**Part 3**

# SHORELINE PROTECTION PROBLEMS

CHAPTER 14

# PRINCIPLES OF SHORE PROTECTION FOR THE GREAT LAKES

Martin A. Mason
Dean, School of Engineering
The George Washington University
Washington 6, D. C.

The Great Lakes region is one of quiet challenge and absorbing interest to the coastal engineer. From the broad pattern of its morphologic history to the detail of its present-day shoreline it presents a fascinating variety of natural phenomena and man-imposed regimen that has controlled and still conditions its shoreline behavior. Many of the features of the behavior pattern and its controls are recognized and subject to beneficial management; some of these are either not recognized or are ignored by coastal experts who should know better; while others are as yet beyond the capabilities of the methods of beneficial management available today.

It is the purpose of this paper to examine and describe some of the elements controlling the shore environment of the Great Lakes region, to the end that a better understanding of the problems in coastal engineering in this region may be had. That such understanding is needed must be apparent when one reviews the relics of attempts to control beneficially the shores of the Great Lakes, or when one attempts to evaluate the formerly existing resources now hidden by the waters that ruthlessly exploited the weaknesses of coastal works of the past. In fact, the distinguishing achievement of coastal engineering in the Great Lakes region probably has been the almost unvaried attainment of inefficient or ineffective coastal works. When one applies the rigorous criterion of engineering excellence - that of requiring a completely satisfactory technical solution at a minimum cost - to the works in this region one is lead to concede that the engineering of works in the Lakes shore has been something less than distinguished. The few notable exceptions to this vicious generalization are outstanding; among them one must cite certainly the exceptionally successful treatment of the Chicago shore, and the extensive but largely unused harbor at Cleveland.

These remarks are not necessarily a diatribe in support of a contention that past designers of Great Lakes coastal works have not been adequate to the task - though this must have been true in many cases. They are rather more a model of the passionate feelings of many property owners and taxpayers whose scanty financial resources have been expended on structures that either didn't perform their intended function, or did so at the expense of aggravating other problems.

Can the coastal engineer today serve more adequately the needs of his clients than did his predecessors? The answer is affirmative, if he avails himself of existing knowledge and analyzes the problems involved by engineering methods rather than by analogy or pseudo-scientific hocus-pocus. What, then, are the features of the Great Lakes that are pertinent to the coastal engineer, and what are the design principles he must employ?

Basically the Great Lakes coastal engineer has to solve a management problem, in that he must so guide, control, and manipulate a very few dynamic forces as to achieve an equilibrium of the type he desires. Not only in the Great Lakes region - but as well anywhere, the shore situation is the result of the dynamic action of two fluids, air and water, on an essentially static body, the land.

Whatever the coastal engineer's problem in the Great Lakes, be it protection against erosion, provision of a beach, design of a harbor, or maintenance of a navigable channel, the solution usually lies in management of the movement of sand and similar material on the shore face, and in control of wave action. Other features, such as drainage, enter some problems; however, the great majority fall in the general category described.

Before we can manage the natural regimen of the Lakes to our benefit we must know the regimen intimately. Let us then first define the dynamic features, i.e. those features that provide the energy to move the inherently static shorematerial and to damage coastal works. Initially it must be recognized that the Lakes are essentially calm most of the time. For four to six months of the year ice on the lakes or at the shore prohibits wave and current action. During the open or non-ice season the wave action in the Lakes is strictly limited. According to statistics published by the Beach Erosion Board, waves are less than 0.5 ft. high in Lake Erie for about 80% of the open season; in Lake Michigan calm prevails for about 60% of the open season; and in Lake Ontario it is calm about 80% of the time.

When waves do occur they appear to be related closely to local storms over the Lakes and exist for about the same length of time. Waves of height 6 to 8 ft. occur on the average not oftener than once a month and exist in terms of hours rather than days. Rarely, say once or less a year on the average, waves as high as about 10 ft. occur and exist for relatively short periods.

Thus, for a preponderant part of the time the shore environment is practically static, and any significant movement of material or stress due to waves must occur during the isolated short intervals when wave action is relatively violent. Further it is recognized that the structural design of any works to be built must be based on two types of forces; the ice forces (viz. loading, uplift, pressure movement); and the wave forces (impact and water flow). Therefore, the coastal engineer's problem is to manage wave forces of moderate magnitude that endure for short periods, and ice forces that may be active continuously for long periods. Regarding these latter our state of ignorance is appalling.

A second important feature of the shore environment is the nature of the land, which is a resource to be conserved and the source of the material whose beneficial or contrary influences are to be managed. A review of the morphologic history of the area, of which the most important period to our discussion is the glacial lake period, establishes the following features as pertinent to the coastal engineer. In general the land is heterogeneous in character; at the shore it may be erosion-resistant rock, or glacial lake moraine, or lacustrine deposits. The two latter are easily eroded, they have been the source in the past and presently provide all the material now moving on the lake shores, since the contribution of material by drainage features can be shown to be negligible. The coastal engineer must define the nature and source of the material in his area of interest before he is in position to approach the analysis of his problem.

The principal conclusion to be drawn from past studies of the shore geology in the Lakes region is that, as a general rule, the economy of the material situation is one of scarcity. Local abundance of material occurs rarely and is usually obvious because of its rarity.

Another pertinent feature is that of the effects of wind. Aside from its obvious contribution in the generation of lake waves, the wind is important in the Lakes area as the cause of short-term variations in lake level elevation, and as a medium for the removal of material by wind transportation from the shore face. Of these the wind set-up contribution is believed presently to be the more important.

The last pertinent feature of the Lakes environment is the variation in lake level elevations. This is important in that it defines the water-land boundary of prime concern to the coastal engineer. Various patterns of behavior of lake level elevation have been formulated and are available from the Corps of Engineers or the Beach Erosion Board. Their chief utility derives from the fact that a shift in lake level moves the locus of action on the shore, and by this motion alone may occasion or remedy a shore problem. From the point of view of design of shore works the one element of importance is the short-term duration and frequency of occurrence of the levels of elevation. Here published data are deficient, for it is to be noted that the important consideration is the probability of short-term (i.e. order of hours) concurrent occurrence of wave action and high water. Thus design based on average lake levels may be seriously deficient for the few hours of concurrent occurrence of high waves and wind set-up or raised lake level that is required to cause damage. Perhaps the destructive combination may exist for only a few hours in a long period of years. The engineer's problem is to decide what combination to select for design purposes that is neither too conservative nor dangerously radical and yet economical.

The author suggests that a probability of one occurrence of two hours duration in 10 years represents one of several reasonable design criteria. Suppose, for example, that at Erie, Pennsylvania 10 ft. high waves may be expected to occur for a two hour period once in ten years and at the same location, a short period rise of lake level of about two ft. above the maximum monthly average level of the open season may be expected once in 10 years. Following the suggested criterion the acceptable design conditions would be 10 ft. high waves, occurring concurrently with a lake level two ft. above the maximum monthly average lake level of the open season.

In summary the author believes that the problem of design of Great Lakes coastal works is one of design for some selected, infrequent, concurrent occurrence of maxima of wave action and lake level elevation in reference to a localized area of action, and with consideration given to long-period ice effects as they may control structural requirements. The works may serve little or no useful purpose for a major part of their life, perhaps as much as 80% of the time, yet their construction be justified by their benefits during periods as short as two hours in an interval of ten years. The close correlation of economic analysis and engineering design is apparent and represents one of the very difficult problems to be solved.

Let us turn our attention now to some particulars of the Great Lakes shore environment and coastal works design.

It has been mentioned that wave action in the Great Lakes is characterized by its sporadic occurrence related closely to the storm regimen. Available evidence leads to the belief that waves are predominantly steep, short in length, and of short duration. The probability is very good that the maximum design waves are of the order of 10 ft. high, 250 ft. long, and with durations of the order of 12 hours maximum. Appreciable wave action seldom persists for longer than two days at a time, followed usually by a period of essential calm. Swell, in the sense applicable to oceanic wave phenomena, probably never occurs although some "ground swell" may occur as a short time forerunner or remnant of a lake storm. In general the wave action builds and subsides quickly, following the generating storm life closely. For design purposes it appears that information on the duration times and frequency of occurrence of various wave heights is indispensable to sound engineering of coastal works in the Lakes region. Such data is not available generally but its importance would seem to warrant some appreciable effort toward its development.

It is not sufficient for purposes of rigorous design analysis to know only duration times and frequency of occurrence. Equally important is knowledge of the time element involved in wave damage to shores or structures. For example, is a jetty or seawall damaged by the occurrence of one 10 ft. high wave, or must 10 ft. high waves act on the structure for an hour, or three hours, or a day before damage occurs. If material movement is the problem, how much material is removed or deposited in a given time by a given regimen of wave action.

Almost no useful information on the time factor in shore problems is available. Here again one may insist that such data is prerequisite to excellence in design, and to suggest that coastal engineers encourage research on this problem even at the expense of less difficult and less important research.

The short, steep waves characteristic of the Lakes are considered usually to be associated with lakeward net movement of material, i.e. they are degenerative in that they carry material from the shore to the lake. The shore area subject to such erosive movement extends from the limit of uprush of the waves on the shore to about the point of breaking of the waves offshore. As a general rule it can be considered that waves break in depths approximating 1.3 the wave height, thus permitting determination of the offshore limit of movement. Maximum protection against material movement therefore demands lakeward extension of structures inhibiting movement, such as groins, to lengths of the order of the distance offshore of breaking waves. Economic considerations may, however, dictate shorter lengths.

Once the design wave characteristics are selected (as shown this is in large part a question of engineering economics) the top elevations of structures, whether they be jetties, bulkheads, seawalls, or others, is determined. In general, vertical face structures will not be overtopped by solid water if their elevation is set above the average water level during wave action a distance equal to the total wave height. A sloping face requires, in general terms, a distance equal to 1.5 the wave height because of wave run-up on the face.

The requirements for structural stability are defined by Sainflou's or Iribarren's methods, both of which are described in Hudson's paper, "Wave Forces on Breakwaters", ASCE Separate No. 113, January 1952.

It must be noted additionally that because of the general paucity of material sources the structures must be impermeable in locations where retention of shore material is an important part of the function of the structure. Permeable structures appear to be poorly suited to this area and probably result in a profligate waste of scarce natural shore material; whether the structures be groins or armoring. It is highly doubtful that they can be considered adequate for any protective purpose in the Great Lakes or similar areas of limited natural resources of shore building materials. Insofar as groins are concerned the requirement of impermeability is absolute. Feeding of down-drift beaches often claimed as a unique benefit of permeable groins can be achieved better by employing impermeable groins with low top elevations, that allow material to pass over the structure once it has impounded its designed capacity. This represents sound engineering management of natural forces in accordance with the present state of our knowledge of shore processes. In the Lakes area there seems to be no effective substitute for impermeable groins whose top elevations essentially follow the profile of the beach desired. Consideration must be given to varying lake elevations in determining the profile, but a straight-line approximation of the profile is acceptable if it is desirable for ease of construction.

In many Lakes locations the deficiency of material suitable for protective or recreational beaches is extreme. In these locations armoring of the shore face may be the best engineering solution. However, when beaches are desired nevertheless, artificially supplied material is required. The design methods described in Technical Memo No. 29 of the Beach Erosion Board represent the best technology now available in this field. Direct placement methods probably are best for Lakes locations.

The relatively high density of shorefront occupation and the general scarcity of natural shore protection in these normally eroding Lake areas combine to require unusually careful evaluation of the effects on adjacent shorefronts of coastal works. Harbor jetties, or extensive groins, unless otherwise designed, may act so effectively as sand traps as to starve down-drift areas depending upon up-drift sources of material for complete or partial protection. Armoring of an eroding bluff may eliminate the bluff as a source of nourishment for a beach. An acceptable engineering solution in such cases must include an evaluation of these effects. Since the effects easily could impose very large burdens for protective works both the economic and engineering implications of protective works should be a part of every coastal study. Although it is not within the province of this paper to discuss the legal aspects of these questions they do exist.

The advantages of some sort of control by a technically competent and responsible group over coastal works design and construction seem apparent. The assignment of such responsibility as an extra activity to highway departments, park authorities, or municipal engineers can be successful only when the technical personnel in these offices are adequately trained in the highly specialized field of coastal engineering knowledge, or the services of qualified personnel can be obtained otherwise. In few engineering activities can so much damage be done by well-meaning, hard working personnel whose coastal engineering judgment is faulty only because they lack intimate knowledge of the complex of natural processes at a shore.

In closing, a few words must be directed to those who are most intimately concerned with shore problems in the Lakes area, the property owners, the taxpayers, the municipalities and the states. Without intelligent action on their part in insisting on competent technical analysis of their problems none of the mass of useful technology now available can be of value to them. So as the first principle in the design and construction of coastal works in the Great Lakes I suggest the principle of obtaining the best technical assistance that can be found and abiding by their recommendations. Without this elementary but necessary approach there is no hope for satisfactory solution of their coastal problems.