakes	Experience	Principal benefit of short groins (100' or less) on the Great Lakes is to retain a narrow protective beach from material eroded from bluffs, in order that further bluff erosion be retarded.
Kemp, P.H., 1962	England	Movable bed, model study	Groin Orientation from Normal Groin Length: 30° Updrift / Normal to Coast / 20° Downdrift Long: 43 / 50 / 55 Short: 67 / 71 / 67 } Quantities of material collected in downdrift traps as % of total material after 3 wave cycles. High, impermeable groins used.
Bruun, Per, and Manohar, Madhav, 1963	North Sea	Field Experience	Most effective when extended out to depths of 12 to 18 feet of water.
Ishihara, Tojiro, and Sawaragi, Toro 1964	Japan	Field study	Observed results showed that structures of T-groin design should be at least 60 meters in length.
Dunham, J.W., 1965	California	Field	Notes use of long groins to form artificial headlands to permanently hold sand, regardless of effects produced along adjoining segments of the shore.
Shore Protection, Planning and Design, Coastal Engineering Research Ctr., T.R. 4, 1966	General	Manual	Correct length is dependent upon prediction of ultimate stabilized beach profile. Original beach profile, conditions of littoral drift, refraction patterns, desired beach width are some of the factors utilized in methods for designing groins. Groin Type / Depth to which extended below MLLW / Amount of Littoral Drift Interrupted High / 10' or more / 100% High / 4 to 10' / 75% Low / 10' or more / 75% High / 1 to 4' / 50% Low / < 10' / 50%
Barcelo, J.P., 1970	Portugal	Model study, movable bed	Inclined groins must be extended for conditions of same spacing, e.g. where α_0=20°, inclined angle =70°, inclined groins must be 30% longer than corresponding normal groins.
Kolp, Otto, 1971	Fischland, Zempin, Nevendorf	Field, Experimental	Generally recommends use of long groins, short groins fail to trap and retain sand efficiently; use of artificial fill in conjunction with long groins.

TABLE 2. HEIGHT OF GROINS

INVESTIGATOR, YEAR	AREA OF INVESTIGATION	TYPE OF INVESTIGATION	HEIGHT / REMARKS
Owen, J.S., and Case, G.O., 1908	England, General	Theory, Experience	Low, to allow some sand to pass over the structure.
Case, G.O., 1915	England, New York, New Jersey	Field	Groins should not exceed 2-3 ft. in height and should follow low profile of the beach. Low, long groins of adjustable type are recommended. High groins are too costly; stop all littoral drift and lead to erosion downdrift of groins.
Dent, E.J., 1931	East Coast United States	Field	Low groins recommended - allow sand to drift over the structure and maintain leeward beach.
Coen-Cagli, M.E., 1932	General	Theory, Experience	1 meter height above high tide sufficient for outer portion of groins on a pebble beach. Beach Section: 50-60 cm. above original beach level. Intermediate Horizontal Section: 50 cm. above low tide level. Inclined End Section: end should be 50 cm. lower than horizontal intermed. section. } Recommendations for groins maintaining a sandy beach
Brown, E.I., 1939; 1940	General	Experience	Horizontal Beach Section: berm height. Sloping Intermediate Section: berm height to below low water line; slope of groin top slightly less than natural beach slope Outer Section: gentle underwater slope seaward.
Evans, O.F., 1943	General, United States	Field	Prefers low groins as they reduce scour on downdrift side caused by wave overtopping. Recommends gradual decrease in height seaward; end should be at low water level or somewhat lower.
Duvivier, Jack, 1947; 1949	England	Experience	No higher than 3 ft. above beach level; as groin fills, it should be gradually heightened; higher groins cause scour.
Jones, J.H., 1948	United States	Movable bed, model study	Low, impermeable groins did not trap and retain as much material as high, impermeable structures.
Brater, E.F., 1953	Great Lakes	General Theory Field	1 ft. above high lake level has given good results.
"Basic Coastal Model" Hydraulic Research, London, 1957	England	Movable bed, model study	High, impermeable groins closely spaced (1:1) arrested greatest amounts of drift, but caused sand to be eroded from upper beach. Reduced drift to 1/8 of former value. Low, impermeable groins widely spaced (1:2) arrested 1/2 of littoral drift, but upper beach did not erode. Recommends use of low groins over high structures.
Wicker, D.F., 1958	General	Theory	Recommends use of high groins (see text).
Savage, R.P., 1959	United States	Movable bed, model study	Low, short groins: trapped 12% of test sand. High, short groins: " 25% of test sand. High, long groins: " 60% of test sand.
Schijf, J.B., 1959	Holland, General	Theory	Groins should remain as low as is compatible with their reducing effect on littoral drift.
Lee, C.E., 1961	Great Lakes	Field Study	Horizontal Shore Section: minimum height should be berm height of existing beach. Intermediate Section: not steeper than existing beach profile; should approximate anticipated beach slope. Seaward Section: governed by expected still water elevation at time of construction. (specific criteria given for rubble-mound structures).
Kemp, P.H., 1962	England	Movable bed, model study	Groin Type / Orientation with Shore: 30° updrift, 0°, 20° downdrift low: 51, 60, 87 high, long: 43, 50, 55 high, short: 67, 71, 67 } Quantities of material collected in downdrift traps as % of total material after 3 wave cycles, for impermeable groins.
Bruun, Per, and Manohar, Madhav, 1963	General	Field, Experience	Minimum height should equal maximum water level plus height of normal wave uprush.
Shore Protection, Planning and Design, Coastal Engr. Research Ctr., TR4, 1966	General	Theory, Experience	Groin is built in 3 sections, (a.) horizontal shore section (b.) intermediate sloped section, (c.) outer section. Height dependent upon construction methods used, economics and beach profiles, wave uprush, and littoral drift (see Table 1).

TABLE 3. SPACING GROINS IN A SYSTEM

INVESTIGATOR, YEAR	AREA OF INVESTIGATION	TYPE OF INVESTIGATION	SPACING / REMARKS
Owen, J.S., and Case, G.O., 1915	England, General	Theory, Experience	1:1 - Recommended spacing.
Case, G.O., 1915	England, New York, New Jersey	Field, Experience	No greater spacing than distance from high to low water line.
Kressner, B., 1928	Germany	Movable bed, model study	1:2 - 1:3 - Tests show this to be optimum spacing requirement; smaller spacing unnecessary, wider spacing unadvisable
Coen-Cagli, M.E., 1932	General	Theory, Experience	1:1.5 to 1:2 - Initial spacing for systems on pebble beaches, then decrease until desired effect is produced. 1:1.5 - Usually spacing of groins on a sandy beach.
Steiner, C.T., 1936	Rockaway Bch, New York	Field	1:1 - Will maintain a beach about 1/2 this length.
Brown, E.I., 1939; 1940	Genaral	Experience, Wave Tank Studias	1:1 - 1:3 - 1:1 and less is never economical. 1:3 is maximum limit for spacing. Suggests that after length is decided, draw a line through the end of the groin parallel with direction of the storm approach. Projection of this line on line of connecting landward edge of groins will determine proper spacing.
Dobbie, C.H., 1946	England	Experience	1:1 to 1:1.5 - Considered as best spacing.
Frech, F.F., 1948	General		1:1.5 - Generally accepted spacing ratio.
Brater, E.F., 1953	Great Lakes	Field, General	1:1 - Where wava action is severa and beach material is fine. 1:2 - Where wave action is less severe, and beach material is coarse sand or gravel.
Nagai, Shositiro, 1956	Japan	Movable bed, model study	1:3 - Provided optimum spacing for conditions during testing.
"Basic Coastal Model" Hydraulics Research, London, 1957	England	Movable bed, model study	1:1 - High, impermeable arrested 7/8 of drift, but upper beach eroded. 1:2 - Low, impermeable arrested 1/2 of littoral drift, but upper did not erode. Use of this plan recommended.
Nagai, Shoshichiro, and Kubo, Hirokazu, 1958	Japan	Fixed bed, model study	1:3 & 1:4 - Most effective spacing found from testing.
Hiranandini, M.G., and Gole, C.V., 1961	Cochin, India	Field study-prototype conditions, model study	1:3 - Should not exceed this ratio. 1:2 - Recommended spacing at Cochin.
Lea, C.E., 1961	Great Lakes	Field study	Govarned by: 1.) Angle beach normally makes with shoreline 2.) Minimum width of beach required on the downdrift side of groins.
Bruun, Per, and Manohar, Madhav, 1963, Bruun, Per, 1955	General	Field, Experience	1:1.S - 1:4 - Generally the range of ratios used. As size of material and amount of littoral drift increases, so should spacing. As steepness of beach profile and steepness of waves increases, spacing distance should decrease. 1:1 - 1:1.5 - If ratio is less than this groins in most cases will not work well.
Ishihara, Tojiro, and Sawaragi, Toru, 1964	Japan	Field	1:1.S - 1:2 - Utilized this spacing in actual situation.
Wiegel, R.L., 1964		Lab. Tests	1:2 - 1:3 - Most desirable distance between groins; the greater the relative groin length, the smaller should be the distance between groins (After Horikawa and Sonu, 1958). 1:4 - Desirable for conditions of waves of variable direction for groins normal to shoreline (After Hoyle and King, 1955).
Shore Protaction, Planning and Design, Coastal Engr. Research ctr., TR4, 1966	General	Manual	1:2 or 1:3 - Suggested as rule of thumb method. Distance from berm crest to seaward end. Other considerations offerred in taxt. A groin system too closely spaced diverts material offshore rather than create a wide beach.
Garcelo, J.P., 1968	Portugal	Model study	1:2.S - for $\alpha_o = 20°$ Where α_o is the angle of wave inci- 1:3:S - for $\alpha_o = 10°$ dence with the shoreline. 1:4 - for $\alpha_o = 5°$
Price, W.A., and Tomlinson, K.W., 1968	England	Movable bed, model study	1:1.5 - 1:2 - These ratios caused considerable deposition during tests.
Kolp, Otto, 1971	Fischland, Zempin, Neuendorf	Field, Experimental	1:1 - A change in this ratio in terms of greater groin length will cause a reduction in rips at groin flanks.

on a broader scale that beaches downdrift from a system of groins would not suffer recession due to lack of littoral material reaching those areas. Most investigators are in agreement with the statement that "permeable groins should not be used as individual units isolated along the beach but in a group, i.e. in a system of groins" (Shay and Johnson, 1951). Other plans have used designs wherein structures are initially built low, following closely the natural beach profile, but being adjustable, they may be readily heightened as the beach builds up, or lowered as the beach loses material. Many investigators feel that groins of the low, impermeable type approach closely the capabilities that permeable groins offer, and on that basis recommend use of impermeable groins exclusively. Table 4 presents a list of articles giving views held by investigators concerning the permeability and adjustability of groins.

TABLE 4. PERMEABILITY -- ADJUSTABILITY OF GROINS

INVESTIGATOR, YEAR	AREA OF INVESTIGATION	TYPE OF INVESTIGATION	PERMEABILITY-ADJUSTABILITY	REMARKS
Case, G.O., 1915	England, New York, New Jersey	Field, Experience	Adjustable	Proposes use of adjustable groins so that they can be built up as accration progresses.
Brown, E.I., 1939; 1940	General	Experience	Impermeable	Groins should be sand-tight.
Evans, D.F., 1943	General, United States	Theory	Permeable	Appear to be sucessful where there are strong prevailing wind and shore currents, or where there is variable beach drifting and weak, variable currents.
Johnson, J.W., 1948	United States	Movable bed, model study	Impermeable	Tests showed that impermeable groins were more effective in causing accretion (single structures used in tests).
Shay, E.A., and Johnson, J.W., 1951	United States	Movable bad, model study	Permeable Impermeable	Should be used in systems only - caused deposition of from 11 to 26% sand under 2 corresponding sets of wave conditions. Much more effective than permeable groins for trapping littoral drift.
Brater, E.F., 1953	Great Lakes	Field, General	Impermeable	Permeable groins work only where wave action is mild or beach material is coarse.
Mason, M.A., 1953	Great Lakes	Field	Impermeable	Permeable structures appear to be poorly suited to Great Lakes area. The requirement of impermeability is absolute.
"Basic Coastal Model," Hydraulics Research, London, 1957	England	Movable bed, model study	Permeable	Had only a small influence on littoral drift and caused some loss of sand from upper beach. Ratio of voids to solids 1:1.
Bruun, Per, Gerritsen, F., and Morgan, W.H., 1957	Florida	Field, Experience	Permeable Impermeable	Permeable groins are usually accompanied by lee side scour. Recommend usa of low, impermeable, nonadjustable or impermeable adjustable groins on Florida shorelines.
Wicker, C.F., 1958	General	General theory	Impermeable	Recommendation for all situations.
Lee, C.E., 1961	Great Lakes	Field study	Permeable Impermeable	13% } of 841 groins examined, these % re- 87% } ported for the Great Lakes.
Hoyle, J.W., and King, C.T., 1962	England	Genaral	Impermeable	Do not recommend use of permeable groins.
Bruun, Per, and Manohar, Madhav, 1963	General	Field, Experienca	Adjustable	Recommend use of adjustable groins to regulate amount of drift supplied to downdrift beaches.
Shore Protection, Planning, and Design, Coastal Engr. Research Ctr., TR4, 1966	General	Manual	Adjustable Permeable	Useful where attempt is being made to widen beach with a minimum of damage to downdrift area. Present state of knowledge does not lend conclusions as to effectivanass.
Price, W.A., and Tomlinson, K.W., 1968	England	Movable bed, model study	Impermeable	Permeable groins had little effect on longshore drift.
Kolp, Otto, 1971	Fischland, Zempin, Neuendorf	Field, Experimental	Permeable	Found that 37% open space reduced longshore flow 50%; piling was used in groin construction.

Of groin structures utilized today, there is a greater lack of adequate understanding of permeable structures than of any other type of groin design. Generally, it has been determined that "insufficient empirical data have been compiled to establish quantitative relationships between the applied littoral forces, groin permeability, and resulting behavior of the shore" (Shore Protection Planning and Design, U. S. Army Corps of Engineers, 1966). The lack of understanding is displayed through the very term "permeable". In its present usage, the term provides but a casual explanation that permeable groins have openings through which littoral drift may pass. There is not an adequate engineering definition pertaining to the structure itself that can be used comparatively to relate a condition of "permeability" of one type of structure to another. A standard concept will need to be established in order that an organized evaluation of the structure can be made.

Model investigations have apparently used an implied definition of permeability as:

1.) ratio of void area to total area, or;

2.) a ratio of the volume of voids to total volume of the mass (porosity).

The former definition would, of course, be the easier to work with, but regardless of which is used, a standard definition is needed where, in this case, the ratios can be related to amounts of drift that pass through a structure. Few endeavors, either in the form of experiments or field studies, have been conducted which commit themselves to such a goal. Laboratory tests to date have been concerned only with voids of rectangular shape oriented in a vertical direction, although most prototype structures known to the authors have been constructed with the voids oriented in a horizontal direction. Geometric variations of both voids and their orientation other than those utilized may be more beneficial, and though the variations are almost inconceivable in number, investigations are warranted.

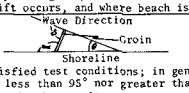
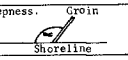
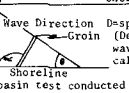
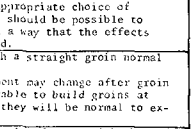
Orientation of Groins to the Shoreline:

Orientation of groins to the shoreline has not received as much attention as previously discussed criteria. There have, however, been several papers that have devoted considerable discussion to this topic. The potential benefits of varying the orientation from normal, as presented in the literature, and the controversial nature of the concept warrants discussion.

Generally it has been defined that orientation of groins is a function of the angle of wave approach. Various investigators have shown that groins oriented slightly updrift from the normal to the shoreline collect greater amounts of littoral material than normal groins when the angle of incidence of waves with the shoreline is relatively constant with time. Kemp (1962) suggests, from results of his experiments, that where a beach is receding due to destructive wave action (again where wave approach is relatively constant),

that groins correctly oriented to the shoreline could reorient the shore such that the erosive effect would be minimized. Where variable wave conditions exist, groins constructed normal to the coast are preferred. Table 5 presents a spectrum of opinions on groin orientation.

TABLE. 5. ORIENTATION OF GROINS WITH THE SHORELINE

INVESTIGATOR, YEAR	AREA OF INVESTIGATION	TYPE OF INVESTIGATION	ORIENTATION / REMARKS
Case, G.O., 1915	England, New York, New Jersey	Field, Experience	Recommends use of normal groins only. Oblique groins are more costly, are liable to be damaged by waves because of greater surface area exposed to waves, and cause more scour than groins constructed normal to the coast.
Duvivier, Jack, 1947; 1949	England	Experience	Normal to shoreline: use where direction of drift is variable. 10° from normal, pointing away from drift: use where there is prevailing drift, and where beach material is shingle. 20° from normal, pointing away from drift: use where prevailing drift occurs, and where beach is sandy.
Nagai, Shositiro, 1956	Japan	Movable bed, model study	θ / δ / α 30° / 100° / 110° 40° / 110° / 100°  These angles satisfied test conditions; in general δ should not be less than 95° nor greater than 120°, otherwise scour is the result.
Shimano, T., Hom-ma, M., Horikawa, K., Sakou, T., 1957	Japan	Movable bed, model study	Should consider building groins upcoast (toward updrift direction).
Horikawa, Kiyoshi, and Sonu, C., 1958	Japan	Movable bed, model study	Best orientation depends upon wave steepness. For steep storm waves, α=105° For relatively flat waves. α=90° (Taken from Wiegel, 1964) 
Nagai, Shoshichiro, and Kubo, Hirokazo, 1958	Japan	Fixed basin, model study	θ / α / D 30° / 110° / 1:3 45° / 90, 110° / 1:3 60, 90° / 90° / 1:3-1:4  D=spacing. (Deep water waves used for calculations) Above are results of fixed basin test conducted to compare with movable bed study by Nagai, 1956.
Hiranandini, M.G., and Gole, C.V., 1961	Cochin, India	Field study-prototype conditions, model study	Inclined groins did not commend themselves for adoption on this coast.
Lee, C.E., 1961	Great Lakes	Field study	Inclined groins are ineffective or too costly for the effects produced.
Kemp, P.H., 1962	England	Movable bed, model study	Orientation / Low Groin / High, Long Groin / High, Short Groin 30° updrift / 51 / 43 / 67 Normal to Coast / 60 / 50 / 71 20° downdrift / 87 / 55 / 67 Table gives quantities of material collected in downdrift traps as % of total material after 3 wave cycles, for impermeable groins. Gives results showing that by appropriate choice of groin type and alignment, it should be possible to orient the shoreline in such a way that the effects of storm attack are minimized.
Shore Protection, Planning and Design, Coastal Engr. Research Ctr., TR4, 1966	General	Manual	Maximum economy is achieved with a straight groin normal to the shoreline. In cases where shoreline alignment may change after groin construction it may be desirable to build groins at an angle initially, so that they will be normal to expected adjustment of shore.
Barcelo, J.P., 1970	Portugal	Model study	β = 90° for α = 20° β = 70° for α = 10° β = angle of groin with shoreline. α = obliquity of waves.  Where variable wave conditions persist, groins constructed normal to the shoreline are preferred.

Special Designs:

Variation is not only found in the design of component parts of conventional groins, but also in the overall configuration of special types of groins. Component parts of groins are constructed of rock, timber, concrete, or steel, and have assumed a variety of shapes. Groins of the Budd-Wall (E. & E. Associates, 1965) and S. M. Wood (1937, 1945) design, and structures such as the cellular and crib groins provide examples of such variations. Special features have been added to the design of conventional straight groins to produce such structures as curved-, spur-, corner-, L-, Z-, and T-groins. Each has been designed to produce special effects where they are intended to improve upon effectiveness of conventional structures.

SUMMARY COMMENTS

This paper has presented in tabular format and accompanying discussion some of the basic criteria used in the functional design of groins. From data presented here and from the review of pertinent literature in general, the following comments are offered:

1.) Prior to undertaking the design of a groin or groin system, complete understanding of littoral processes that predominate in the area of concern is required. Particular attention must be devoted to the determination of:

a.) longshore transport rates;

b.) longshore transport directions, and

c.) prediction of possible modifications of the preceding by the intended structure(s) and the effect of such structure(s) on adjoining shores.

2.) There are a number of factors concerning groin design criteria that need further investigation and refinement. Some of the factors include:

a.) standardization of a reliable formula for computing longshore transport rates, and an efficient method for obtaining or verifying longshore transport data needed. These will be utilized to produce and verify more effective designs of groins and groin systems for a particular coastal locality. Factors that modify longshore transport rates, especially storms and the onshore-offshore movement of beach material must be integrated into design formulas;

b.) a scientific definition that adequately defines the permeability of groins: experimental work has apparently implied that this

design concept can be expressed as a ratio of void area to total area, or as a ratio of void volume to total volume of mass; such concepts should be formalized into a definition for standard application where the ratios can be related to the amounts of material passing through one type of permeable structure to another; types of voids and their interstructure orientation may be a decisive factor for an increase in efficiency of such groins, especially if they are built in areas of frequent reversals of littoral drift;

c.) use of artificial nourishment: as a general rule, groins should not be built where there are inadequate supplies of longshore moving drift; where supplies are inadequate, artificial fill should be used either independently or in conjunction with groins; some investigators maintain that groin construction should always be accompanied by fill; it has been stated that where technically possible and economically feasible, artificial nourishment should be utilized exclusive to permanent structures, since the fill does not "entail a permanent commitment" (Barcelo, 1970).

3.) Of critical statements, the following is probably most pertinent in terms of the state-of-the-art in groin design. By the very nature of beaches, that no two are the same, it is erroneous to assume that one specific groin design will provide the answer to all shore erosion problems.

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REFERENCES

1. Balsillie, J. H. and Bruno, R. O., "Groins: an Annotated Bibliography", Coastal Engr. Research Center Misc. Paper No. 1-72, Washington, D. C., April 1972, 249 pp.

2. Barcelo, J. P., "Experimental Study of the Hydraulic Behavior of Groyne Systems", Proceedings of Eleventh Conference on Coastal Engineering, ASCE, Vol. 1, Sept. 1968, pp. 526-548.

3. Barcelo, J. P., "Experimental Study of the Hydraulic Behavior of Inclined Groyne Systems", Proceedings of the Twelfth Coastal Engineering Conference, ASCE, Vol. 2, Sept. 1970, pp. 1020-1040.

4. "Basic Coastal Model", Hydraulics Research 1957, Department of Scientific and Industrial Research, Her Majesty's Stationery Office, London, 1958, pp. 52-54.

5. Brater, E. F., "Low Cost Shore Protection Used on the Great Lakes", Proceedings of Fourth Conference on Coastal Engineering, Council on Wave Research of the Engineering Foundation, Oct. 1953, pp. 214-226.

6. Brown, E. I., "Beach Erosion Studies", Shore and Beach, American Shore and Beach Preservation Association, Vol. 7, No. 1, Jan. 1939, pp. 3-23.

7. Brown, E. I., "Beach Erosion Studies", Transactions of the American Society of Civil Engineers, Vol. 105, Paper No. 2076, 1940, pp. 869-918.

8. Bruun, P., Gerritsen, F. and Morgan, W. H., "Florida Coastal Problems", Proceedings of Sixth Conference on Coastal Engineering, Council on Wave Research of the Engineering Foundation, Dec. 1957, pp. 463-509.

9. Bruun, P. and Manohar, M., "Coastal Protection for Florida", Engineering Progress at the University of Florida, Engineering and Industrial Experiment Station, Gainesville, Bulletin Series 113, Vol. 17, No. 8, Aug. 1963, 56 pp.

10. Case, G. O., "Coast Erosion and Protection on Long Island and New Jersey", Engineering News, Engineering, Chemical and Marine Press, Ltd., London, Vol. 74, No. 10, Sept. 1915, pp. 439-442.

11. Coen-Cagli, M. E., "Protection of Coasts against the Sea, with or without Preponderating Coastal Drift of Materials", World Ports, American Shore and Beach Preservation Association, Vol. 20, No. 4, Feb. 1932, pp. 286-293.

12. Dent, E. J., "Sand Movement and Beach Erosion", Civil Engineering, ASCE, Vol. 1, No. 9, June 1931, pp. 821-826.

13. Dobbie, C. H., "Some Sea Defence Works for Reclaimed Lands", Journal of the Institution of Civil Engineers, London, Vol. 22, No. 4, Feb. 1946, pp. 267-272.

14. Dunham, J. W., "Use of Long Groins as Artificial Headlands", Coastal Engineering Santa Barbara Specialty Conference, ASCE, Oct. 1965, pp. 755-762.

15. Duvivier, J., "The Problem of Coast Erosion", Proceedings of Institution of Civil Engineers, London, 1947, 47 pp.

16. Duvivier, J., "Report to the Seventeenth International Navigation Congress", Seventeenth International Navigation Congress, Permanent International Association of Navigation Congresses, Brussels, Belgium, Section 2 - Ocean Navigation, Communication 1, 1949, pp. 75-84.

17. E. & E. Associates, 1968 Budd Groins, Brochure, Venice, Florida.

18. Evans, O. F., "The Relation of the Action of Waves and Currents on Headlands to the Control of Shore Erosion by Groins", Proceedings of the Oklahoma Academy of Science, 1943, pp. 9-13.

19. Frech, F. F., "Paper on Protective Works Adopted to Limit Erosion Along the Open Coast: How They Work", U. S. Army Corps of Engineers, Philadelphia District, June 1948, 35 pp. (Unpublished).

20. Hiranandini, M. G. and Gole, C. V., "Shoreline Advancement by Sea Wall and Groynes at Cochin", Proceedings of the Seventh Conference on Coastal Engineering, Council on Wave Research of the Engineering Foundation, Vol. 2, Aug. 1960, pp. 860-871.

21. Horikawa, K. and Sonu, C., "An Experimental Study on the Effect of Coastal Groins", Coastal Engineering in Japan, Committee of Coastal Engineering, JSCE, Vol. 1, Oct. 1968, pp. 59-74.

22. Horikawa, K., "Japanese Construction Practice on Groins", Seminar on Groin at Princeton, N. J., ASCE sponsored, Oct. 1958, (Unpublished).

23. Hoyle, J. W. and King, G. T., "The Origin and Stability of Beaches", Proceedings of Sixth Conference on Coastal Engineering, Council on Wave Research of the Engineering Foundation, Dec. 1957, pp. 281-301.

24. Hoyle, J. W. and King, G. T., "Coast Protection - Groyne Systems", Surveyor and Municipal and County Engineer, London, Vol. 121, No. 3647, April 1962, pp. 575-579.

25. Ishihara, T. and Sawarogi, T., "Stability of Beaches Using Groins", Proceedings of the Ninth Conference on Coastal Engineering, ASCE, June 1964, pp. 299-303.

26. Johnson, J. W., "The Action of Groins on Beach Stabilization", University of California, Department of Engineering, Navy Department Bureau of Ships Contract NObs 2490, Technical Report HE-116-283, April 1948.

27. Jones, J. H., "Wave Action on Beaches", University of California, M.S. Thesis, June 1948.

28. Kemp, P. H., "A Model Study of the Behavior of Beaches and Groynes", Journal of the Institution of Civil Engineers, London, Vol. 22, 1962, pp. 191-210.

29. Kolp, O., "Sea Groins Effectiveness Investigations, Dyed Sand Tests", Beitrage zur Meereskunde, Deutsche Akademie der Wissenschuften zu Berlin Institute fur Meereskunde, Berlin, Issue 17-18, 1966, pp. 6-90.

30. Kressner, B., "Tests with Scale Models to Determine the Effects of Currents and Breakers upon a Sandy Beach and the Advantageous Installation of Groins", Bautechnik, Berlin, Vol. 25, June 1928.

31. Lee, C. E., "Groins on the Shores of the Great Lakes", Journal of the Waterways and Harbors Division, ASCE, Vol. 87, No. WW2, Paper 2819, May 1961, pp. 89-111.

32. Mason, M. A., "Principles of Shore Protection for the Great Lakes", Proceedings of Fourth Conference on Coastal Engineering, Council on Wave Research of the Engineering Foundation, Oct. 1953, pp. 207-213.

33. Nagai, S., "Arrangement of Groins on a Sandy Beach", Journal of Waterways and Harbors Division, ASCE, Vol. 82, No. WW4, Paper 1063, Sept. 1956, 13 pp.

34. Nagai, S. and Kubo, H., "Motion of Sand Particles Between Groins", Journal of Waterways and Harbors Division, ASCE, Vol. 84, No. WW5, Paper 1876, Dec. 1958, 28 pp.

35. Owen, J. S. and Case, G. O., Chapter 11 Coast Erosion and Foreshore Protection, St. Brides Press, London, 1908.

36. Price, W. A. and Tomlinson, K. W., "The Effect of Groynes on Stable Beaches", Proceedings of Eleventh Conference on Coastal Engineering ASCE, Vol. 1, 1968, pp. 518-525.

37. Raynor, A. C. and Rector, R. L., "Groins on the Shores of the Great Lakes", Journal of the Waterways and Harbors Division, ASCE, Vol. 87, No. WW4, Nov. 1961, p. 137.

38. Savage, R. P., "Laboratory Study of the Effect of Groins on the Rate of Littoral Transport: Equipment Development and Initial Tests", U. S. Army, Beach Erosion Board, Technical Memorandum No. 114, June 1959, 56 pp.

39. Schijf, J. B., "Generalities on Coastal Processes and Protection", Journal of the Waterways and Harbors Division, ASCE, Vol. 85, No. WW1, Pt. 1, March 1959, pp. 1-12.

40. Shay, E. A. and Johnson, J. W., "Influence of Groins on Beach Stabilization", University of California at Berkeley, Department of Engineering, Series 14, Issue 6, Beach Erosion Board Contract W49-055-eng-2, Jan. 1951.

41. Shimano, T., Hom-ma, M., Horikawa, K. and Sakou, T., "Functions of Groins Fundamental Study on Beach Sediment Affected by Groins (1)", Proceedings of the Fourth Conference on Coastal Engineering in Japan, JSCE, 1957, pp. 111-121.

42. Steiner, C. T., "Construction and Maintenance of the Public Beach at Rockaway Beach, Borough of Queens", The Municipal Engineers Journal, Paper 181, Oct. 1936, pp. 107-122.

43. Wicker, C. F., "Summary Statement Concerning Importance of a Groin Design Criterion", Seminar on Groins at Princeton, N. F., ASCE sponsored, Oct. 1958, 2 pp. (Unpublished).

44. Wiegel, R. L., Oceanographical Engineering, Prentice-Hall International Series in Theoretical and Applied Mechanics, Fluid Mechanics Series, Prentice-Hall Incl., Englewood Cliffs, N. J., 1964, 532 pp.

45. Wood, S. M., "Jetty", U. S. Patent Office, Patent No. 2,099,249, Nov. 1937, 3 pp.

46. Wood, S. M., "Art of Beach Protection", U. S. Patent Office, Patent No. 2,387,965, Oct. 1945, 3 pp.

47. U. S. Army Corps of Engineers, "Shore Protection, Planning and Design", Coastal Engineering Research Center, Technical Report No. 4, 3rd ed., June 1966.