OBSERVATIONS ON LOW-COST SHORE PROTECTION

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Abstract

Bluff recession occurs where waves are able to attack the toe of the bluff. Protection can be supplied either by building up the beach or by constructing revetments or barriers. The cost of good quality protection is very high and shore owners often turn to less expensive methods. If low-cost procedures are properly selected, well designed and well built, they prevent erosion during ordinary storms and may reduce the recession rate during major storms. If they are also sufficiently durable to resist being destroyed, they may be a sound economic alternative to more complete protection. The performance of low-cost protection has been investigated by laboratory tests and field observations at many sites including the 18 installations of the Michigan Demonstration Project. Lower cost has been obtained by making the structures smaller, omitting foundations, and using inexpensive materials. Observations by the writer indicate that low-cost groins perform quite well, but that low-cost barriers built parallel to shore are less successful. Wood is one of the best low-cost materials, and low-cost rubble revetments show considerable promise.

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SUMMARY

In most cases, the three or four years of records now available do not provide sufficient information on the economic effectiveness of the field projects. However, a number of results and trends can be summarized. Sand nourishment has been very effective at sites that have some protection, especially when combined with groin systems. One pair of groins in a high energy area has collected beach material and has provided considerable protection under severe conditions. Another system of groins has collected some sand and is providing protection. Three rubble revetments built with relatively small and inexpensive rock have provided excellent protection.

Those structures constructed without foundations to keep them in the "low cost" category have settled from their original positions. Such structures are sand-filled tubes, sand-filled bags, gabions, a concrete wall and an asphalt mastic revetment. In contrast, a wood pile groin, which provides its own foundation, has remained intact under very severe conditions.

Sand-filled bags have suffered damage at all locations where they have been installed on this project. At several locations, the sand-filled tubes have also suffered damage. The construction of experimental sites on Lake Michigan, subject to attack by the prevailing westerly winds, will provide information on effectiveness and durability many years sooner than those built on Lake Huron where the on-shore direction is from the east.

INTRODUCTION

This paper is based on field observations, laboratory investigations, and consulting experience dealing with shore protection on the Great Lakes and oceans. Some erosion areas in Michigan have been observed periodically from 1948 to 1978. Most recently, research efforts have been largely related to a field and laboratory demonstration project. The field portion consists of 18 demonstration projects on Lakes Huron, Michigan, and Superior and a laboratory program in the University of Michigan Lake Hydraulics Laboratory. The names and locations of the field projects are shown in Fig. 1.[8] Table 1[8] shows the type of protection used at each location. All of the projects were installed late in the summer of 1973 or in 1974 except the timber crib groin at Sanilac-Section 26 which was built in 1975.

FIGURE I

SITE LOCATIONS

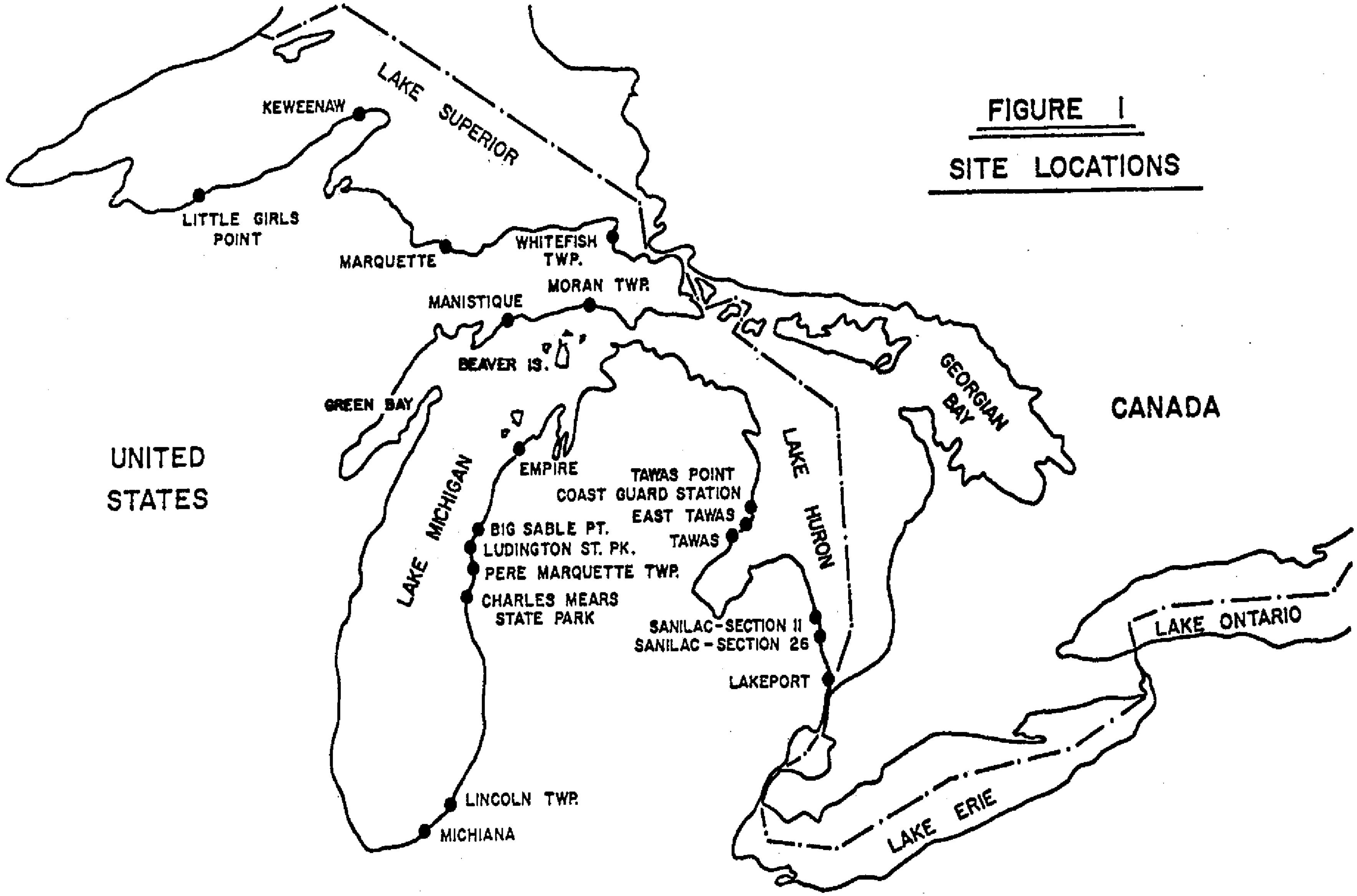


TABLE 1

MICHIGAN SHORE PROTECTION DEMONSTRATION PROJECTS

Project	Type of Protection
LAKE MICHIGAN	
Michiana	Toe protection, asphalt mastic and rock revetment, 300 ft long
Lincoln Township	Wooden groin, Longard tube groin
Mears State Park	Three groins, inner ends are gabions and outer ends are sand-filled bags
Pere Marquette Township	Off-shore breakwater, three segments of zig-zag concrete walls with 50 ft gaps
Ludington State Park	Two groins, steel
Big Sable Point	Steel wall, gabion cutoff groins
Empire	Toe protection, 40-inch Longard tube, 300 feet long
Moran Township	Toe protection, three 40-inch Longard tubes stacked one on two (300 ft), three layers of sand-filled bags (250 ft)
LAKE SUPERIOR	
Whitefish Township	Rock revetment with wooden groins extending to low bluff
Marquette	Sand nourishment, waste sand from local industry
Keweenaw	Revetment, waste rock from local mines
Little Girls Point	Revetment, Nami rings

Table 1 (Continued)

Project	Type of Protection
LAKE HURON	
Tawas Point Coast Guard Station	Revetment, part dumped rock and part placed in two layers
East Tawas	3000 yds^3 sand placed along 400 ft of open shoreline
Tawas City	4350 yds^3 sand placed between new wooden groin and existing pier along 400 ft of shoreline
Sanilac-Sect. 11	Toe protection, 69-inch Longard tube 400 ft long
Sanilac-Sect. 26	Six groins, two 40-inch Longard tubes, one 60-inch Longard tube, gabions, sand-filled bags, rock and asphalt mastic, timber crib
Lakeport	Off-shore barrier, 40-inch Longard tube placed on off-shore bar

WHAT IS LOW-COST PROTECTION?

Because the title of this paper includes the words "low-cost" shore protection, it is necessary to let the reader know what this term means to the author. The term is used in relation to more expensive procedures which can provide more complete protection. The meaning of the term, therefore, must be explained not only from the point of view of actual cost per foot of shoreline, but also in terms of the degree of protection that can be expected from such procedures. In terms of cost, the upper limit is that nebulous value which typical waterfront property owners are willing to pay.

One of the responsibilities of those of us who work in this area is to try to make it possible for the owner of private property or the administrator of public property to make a logical cost-benefit decision regarding low-cost protection.

At the 1978 value of money, materials, and services, the upper limit of low-cost protection is about $125 per foot. Most low-cost installations of private property owners as well as those included in the Michigan demonstration project cost between $25 and $100 per foot. For the purpose of comparison, the cost of high quality structures which supply more complete protection is usually more than $300 per foot.

The term "low-cost" must also be explained in terms of the degree of protection that is provided. The term obviously implies that the product is inferior and therefore will supply less than complete protection. This is certainly true on exposed shorelines of the oceans or Great Lakes. However, for locations where wave heights are limited by fetch or shallow water, "low-cost" protection may be all that is needed.

From a functional point of view, the term is somewhat comparable to the terms low-cost bridges or low-cost dams. Such structures perform adequately a good deal of the time but can be expected to fail during severe storms. This is also true of "low-cost" shore protection. If it is well designed and properly constructed, it will slow the bluff recession during ordinary storms. However, during major storms it may provide little or no protection and ironically, may actually be destroyed.

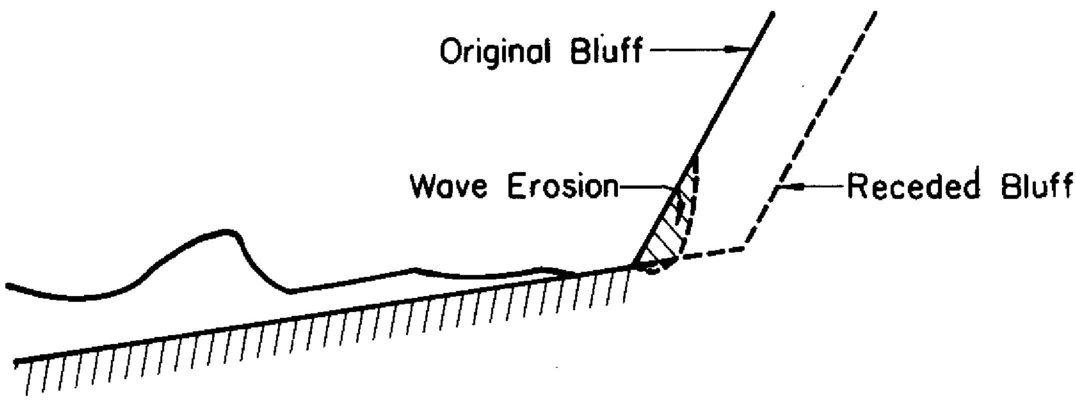
From an engineering-economic point of view, low-cost protection can be expected to prolong the life of the shore property and its value should be judged accordingly. For example, if a building is located 100 feet from the bluff and the long-term recession rate is reduced from 10 to 7 feet per year, the life of the property (assuming the building cannot be moved) will be lengthened from 10 to 14 years. Most property owners will not accept such an engineering-statistical analysis and will hope that their property will prove to be an exceptional case. Because of the irregular timing of major storms and because of the variations in erosion rates from place to place, there is a chance that any individual property may escape damage for a long period of time. Unfortunately, in other areas, the erosion rate may be well above average and the property may be destroyed very soon after the low-cost protection is installed.

THE SHORE EROSION PROCESS

This is how water and wave actions cause erosion of the shoreline. Wave action creates turbulence which loosens beach material and places it in suspension or makes it vulnerable for bed-load movement. The littoral currents which are created by the wind and waves move the beach material along the shore. This is called littoral drift. If there is a plentiful supply of beach material from the up-current direction, the material that is removed may be replaced by other material. When the supply of material is limited, the process will gradually deplete a beach area. The presence of a good beach protects the back shore or bluff because it causes the waves to break farther from shore. When the beach is depleted, the bluff becomes more vulnerable to direct wave attack. In many shore areas, the waves are able to attack the bluff during major storms even though there is some protective beach. Under these conditions the process is as depicted in Fig. 2. The material at the base of the bluff is removed by the waves thus leaving the bluff in such an unstable condition that it will slump due to the action of wind, frost, or vibrations. The slumped material is then vulnerable to attack by the next large storm and the process is repeated.

Obviously, the water level plays an important part in the erosion process. Reference to Fig. 2 helps visualize how during higher levels, waves break nearer to shore or even at the bluff itself, thus exerting almost their full energy on the bluff. This effect is illustrated by bluff recession rates measured at 68 locations in Allegan County on Lake Michigan. The average recession rate was about 2.2 feet per year during the period 1955-60 when the average lake level was 577.7 feet; and about 6.4 feet per year during the period 1950-55 when the average lake level was 579.1 feet. This would indicate an increase in the recession rate of 3 feet per year per foot of lake level. However, this relationship is not linear because in the erosion-prone areas the average recession rate of such a group of sites did not reach zero even during the lowest observed lake levels.

FIGURE 2



On both the Great Lakes and the oceans, the water level may be raised during storms due to the frictional force of the wind. This is called wind tide or wind set-up. For example, on the west end of Lake Erie, wind tides as great at -5 and +7 feet have occurred.[3] On the oceans, there may be an additional variation due to lunar tides. On the Great Lakes, there is an additional variation in levels of over six feet due to long term variations in precipitation. This variation is shown in Fig. 3 for Lakes Michigan and Huron for the period 1860 to 1974.[7] This graph shows high months for each year, average annual levels, and low months. The period of record shown in Fig. 3 is divided into four 29-year periods. It is of interest to note that the average for the first 29-year period was much higher than the last three periods. There is considerable evidence that this is partly due to changes that have occurred in the St. Clair River which controls the levels of Lakes Michigan and Huron. Studies by the author indicate that for the same precipitation conditions, the levels might have been about a foot lower now than they were during the period from 1860 to 1890 if the control were in its post-1900 condition.

Although it is possible to determine the average rates of bluff recession over a period of years for a large number of locations as in the previous example, the short term rate of recession in any area varies greatly with time. By far, the major portion of erosion is caused by rare and irregularly-spaced major storms. There are often periods of years without large storms. At other times, several major wind storms may occur within a few months. Fig. 4 shows the storms which would have produced significant wave heights of five feet or more at a location near Harbor Beach on Lake Huron for the period 1936-78.*

There were four periods of four years or more when no storms of this magnitude occurred (1931-35, 1946-49, 1964-67 and 1973-76) but 12 storms exceeding this magnitude occurred during the four year period, 1954-57. Fig. 4 also shows the average lake levels for the period. During the years 1953, 1954, and 1955, conditions were favorable for rapid erosion because frequent storms were combined with above-average levels. As might be expected, these were very serious erosion years. On the other hand, during the years 1971-76, when the lake levels were again above average, there were only two large storms. Incidently, the location for which these wave heights were estimated is exposed only to easterly storms. Because the prevailing wind direction is westerly in the Great Lakes area, the number of storms satisfying the criterion of five foot waves would have been much greater for a similar site on the other side of Lake Huron or on the east side of Lake Michigan.

There are also large differences in recession rates from site to site in the same general area. The average rates for the 68 sites in Allegan County over a distance of 38 miles varied from 21.4 to 0.2 feet per year during the

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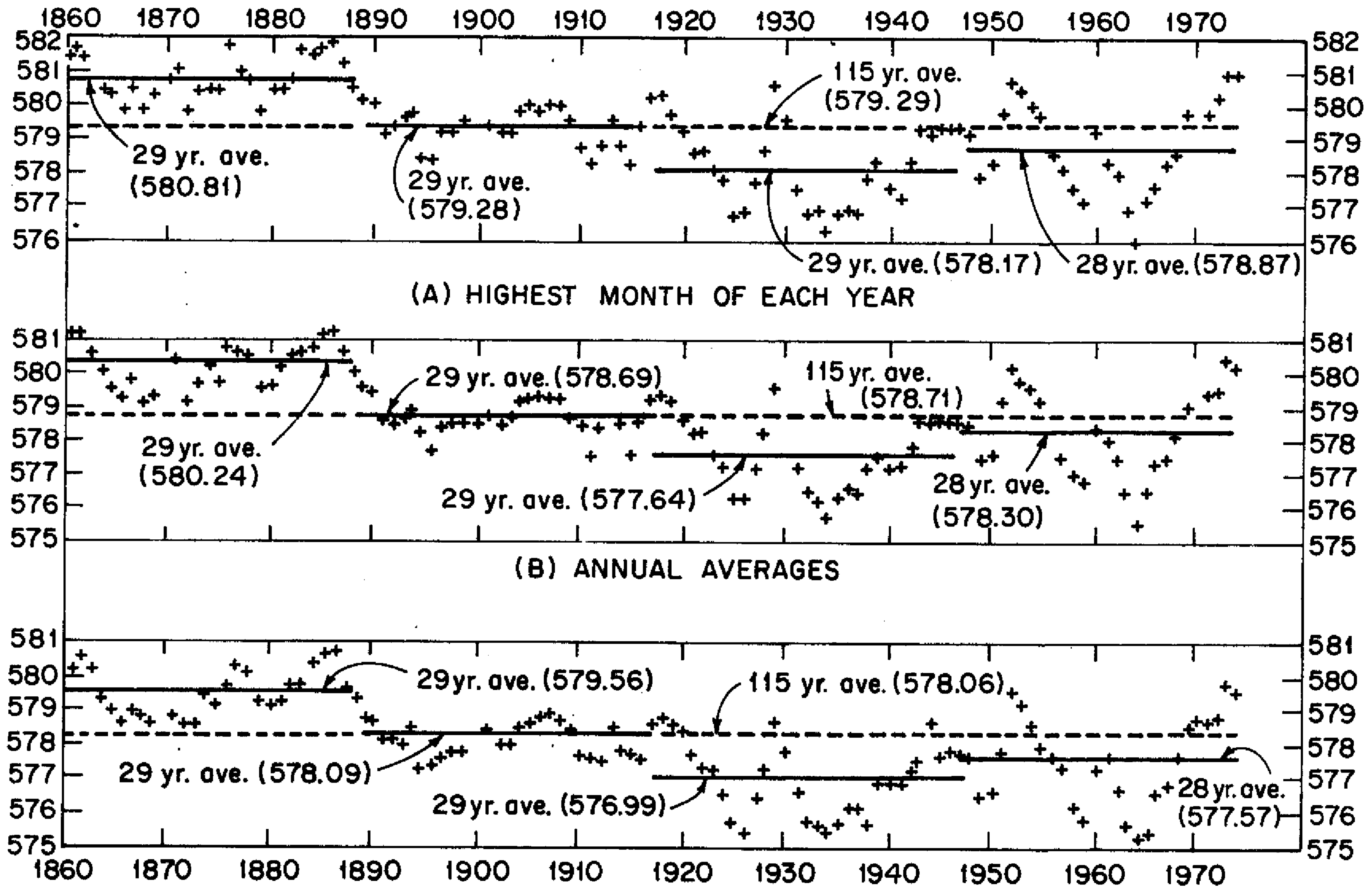
*These winds actually occurred on Lake Erie. They have been transposed to Lake Huron. The significant wave height is the average of the highest one-third of a group of waves (H 1/3).

FIGURE 3

LEVELS OF LAKE MICHIGAN AND HURON



(B) LOWEST MONTH OF EACH YEAR

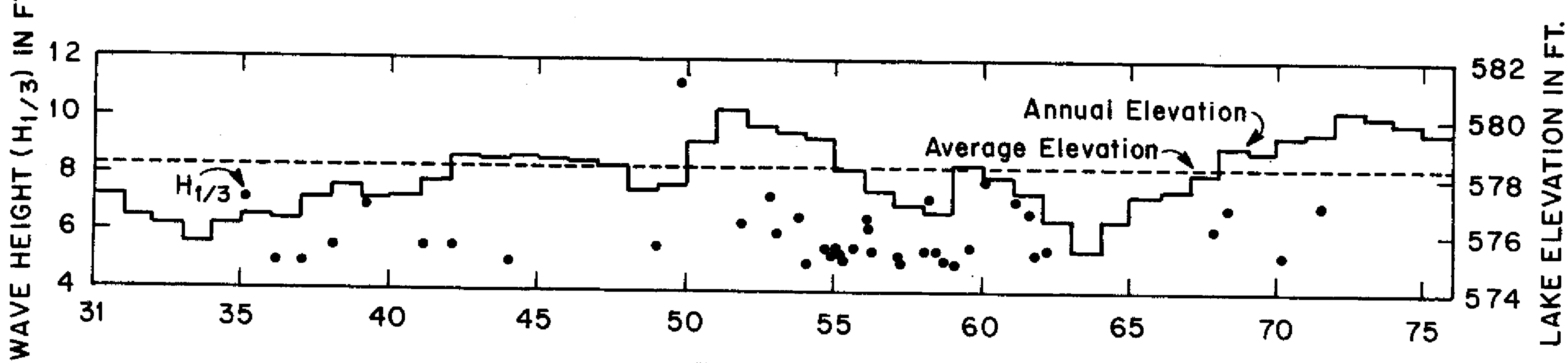


FIGURE 4

STORM WAVE HEIGHT AND LAKE ELEVATIONS

period 1950-55, and from 11.6 to 0.0 feet per year for the period 1955-60. These variations are due to natural and man-made factors which influence the stability of the shoreline, the wave action and littoral currents, and the local supply of littoral drift.

Of Michigan's 3,200 miles of shoreline, about 500 miles are considered rapid erosion areas. At some points the average rate of bluff recession for the 32 year period, 1938-70, was more than 4 feet per year, and for the 20 year period, 1950-70, it was as much as 6 feet per year. It is on such areas that public and private property owners must decide whether to spend money in an attempt to stop or slow down this process in the hope of prolonging the life of the property.

METHODS OF REDUCING EROSION DAMAGE

In case the reader is not familiar with protective procedures, and to make sure that concepts and words used in this article are clear, a brief review of the various alternatives available for preventing shore property damage are presented. I must note that the wave conditions being considered here are so severe that the use of vegetative cover alone is not a feasible alternative. However, when a bluff is stabilized by one of the methods described below, planting grass or shrubs can protect the upper portion of the bluff against wind or rain.

Zoning or Removing Structures

In many locations the best solution to damage prevention is to avoid placing valuable buildings or utilities near the shore in erosion-prone areas. Furthermore, it is often cheaper to move buildings out of such areas than to attempt to reduce the recession rate.

Beach Nourishment

The presence of a beach is one of the best protections against erosion. Therefore, filling shore areas with sand to create an artificial beach is sometimes a feasible procedure. On long reaches of exposed shorelines, sand is usually moved rapidly, and artificial nourishment may provide only temporary protection unless the sand is held in place by a groin system. Sand nourishment has the great advantage of maintaining a beach for bathing and of not destroying the aesthetic values of a shoreline.

Groin Systems

Groins are short piers built perpendicular to the shoreline, usually at uniform intervals over a reach of beach. Their value is in maintaining a beach. They are ineffective on shorelines where there is little or no natural littoral drift (movement of beach material along the shore by wind and wave currents). In such locations they would have to be combined with beach nourishment to provide protection. If groins are built too high or if they are not artificially filled, they may stop the littoral drift completely for a period of time and thus deplete the sand supplied by littoral drift to downdrift properties. Groin systems have the great advantage of retaining the use of a shoreline as a bathing beach.

Toe Protection

If waves can be prevented from attacking the toe of the bluff, the erosion process will be stopped. The toe of the bluff can be protected by a revetment or sea wall. A revetment is a blanket of protective material placed on the face of the toe of the bluff at the natural slope of the bluff. A sea wall may be a vertical sheet-pile wall or a barrier of more massive form made of such materials as concrete, rock, or sand-filled tubes or bags. In locations where there is no sand supply or where wave conditions are very severe, toe protection is usually the most feasible solution.

Off-Shore Breakwaters

The effect of off-shore breakwaters on shore process is two-fold: they prevent some wave energy from reaching the bluff; and by reducing turbulence, they cause some littoral drift to be deposited and form a protective beach. However, they are usually low on the list of alternatives because of their high cost.

HOW DOES LOW-COST PROTECTION DIFFER FROM MORE PERMANENT PROCEDURES?

The following outline attempts to list the more obvious ways in which the cost of shore protection is kept low. The various items outlined are not clearly separable; therefore, there is some overlapping. The discussion is based in part on the field installations and laboratory studies of the Michigan Demonstration Project and in part on observations on structures and procedures installed by private and public owners on the Great Lakes and elsewhere.

In evaluating the various installations, it is necessary to separate failures caused by a lack of competent advice from those caused by changing a high quality design in order to reduce the cost. In the following discussion, the first two items, "Inappropriate or Ineffective Procedures" and "Faulty Structural Design," are the result of lack of advice from a qualified coastal engineer. The next three items, "Smaller Structures," "Omitting Foundations," and "Innovative Materials," are methods of deliberately taking a risk in order to reduce costs.

Inappropriate or Ineffective Procedures

Low-cost protection is often handicapped by using cost-saving techniques which render the protection ineffective. Another cause for failure is that the protection is not suitable for the location. An example of an ineffective procedure is the use of a set of permeable groins in an exposed area. It has been repeatedly demonstrated that permeable groins do not hold beach material in a high energy location. Another classic example is the use of widely spaced blocks or rings. At one location on Lake Michigan, the writer observed 5-foot cubes of concrete placed about 8 feet apart and loosely connected by a steel cable. These blocks will probably provide protection from invasion by amphibious craft but their effect on bluff recession is negligible. Examples of procedures that are inappropriate to the location are the use of groins in areas where there is no littoral drift or the use of sand nourishment in exposed locations of high wave intensity and fast littoral currents.

Such errors occur because very little "low-cost" protection has the benefit of analysis and design by a qualified coastal engineer. Parenthetically, this is unfortunately also true of some high cost protection. The difficulty with "low-cost" protection is that the reach involved is often so short that the cost of engineering advice would be a fairly large percentage of the total cost. This is one important reason for having property owners along a long reach of shore act as an organized group to protect their entire shoreline. The other important reason for group action is that isolated, small areas with protection tend to become peninsulas and then they become vulnerable from their flanks.

Faulty Structural Design

Even with low-cost protection, it is possible to use good design to avoid structural errors which lead to early destruction of the installation.

Erroneous design has occurred most often in sheet pile walls. This is because they are used more than any other procedure. The deep-seated dedication of property owners and contractors to the use of vertical walls usually becomes obvious from the inspection of any highly developed shoreline. The most extreme example observed by the author is a location on Lake Michigan where five walls have been built. Three have fallen but are still visible, the fourth is beginning to fail and the fifth was new when the author visited the site. The fifth wall was being built in the water about 30 feet landward of the original wall and the bluff has receded much farther. Failure of such walls is often caused by arranging structural members and the wall itself to resist wave forces when it is usually the back pressure from saturated earth which causes the problem. Sometimes owners or contractors fail to realize that the presence of the wall increases erosion at the toe of the wall and, therefore, unless there is sufficient penetration or unless toe protection is provided, the walls will eventually be undermined.

Reducing Size of Structure

In a deliberate effort to reduce costs, one of the most obvious methods is to make the structure as small as possible. For example, any device which is built for toe protection is effective only as long as it is not overtopped by the wave run-up. The cost of a structure that is high enough to prevent over-topping during major storms is usually well beyond the low-cost range. A smaller structure may provide protection during nine out of ten storms and provide some help during major storms. The owner may deliberately take the risk of some damage from time to time. If the structure is well built so that it will not be destroyed, this may be an economically sound decision. This strategy would be enhanced if the bluff behind the structure could be graded to a relatively flat slope.

Another procedure which can be effective most of the time is to build relatively short groins. The portion of a groin in shallow water is much less expensive than the portion which extends to deeper water. Such groins may not hold enough beach width for full protection, but would still reduce the energy of large waves.

Omitting the Foundation or the Scour Protection

Any structure placed on sand or clay and exposed to wave action will cause scour followed by undermining and settling. This can be minimized by placing the structure on a graded rubble foundation or by providing adequate toe protection.

As previously mentioned, the lack of scour protection is a common cause of failure of low-cost, vertical, sheet pile walls. More massive structures also tilt and settle but usually at a slower rate, and therefore, may be fairly effective low-cost procedures. The effect of the lack of foundations has been shown by observations on some of the field installations of the Michigan Demonstration Project. One example is a rock revetment covered and impregnated with asphalt mastic. This structure settled several feet during one major storm, thus greatly reducing its value. However, the revetment itself was not badly damaged even though the storm destroyed steel sea walls on adjacent sections of shoreline.

In several projects bluff protection was provided by sand-filled bags or tubes placed at the toe of the bluff. Settlement was observed in four projects, three of which were located on sand, and one on clay. Settlement at the outer ends of groins made of sand-filled tubes, sand-filled bags, and gabions placed without foundations has been observed on both sand and clay.

Another of the installations which illustrates the failure due to lack of a foundation is an off-shore concrete breakwater consisting of pre-cast sections bolted together in a zig-zag pattern. The stresses due to uneven settlement caused some sections of this wall to break. The settlement reduced its effectiveness to the point where wave height reduction was less than 50 percent.

Use of Innovative Materials

The conventional materials for marine construction have been steel, concrete, wood and rubble. Steel and massive concrete are usually in the high-cost category. The best chance of achieving low cost in concrete is by means of pre-cast units used as revetments. There are many such products on the market, one of which was used in the Michigan Project at an exposed site on Lake Superior. These were concrete rings called Nami rings. They were installed without a foundation and they have suffered considerable breakage even though they were placed on a very flat slope.

Wood, particularly when used for groins, is one of the best materials in the low-cost category. On the Great Lakes many well-built wooden groins have lasted 15 years, and with some maintenance would serve much longer.

Rubble revetments are one of the most satisfactory forms of shore protection. In the Michigan Demonstration Project, there are three installations where local stone has been used at a very reasonable cost by eliminating the requirement for the large size of the armor layer that would normally be specified for stability during major storms. These revetments consisted of ungraded rock which provided protection against being penetrated by the jetting action of the waves. They were also entrenched at their toe to prevent sliding and undermining. Two of them have been exposed to major storms. However, at one, there is a submerged rock ledge giving some protection from full exposure to Lake Superior, and at the other, the fetch perpendicular to shore is only about 25 miles.

The quest for achieving lower-cost protection has led to the use of other innovations in materials. Sand-filled bags have been previously mentioned. There were three such installations in the Michigan Demonstration Project, two groins and one sloping wall placed at the toe of the bluff. All of these have suffered considerable damage because bags were punctured by floating timbers or by vandalism, and because of a tendency to slide due to wave action.

Sand-filled tubes, called Longard Tubes, were installed in two locations as groins and in three locations as barriers at the toe of the bluff. These are much more difficult to puncture than the sand-filled bags. However, two of those used as barriers were destroyed completely by large storms, but the others are still giving good service after four years.

Another innovation tried at two locations was stone impregnated and covered with asphalt mastic. The revetment was discussed in the section on "Omitting Foundations." A groin built in this manner has been in service for four years with only minor damage. This material seems to have some promise.

Rock-filled wire cages, called gabions, and rock-filled timber cribs used as groins have given satisfactory service for a number of years.

EVALUATING SHORE PROTECTION METHODS

The characteristics which form the basis for evaluating shore protection are (1) effectiveness in reducing erosion at the toe of the bluff, (2) durability, (3) economy and (4) minimum interference with the use and beauty of the shoreline. The evaluations must be made on a comparative basis, comparison with the cost of using no protection at all and with other more or less costly methods. Evaluations can be made from laboratory tests, from field observations on projects installed for experimental or demonstration purposes and by observations on field projects installed by private and public property owners. Some of the results obtained in the Michigan Project from laboratory tests were reported by the writer.[5] Laboratory tests give relative effectiveness compared with other procedures but do not help with evaluating durability and economy. Moreover, it is not possible to convert actual bluff recession rates from model to prototype. Field installations provide information on all four of the characteristics listed but the difficulty is in the lack of control over the occurrence of high water levels and severe storms.

The question always arises as to how long field observations must be continued to determine effectiveness, durability, and economy. It is obvious that to be economically feasible, a procedure must be effective enough to slow the bluff recession rate, and durable enough to survive the attack of large waves and to resist deterioration due to rot, rust, boring insects and weathering. From an economic point of view it appears that it would be difficult to justify an expenditure of $100 per foot if it did not provide some benefit for at least 10 years. However, because of the unpredictable nature of the weather, the length of time needed to determine effectiveness against waves depends very much on chance, as demonstrated in Figs. 3 and 4.

The evaluation of the effectiveness of a procedure in preventing erosion can only be judged by knowing a complete history of the waves reaching the site. Usually the wave heights must be hindcasted from wind records taking into consideration the intensity, duration, and direction of the wind and the corresponding fetch. The deep water waves must then be modified to take into account the effect of refraction and diffraction.

The effectiveness of a protective procedure may be measured in terms of the decrease in the bluff recession rate caused by its presence. This would require information on recession rates for prior years as well as a complete wave and water level history. Another method of evaluating effectiveness would be by comparing the protected section with adjacent unprotected areas where the wave conditions are believed to be comparable.

In general, the information needed to evaluate a protective project consists of photographs and observations made several times a year by a knowledgeable coastal expert, and profiles from the top of the bluff into the water taken once a year and, if possible, after severe storms. Observations on the direction of littoral currents would also be of interest if they could be made during a storm. However, the direction can usually be determined by observing the deposition of beach material.

The beauty of shore areas and their usefulness for recreation are important assets. Any structure built on a beach diminishes this asset. Therefore any of the protective procedures except beach nourishment has some negative values compared with a natural beach. Groin systems have an advantage over other structural methods because they retain most of the value of the shore as a bathing beach. Rubble revetments have a great advantage over other forms of bluff protection in that they minimize reflection and runup. They tend to maintain shallow water, compared with solid barriers or walls which do not.

CONCLUSIONS

If low-cost shore protection is properly selected for the conditions at the erosion site, and if it is well designed and well built, it will stop erosion during ordinary storms and perhaps reduce the bluff recession rate during large storms. If it is also durable enough to resist destruction, it may be an economically sound alternative to more complete and expensive protection. Lower costs can be achieved by reducing the size of the installation, omitting foundations, and using inexpensive materials. Satisfactory low-cost protection can be achieved quite well in this manner in locations where groin systems will collect and retain a beach. Wood is the most satisfactory low-cost material for groins. Sand nourishment protected by groins is also a successful procedure. Low-cost rubble revetments have shown considerable promise. Low-cost barriers built at the toe of the bluff have been less successful. Off-shore breakwaters are not feasible low-cost procedures.

APPENDIX 1 - REFERENCES

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