CHAPTER 164

LOW-COST SHORE PROTECTION ON THE GREAT LAKES: A DEMONSTRATION/RESEARCH PROGRAM

by

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BACKGROUND

Shore erosion is currently causing millions of dollars of damage to shoreline property along the Great Lakes (1,2). Erosion is caused by the energy of waves and currents which are produced by large wind storms.

The erosion process on the Great Lakes is most severe when lake levels are near the top of their 6-foot (1.8 meter) range for several years as is currently being experienced. The severe erosion process continues even after lake levels fall, as the bluffs have become unstable and waves from intense storms can still attack them. In order to alleviate the erosion damages to beaches and bluffs, shoreline owners must rely on shore protection methods.

Effective methods of shore protection are designed to slow or stop the erosion process by dissipating wave energy and/or preventing bluff attack. However, the most effective methods are very expensive, costing over $200 per foot ($656 per meter) of shoreline. (Costs are calculated, for the purposes of this study, as the length of shoreline which is expected to be protected by the shore protection methods. For sites utilizing revetments, artificial nourishment, and seawalls, the length is the stretch of shoreline actually covered by the method. For locations utilizing groin systems and breakwaters, the system was designed to protect the entire length of the sites; the costs have been calculated on that basis. Whether these systems actually protect that length of shoreline is to be determined by this study.) Shoreline homeowners are usually not able to meet such expenses, and often resort to less efficient and costly alternatives. Private shoreline owners need accurate, reliable information about effective low-cost shore protective methods in order to reduce or alleviate the severe erosion damages to their shoreline.

INTRODUCTION

In response to the urgent need described above, 19 sites were selected along the coast of Michigan in 1973 for the examination of methods of shore protection. The objective of this program was to select, design, install, and evaluate a series of low-cost shore protection systems. The test sites were distributed around the state in areas which experienced severe erosion. Sites were selected on public land where erosion processes were active and typical. Table 1 lists and Figure 1 shows the test site locations. Site selections were in part determined by the willingness of local agencies to share expenses and by the value of the property being threatened.

Methods of shore protection were chosen to demonstrate the effectiveness of well-known, as well as innovative, concepts. Each project was documented and evaluated with respect to the reduction of erosion rates, cost, construction problems, and durability. A particular effort was made to find reasonable effective and low-cost methods which the homeowner could personally utilize. Emphasis was placed on providing sufficient information to shoreline owners for comparing costs of protective structures against reasonable chances for effective protection.

The selection of the method of shore protection to be used at each site was based upon several criteria. The first criterion corresponds to the stated objective of the program in testing shore protection procedures suitable for use by shoreline owners. It was necessary to stay within an acceptable cost range for property owners. This range had risen over the past 20 years from $25 per foot ($82 per meter) of shoreline to $100 per foot ($328 per meter) based on previous interactions with homeowners. All of the structures were intended to be in the "low-cost" category, defined for study purposes as costing less than $100 per foot ($328 per meter) of shoreline protected. The average cost of methods selected for examination was approximately $50 per foot ($164 per meter) of frontage, a desired goal of the study. This cost constraint limited the design options severely. For example, a structure which would be expected to provide protection for all but very rare storms, such as 25- or 50-year frequency storms, would cost from $200 to $400 per foot ($656 to $1,312 per meter). The low-cost designs used in the demonstration projects can be expected to suffer damage from much less severe storms, such as 5- to 10-year frequency storms.

The second criterion involved testing innovative ideas and procedures with the objective of keeping costs low while maintaining reasonable effectiveness. Innovative, yet untested, methods were important aspects of the program as it was as essential to demonstrate to the homeowner what not to do as well as to show proper shore protection methods. Methods which reflected strong public interest and offered hope for permanence and low-cost effectiveness were also examined for potential testing. Shore protection methods were not included, however, which could adversely affect the environment or degrade the aesthetic qualities of the shoreline. This excluded from the study poorly designed structures and such attempts as the placement of discarded automobiles or straw and hay on the bluff.

The methods of shore protection included in the study are artificial nourishment, groins, revetments, offshore breakwaters, and "seawalls." (The term seawalls as used in this paper does not refer to the traditional concept of seawalls. The term applies to structures which combine the characteristics of seawalls and revetments, yet which resemble neither in the traditional sense.) Materials used in the projects vary from sand to reinforced concrete walls.

Artificial nourishment concists of adding sand to a nearshore area. This raises the beach bottom profile enough to cause waves to break and lose their energy before reaching the former shoreline. This method is aesthetically pleasing as it preserves the beach in its natural condition. It is also an excellent means of shore protection.

Groins are protective structures, similar to a wall, built approximately perpendicular to the shore, which trap sand from the littoral drift. A groin is anchored in the toe of the bluff and extends into the water. Groins used in the study were constructed of wood piling, steel piling, asphalt mastic, rock-filled timber cribs, gabions, giant sandbags, and Longard tubes. (Giant sandbags are nylon bags which can be pumped full of sand. Two of the sizes referred to as "giant" are 2 feet by 5 feet by 10 feet [.6 meters by 1.5 meters by 3.0 meters] and 1.5 feet by 6 feet by 20 feet [.46 meters by 1.8 meters by 6.1 meters]. Longard tubes consist of high density polyetheylene casings lined with low density polyethylene. These casings are filled with sand to form tubes). The sand trapped by the groin raises the beach profile and protects the bluff. Regular spacing of groins along the shoreline enhances their effectiveness in building up the beach.

Revetments are protective blanket-type structures built at the toe of a bluff. The bluff is graded to a stable slope of three or two to one, horizontal to vertical, before placement of the revetment. Rock, asphalt mastic, and preformed concrete rings were used for the construction of revetments. Any material utilized must be strong enough to resist wave attack and built high enough to prevent overtopping. The toe of the revetment should be protected from undercutting as wave energy during storms accelerates erosion at the toe. Revetments are very effective in areas where groins cannot be constructed. They also often leave a portion of the beach available for recreational activities.

Seawalls are built in front of a bluff and backfilled so that the bluff is continuous to the wall. The purpose of a seawall is to prevent wave energy from reaching the bluff. However, due to the violent turbulence created when waves strike the structure, erosion is greatly accelerated in front of the wall. This undercutting combined with the pressure of saturated soil on the land side, often leads to structure failure. Seawalls were constructed of Longard tubes and giant sandbags. Seawalls traditionally are not suitable methods of shore protection in recreational areas due to the difficulty of water access and the development of deep water in front of the walls. Seawalls are useful in areas where no other means of protection will work and/or the bluff requires support (the seawall becomes a retaining wall). Caution must be exercised to properly design the seawall which can be expensive.

Offshore breakwaters are walls installed in the water parallel to the shoreline. They attenuate wave energy and depending on their distance from shore the reduced turbulence immediately behind the breakwater enhances the deposition of sand. Offshore breakwaters were built with precast concrete panels and Longard tubes.

To evaluate the effectiveness and durability of the shore protection examined as well as their effect on the nearshore environment, a field monitoring program was established. This involved photographic and subaerial/subaqueous surveys of the sites to obtain profiles of the bluff and beach. The procedure for surveying seawalls, revetments, breakwaters, and nourishment projects consisted of establishing profile lines. Profiles originated inland behind the top of the bluff and extended into the water (limited to the depth a man could wade). These profile lines were established 25 feet (7.6 meters) apart over the length of a project. Groins also were surveyed using profile lines as described above. These profiles, however, were located along the centerline of the structure, immediately adjacent to it, as well as 10 and 25 feet (3.0 and 7.6 meters) on both sides.

Data was collected during and immediately after construction and additionally during the year to provide further site observations. During the first year of study, the surveys were conducted after major storms so that surveys could be conducted at optimum times in terms of checking a structure's effectiveness. Such a storm was defined as one that will be equalled or exceeded on an average of three or four times each year. Initially, major storms were described only by onshore wind speeds and duration because winds play an important role in wave formation. Later, major storms were described by wave size: a 6-foot (1.8 meter) breaking wave at the site was established as the criterion. In subsequent years, sites were surveyed in the spring and fall. It was possible to record the major storms between surveys and still obtain the desired information.

In summary, the 19 locations were monitored utilizing the photographic reviews and conventional surveying techniques described previously. This monitoring program collected data regarding structure effectiveness and durability as well as the feasibility of shoreline owners employing these methods themselves. The following section describes some sites in detail and provides preliminary observations.

SITE DESCRIPTION AND ANALYSIS

Sites 1-4, 16, and 19 were evaluated using photographs and will not be discussed at further length. However, Tables 2 and 4 provide summary information concerning these sites. The remaining sites were surveyed using the conventional surveying techniques previously discussed. Summary information for these sites can be found in Tables 2 and 3. Complete and reliable data regarding structure effectiveness and durability will be available only after a number of years. Evaluations are based on the structure's performance over time and in various storm conditions. However, general observations of the effectiveness of some of these structures can be made after the first two years of study. Data have been collected continuously since installation. This paper includes all data collected through the fall of 1975.

Site 6, Sanilac 26

A roadside park 4 miles (6.4 kilometers) south of Port Sanilac in Sanilac Township was selected for testing six different groin types. This location has high steep clay bluffs and a tough clay lake bottom. These bluffs have been eroding over the years. The clay lake bottom makes the driving of any type of piles difficult. Thus, the groins selected for this site were designed to rest on the lake bottom. An important aspect of this project was the 200-foot (61.0 meter) spacing between each of the groins. Groins are usually spaced two to three times the length of the groin extending into the lake (3). The distance between the study groin systems was three to four times their length. Table 5 describes the various groin systems installed as well as costs incurred for construction. The structures are listed in successive order from the north end of the site progressing south. Four of the structures can be seen in Figure 2. A plan view of the site is shown in Figure 3. Discussions of each structure's performance will be followed by observations of the entire system's effectiveness.

Two 40-Inch (101.6 cm) Diameter Longard Tubes. These tubes are 100 feet (30.5 meters) long and were installed in the fall of 1973 at a cost of $30 per foot ($98 per meter) of shoreline. A third tube was planned to be stacked on those two in a pyramid fashion. Storm interruption during construction prevented placement of the third tube. The two tubes installed were monitored and were found to be trapping sand. This groin appears to be working well. Although some settlement has occurred along both tubes (particularly the southern tube), this movement has not hurt the groin's performance. The tubes have helped to build up the beach and thus resist wave attack. Recession at the top of the bluff has been about 10 feet (3.0 meters) in the immediate vicinity and some slumping has occurred. This could be due to terrestrial processes or the movement of the slope to reach a more stable position.

One 69-Inch (175.3 cm) Diameter Longard Tube. This tube is 50 feet (15.2 meters) long and was installed in the spring of 1974 at a cost of $25 per foot ($82 per meter). It was expected to trap sand more effectively than the 40-inch (101.6 cm) diameter tube because it has more freeboard. Freeboard is the height of a structure above the still waterline. However, as of the last survey both groins have performed equally well. Only minor settlement was experienced with this tube. The lack of settlement indicates that this structure can be placed directly on the lake bottom (without a supporting foundation) in areas where the soil is clay. This tube has effectively trapped sand and prevented direct wave attack on the bluff, although minor recession rates have been recorded in the immediate area.

Gabion Groin. The gabion groin installed at this site in the spring of 1975 is 70 feet (21.3 meters) long and costs $30 per foot ($98 per meter) to construct. It has not been under examination long enough to provide significant data. It is in very good condition and has trapped sand as expected. Despite the beach build-up, slumping of the bluff has occurred. This may be due to natural processes other than wave attack.

Giant Sandbag Groin. The giant sandbag groin was installed in the late fall of 1973 and suffered major damage in the first year. The length of the groin is 60 feet (18.3 meters) and costs $30 per foot ($98 per meter) to install. Nearly 15 feet (4.6 meters) of sandbags were lost at the lake end of the groin. Vandalism is probably not the cause since the lost bags are at the lakeward end of the structure. No further sandbag loss has been detected, but some bags have shifted since April 1975. The structure appears to be effectively trapping sand despite the damage. Preliminary conclusions as to its effectiveness and durability indicated that sandbag groins could only offer temporary protection. After further study under mild storm activity, it appears that the bags can offer more than just temporary protection. However, they are not as durable as other structures. With annual replacement of damaged bags and protection against tearing, sandbag groins could function effectively for several years.

Asphalt-Mastic Groin. This asphalt-mastic groin was completed in the fall of 1973. Design and construction supervision of this groin was provided by The University of Michigan's Coastal Zone Laboratory. The successful installation of this structure demonstrated that asphalt mastic could be placed through deeper water than previously documented. The asphalt-mastic groin is 60 feet long (18.3 meters) and was installed at a cost of $45 per foot ($146 per meter). To date the structure has performed very well. Large amounts of sand have been trapped, providing a protective beach. No movement of the groin has been visible at all; however, there has been minor damage to the north edge. A section of the mastic and underlying rock was broken off at the lake edge. Minor recession and slumping of the bluff has occurred, probably due to terrestrial processes. This type of structure has proven stable and effective although it lacks the aesthetic qualities of other methods. The lack of maintenance requirements indicated that only an initial expense for building will be incurred. This structure has performed as well as the more expensive conventional layered rock with armor stone groin, and is a good example of successful low-cost shore protection.

Timber Crib Groin. Very few data are available for the timber crib groin installed at the extreme south end of the site in the fall of 1975. It extends 50 feet (15.2 meters) and costs $30 per foot ($98 per meter) to install. To date it has remained in excellent condition.

In general, the wider spacing between the different groins has proven effective. Minor bank recession has been recorded for small stretches of the shoreline. However, as stated earlier, this could be completely due to terrestrial processes. Of the six groins studied at Sanilac 26, the asphalt-mastic groin has been the most stable. The sandbag groin has suffered the most damage. The Longard tube groins are performing adequately. Both the gabion and the timber crib groins are in excellent condition.

Site 7, Sanilac 11

Site 7 is located about 1.5 miles (2.42 kilometers) north of Site 6 and has the same high clay bluff shoreline. Two 69-inch (175.3 cm) diameter Longard tubes were installed here as a seawall rather than as the groin system utilized at Site 6. The tubes were placed end-to-end at the toe of the bluff parallel to the shoreline, extending 400 feet (121.9 meters). Cost of construction was $65 per foot ($213 per meter) of shoreline at the time of installation in the early fall of 1974. Figure 4 shows the condition of the site in the spring of 1975. While the tubes appear to have performed well at this location, there has been minor shifting and damage. Some sand has been lost at the center of the structure where the tubes meet. The north end of the seawall has moved lakeward by more than 5 feet (1.5 meters), but the entire structure has, in general, resisted back pressure from the slumping bluff. Only slight vertical settlement of the tubes has been detected. The one major storm experienced at this site had no effect on the seawall's performance.

Site 8, Tawas City

Tawas City Park was selected for the examination of a sand nourishment project. The site is sheltered by Tawas Bay and has a sand shoreline with no bluff. Sand nourishment was the selected method of shore protection due to its aesthetic qualities and the site's sheltered location. There is an existing pier (jetty) at the southwest end of the project area. Tawas City installed a timber crib groin at the northeastern limit of the site, which was not included in the study. Installation of the sand fill began in the fall of 1973 and was completed by the spring of 1974. Four hundred linear feet (122.0 meters) of shoreline (between the groin and jetty) was protected with 4,350 cubic yards (3,328 cubic meters) of sand fill. The fill sand used had a size distribution similar to the natural beach sand. The nourishment project costs $20 per foot ($66 per meter). (As some sand would probably have been lost without the addition of the timber groin, total cost including the groin is $80 per foot [$262 per meter] of shoreline.) After some initial shifting the sand remained relatively stable through the spring of 1975. Minor shifting was again detected upon completion of the fall survey of that year. The timber crib groin and pier have helped to hold the fill sand in place as well as trap additional sand. However, only minor storm activity has been experienced, so further evaluation of this project is required to determine overall effectiveness. To date the nourishment project has been very successful and inexpensive at this site. This project requires minimal maintenance, thus its long-term effectiveness is high.

Site 9, East Tawas

East Tawas City Park in Tawas Bay was selected as another test site. The same shoreform is found at this site as at Tawas City and a similar method of shore protection was examined. Sand nourishment was used, but without any groins or jetties for protection, at a cost of $15 per foot ($48 per meter). Three thousand cubic yards (2,295 cubic meters) of sand fill were placed along 400 feet (121.9 meters) of shoreline in the spring of 1974. For nearly a year the sand nourishment remained stable. During the winter of 1974-75 much of the sand was dispersed. By the fall survey of 1975, some sand had shifted back into the area of the original nourishment. This site experienced the same storm activity as Site 8, yet had much more sand movement. This suggests that stabilization of sand nourishment by a groin system will maintain the initial fill over a longer period of time.

Site 10, Tawas Point Coast Guard Station

A rock revetment was selected for testing at this site and was constructed in the summer of 1974. The shoreline is exposed to direct wave attack and has 10-foot (3.0 meter) sand bluffs. To install the 400-foot (121.9 meter) revetment, a foundation layer of rock (4- to 10-inch [10.6 to 24.4 cm]) was graded to a 3:1 slope 30 feet (9.1 meters) wide. At the top of the revetment a 3 by 5 foot (.9 meter to 1.5 meter) trench was dug and filled with smaller rock (1 to 3 inch [2.5 to 7.6 cm]). This would prevent erosion in back of the revetment caused by wave overtopping. Only the north half of the structure was capped with medium size armor stone (11 to 16 inch [27.9 to 40.6 cm]). Total cost of construction was $50 per foot ($164 per meter) of shoreline.

The revetment has been effective in preventing further bluff recession. Although only minor storm activity has been experienced, slight slumping and shifting of the rock is evident. Further rock movement may occur if major storms are experienced. While this structure is very effective in protecting the shoreline, it lacks any aesthetic qualities. This method of shore protection should not be installed in areas where beach use, such as swimming, is allowed.

Site 11, Michiana

This site in the Village of Michiana is an open coast area with 30-foot (9.1 meter) sand bluffs. North and south of the project area there is an existing seawall on a narrow beach. This shoreline is exposed to long fetches from the west and northwest and has been undergoing severe erosion for many years. A new concept in revetment construction on the Great Lakes was chosen for testing at this site. An inexpensive European technique using rock and asphalt mastic (a mixture of sand, mineral filler, and asphalt) was adapted for constructing the revetment. The structure was installed at an expense of $70 per foot ($230 per meter) in the fall of 1973 and is 400 feet (121.9 meters) long.

During the first year of study the structure performed very effectively and withstood four major storms. The revetment is shown in Figure 5. However, a storm in the spring of 1975 which produced breaking waves of about 7 feet (2.1 meters) for a duration of 24 hours caused most of the structure to collapse. The damage can be seen in Figure 6. The long duration of the storm rather than the wave heights had the most damaging effect. The storm was so severe that the steel seawall at the top of the bluff was threatened. Damage to the revetment resulted in a change of its slope from a ratio of 2 to 1 to 4 to 1. This left the backside 3 feet (.9 meters) lower after the storm. The underwater region immediately offshore had been severely eroded. The deeper water permitted waves larger than the revetment was designed to withstand to reach the shore. This contributed to the loss of sand behind the structure. Undermining of the revetment was probably caused by scour at the toe and overtopping. The asphalt-mastic revetment was more effective than the seawall as it was able to protect the bluff (and the road) even in its damaged condition.

It appears that the asphalt-mastic revetment performs quite well during most storm activity. The damage to the revetment from the unusually long storm also may have been caused by wave reflection off the steel wall at the north end. This is supported by the fact that 75 feet (22.9 meters) of revetment closest to the wall suffered severe slumping whereas the next 75 feet (22.9 meters) was hardly damaged.

Until it failed, the revetment was able to withstand all wave attacks. Even in its collapsed position, it provides a small level of protection from minor storms. The revetment has remained unchanged since the spring storm. Bluff recession has continued, however, and the road at the top of the bluff is threatened.

Site 12, Lincoln Township

Lincoln Township Park was the site selected for this project and is located near Stevensville. The shoreline is unprotected with a narrow beach backed by 20-foot (6.1 meter) sand dunes. An existing steel seawall marks the southern border of the site and a concrete wall forms the northern border.

The shore protection structures installed at this site consist of a groin system with two groins 240 feet (73.2 meters) apart. Two types of groins were used: a 40-inch (101.6 cm) diameter Longard tube, 120 feet (36.6 meters) long, and a 90-foot (27.4 meter) long timber pile groin. The two structures are shown in Figure 7.

The Longard tube was the first structure installed at this site in the spring of 1973 at a cost of $30 per foot ($98 per meter). The tube was torn by construction equipment during installation of the timber pile groin.

Despite the initial tear, the Longard tube has suffered only moderate damage. The lake end of the tube (approximately 30 feet [9.1 meters]) has been lost and the whole structure has settled about 3 feet (.9 meters) along the centerline. It is very possible that the tube would have settled in this locale even without the influence of the heavy equipment. The rate of settlement increased again in the fall of 1975 after remaining relatively stable for about a year. It has not been determined if this is due to sand washing out of the tube from the lakeward end or by settlement. The tube still acts successfully as a groin in trapping sand and protecting the bluff. Design modifications could be incorporated, such as placing the tube on a foundation (preferably rubble) and covering the tube with an armored protective coating. This modified groin would be a good low-cost method of shore protection, though not as inexpensive as the present design. The present method of placing a 40-inch (101.6 cm) diameter Longard tube on a sandy lake bottom will only serve as a temporary method of erosion control.

The timber pile groin was completed while working through the ice in the winter of 1973 at a cost of $50 per foot ($164 per meter). This structure has performed well and shows no sign of any deterioration, thus providing additional evidence that wood is an excellent material for groin construction. An impervious timber pile groin is an old and proven means of shore protection in areas where there is adequate littoral drift.

The wide spacing between groins has proven quite successful and the entire system has worked very effectively in protecting the site by trapping sand and raising the beach profile. Both structures are still stabilizing the bluff although it has slumped somewhat. This slumping is probably due to factors other than wave attack, such as terrestrial processes or heavy human traffic on the bluff, as the beach profile is still raised around the groins and immediately adjacent to the bluff.

Site 14, Pere Marquette Township

This site is located 1 mile (1.6 kilometers) south of the Pere Marquette navigation structure. The shoreline consists of 20-foot (6.1 meter) sand bluffs and a narrow beach. A new concept in breakwater design was selected for testing at this site. The breakwater consists of precast, reinforced concrete panels bolted together to form zig-zag walls. Two 70-foot (21.3 meter) walls and one 56-foot (17.1 meter) wall were constructed. The zig-zag walls were placed offshore parallel to the shoreline with 50-foot (15.2 meter) spacings between structures. The panels were originally to be placed at a water depth giving 1 foot of freeboard. Depth increased so rapidly that panels were placed only 50 feet (15.2 meters) from shore. Such a short distance causes high-water velocities between the bank and breakwater which accelerates erosion. Cost per foot (per meter) of shoreline "protected" equalled $70 ($230) when installed in the fall of 1973.

The breakwater system performed quite effectively in building up a beach and preventing bluff recession for the first year. Figure 8 shows the structure in the spring of 1974. Eight major storms were experienced at this site. A major storm with 6- to 10-foot (1.8 to 3.0 meter) waves in the winter of 1975 caused extensive damage to the structure and bluff. All three structures were damaged by settlement and panel breakage. The north section lost two entire panels and settled over 3 feet (.9 meters). It is now completely submerged; this can be seen in Figure 9. One panel was lost off of the center section which also settled and tilted radically. The remaining walls are badly chipped and cracked and have tilted toward shore. Major bluff recession has continued, up to 30 feet (9.1 meters) during the second study year. The bathhouse protected by the breakwater has been completely destroyed.

This experimental use of precast zig-zag walls was intended for onshore use only. Unless redesigned, this type of structure should not be used as an offshore breakwater. Necessary design modifications, however, would eliminate this system from the low-cost category. The private homeowner could not install this structure himself because heavy construction equipment is required. This is not a recommended method of shoreline protection as used in this program. Other breakwater designs, although very expensive, should be used if site conditions require that method of shore protection.

Site 15, Ludington State Park

Ludington State Park was selected for testing two steel pile groins. The low, wide sand beach in front of high dunes was suitable for this method of protection. The groins were installed 125 feet (38.1 meters) apart to stabilize the beach. The north groin in 100 feet (30.5 meters) long and the south groin is 70 feet (21.3 meters) long. It is not possible to determine the final costs of construction as some materials and labor were provided at no charge. Improper anchoring and tie back into the beach has prevented the north groin from performing well. This groin was flanked shortly after construction and deep holes scoured in the lake bottom. This scour caused some shifting of the groin and the breaking of the vales. Repairs had to be made to the north groin. The lake portion had to be pulled out, straightened, and redriven. Above normal maintenance and sand fill has been required for these structures. With the additional filling the groins have successfully prevented beach erosion and protected an adjacent parking area. Since the original construction related problems, the groins have remained stable.

The problems experienced at this site illustrate that good design, when improperly installed, may fail. Steel sheet piling groins are normally effective shore protective structures.

Site 17, Empire

Recession rates as high as 30 feet (9.1 meters) a year have been experienced at the Village Park in Empire Village. This open coast area with 3-foot (.9 meter) sand bluffs was selected for testing a 40-inch (101.6 cm) diameter Longard tube utilized as a seawall. The 300-foot (91.4 meter) tube was laid on a filter cloth foundation parallel to shore at a cost of $30 per foot ($98 per meter) of shoreline. The tube can be seen immediately after it was installed in the fall of 1973 in Figure 10. Shortly after construction, the tube was attacked by 5-foot (1.5 meter) breaking waves for a 14-hour period. Probable maximum wave height was 11 feet (3.4 meters). Due to the shoreline configuration, waves pounded directly against the structure. The single tube was unable to withstand this wave attack and was destroyed. The damage can be seen in Figure 11. If the tube had been sewn to the filter cloth, it may have been more effective.

Site 18, Moran Township

This site is located along U.S. 2 in Moran Township. The 30-foot (9.1 meter) sand bluffs found here have been severely eroded. Two styles of seawalls were selected for testing. Three 40-inch (101.6 cm) diameter Longard tubes were installed in a pyramid configuration (one on top of two) on filter cloth parallel to the shoreline within 10 feet (3.0 meters) of the waterline. The tubes extended for 300 feet (91.4 meters). The second structure consisted of giant sandbags placed in four different stacking patterns at the toe of the bluff, parallel to the shoreline, for 250 feet (76.2 meters). The different stacking sequences were incorporated to test their relative effectiveness. All Longard tubes were installed in the fall of 1973. At the east end of the tubes, the sandbag structure was installed in the spring of 1974. A view of this site can be seen in Figure 12. The costs of construction per foot (meter) of shoreline for each was $60 ($197). Five major storms have since been experienced but only minor problems have been experienced. The top Longard tube shifted out of position due to back pressure from the slumping bluff and had to be shimmed up. The western 50 feet (15.2 meters) moved lakeward about 3 feet (.9 meters). The lower tube is now covered with sand, apparently from sand washing in and around it (no vertical movement of the tube has occurred). The condition of the structures in the fall of 1975 is shown in Figure 13. Despite this, the tubes have retained their original effectiveness. The top of the bluff behind the structures has continued to recede and slump. This occurred because the sand bluff was not in a stable position. The most dramatic bluff loss has occurred behind the sandbags and between the two structures. The sandbag structure, despite some bag loss due to vandalism, has remained stable and performs effectively. Both structures have effectively protected the bluff from major erosion damage (although the shoreline adjacent to the structures has also only experienced minor recession). There is a wider expanse of beach in front of the Longard tubes than the sandbags. This appears to be more of a natural phenomenon than an indication of relative structure effectiveness.

Tables 2, 3, and 4 present summary details of the research effort. A brief description of all the sites is included in Table 2 along with method of protection. Table 3 reports the number of major storms at the surveyed sites since the time of construction as well as the condition of the structure and nearshore environment. Table 4 gives structure and nearshore environment condition for the sites studied utilizing photographic methods.

CONCLUSIONS

The durability of shore protective structures depends on the number of major storms that occur, their intensity and duration as well as on soil type, geologic structure of the lake bottom, topography of the shoreland, etc. These site specific variables prevent broad comparisons of structure effectiveness. Long-term effectiveness of the installations cannot be judged until more time has passed. Some of the test sites have not been exposed to a number of major storms common to the Great Lakes. This makes it difficult to evaluate the structure's performance as a form of low-cost shore protection. The ongoing nature of this study is designed to gather the data necessary to fully evaluate the test methods.

Over the short period of the program, the methods of shore protection at East Tawas, Michiana, and Empire have been lost. The breakwaters at Pere Marquette Township and the Longard tube at Lincoln Township have been damaged and the effectiveness of these structures has been substantially reduced. Sandbags have been lost from the Sanilac 26 and Moran Township projects. The loss documents the necessary replacement of sandbags on a yearly basis.

The shore protection methods used at the remaining project sites have experienced only minor changes.

The following observations can be made based on the two years of study:

-- Artificial nourishment projects are very effective methods of shore protection, especially in areas with limited littoral drift which eliminates the use of groins. (Artificial nourishment should not be used in areas with strong littoral currents which rapidly remove the sand.) Groins may be used in conjunction with this method to help hold the sand in place. Nourishment is also aesthetically pleasing as it preserves the beach in its natural state.

-- Groin systems are appropriate methods of shore protection in areas with ample littoral drift. If a groin system is installed where there is not ample littoral drift, sand nourishment may be required to make the system functional. The longer spacing used between groins at Sanilac 26 shows no adverse effects on the performance of the groin system. Longard tubes can be effectively used as groins; however, in sandy areas they may settle and eventually require replacement. Sandbag groins will require yearly replacement of bags. Gabions, asphalt-mastic, and timber crib groins have been stable at the Sanilac 11 site and pile groins, both timber and steel, are generally effective.

-- When site conditions require, revetments and seawalls may be utilized effectively. However, they experience accelerated destruction when overtopped by waves as shown at Michiana and Empire. Longard tubes used at Moran Township and Sanilac 11 as well as the sandbags used at Moran Township, to date, have been suitable methods of shore protection. The rock revetment installed at Tawas Point Coast Guard Station also has been successful.

-- Offshore breakwaters have traditionally been an expensive, yet effective, method. However, as shown by the breakwater system used at Pere Marquette Township, low-cost breakwaters are not suitable shore protection systems.

The data derived from this project have given insight into the possible solutions for preventing shoreline erosion. Only further years of study will provide the data necessary to properly build effective low-cost methods of shore protection. The general conclusions of two years of study presented in this paper contribute to the development of proper methods of shoreline protection from erosion damages.

REFERENCES

1. U.S. Department of the Army Corps of Engineers, North Central Division, National Shoreline Study: Great Lakes Region Inventory Report, Vol. V, 1971, 221 p.

2. U.S. Department of the Army Corps of Engineers, North Central Division, Preliminary Draft: Summary Report of Pilot Study Program of Great Lakes Shoreland Damage Study, undated, unpublished, 100 p.

3. U.S. Department of the Army Corps of Engineers, Coastal Engineering Research Center, Shore Protection Manual, Vol. 2, 1973, 529 pp.

TABLE 1

IDENTIFICATION OF TEST SITES

Site Name	Site Number	Lake
Little Girls Point	1	Superior
Keweenaw Peninsula	2	Superior
Marquette	3	Superior
Whitefish Township	4	Superior
Lakeport State Park	5	Huron
Sanilac 26	6	Huron
Sanilac 11	7	Huron
Tawas City	8	Huron
East Tawas	9	Huron
Tawas Point Coast Guard Station	10	Huron
Michiana	11	Michigan
Lincoln Township	12	Michigan
Charles Mears State Park	13	Michigan
Pere Marquette Township Park	14	Michigan
Ludington State Park	15	Michigan
Big Sable Point	16	Michigan
Empire	17	Michigan
Moran Township	18	Michigan
Manistique	19	Michigan

TABLE 2

PROJECT DESCRIPTION

PROJECT NUMBER	PROJECT LOCATION	SITE DESCRIPTION	METHOD OF PROTECTION:	TEST CONSTRUCTION COST[1]	
				($ per foot)	($ per meter)
		LAKE	SUPERIOR		
1	Little Girls Point	Open coast area with 20-foot (6.1 meter) high, predominantly clay bluffs with little to no beach.	"Nami Rings" (2.5 foot by 1 foot [.8 meter by .3 meter] concrete rings weighing 265 lbs. [120.2 kg]). Part of this structure was placed on filter cloth, part on a rock foundation, the remainder was not placed on a foundation. Some of the rings were fastened together.	35	114
2	Keweenaw Peninsula	Open coast area with 15-foot (4.6 meter) sandy bluff with narrow beach.	Revetment using waste mine rock in a size smaller than normally accepted for a revetment of this type.	20	66
3	Marquette	Partially sheltered coast area with a low sand bluff, partially "protected" with broken concrete rubble, little to no beach.	Dredge sand with a large percentage of fines and a steel sheet pile groin.	*	*
4	Whitefish Township	Predominantly sheltered coast area with a low (about 3-foot [.9 meter]) sandy loam bluff, no beach.	Rock revetment with groins "tying" the revetment to the land area behind.	45	148
			LAKE HURON		
5	Lakeport State Park	Open coast area with high sand bluff, low foredunes and some beach.	40-inch (101.6 cm) diameter Longard tube installed on bar to form an offshore breakwater.	25	82
6	Sanilac 26	Open coast area with 30-foot (9.1 meter) clay bluffs and no beach.	An experimental groin system with a spacing between groins of about 200 feet (61.0 meters) consisting of:		
			2 40-inch (101.6 cm) diameter Longard tubes, 100 feet (30.5 meters) long	30	98
			69-inch (175.3 cm) diameter Longard tube, 50 feet (15.2 meters) long	25	82
			Gabion baskets, 70 feet (21.3 meters) long	30	98
			Giant sandbags, 60 feet (18.3 meters) long	30	98
			Asphalt mastic, 60 feet (18.3 meters) long	45	148
			Timber crib, 50 feet (15.3 long	30	98
7	Sanilac 11	Open coast area with 35-foot (10.7 meter) clay bluffs and no beach.	Seawall of 69-inch (175.3 diameter Longard tube.	65	213

TABLE 2

PROJECT DESCRIPTION

				TEST CONSTRUCTION COST	
PROJECT NUMBER	PROJECT LOCATION	SITE DESCRIPTION	METHOD OF PROTECTION:	($ per foot)	($ per meter)
8	Tawas City	Sheltered sand coast area with no bluff and an existing pier (jetty) at the southwest end of the project area and a newly constructed timber pile groin at the northeast limit of the project area.	Nourishment project between a jetty and wood groin. Fill sand has a size distribution similar to the natural beach sand.	20	66
9	East Tawas	Sheltered sand coast area with no bluff.	Nourishment project using fill sand which has a size distribution similar to the natural beach sand.	15	49
10	Tawas Point Coast Guard Station	Open coast area with 10-foot (3.0 meter) sandy soil bluff, no beach.	Layered (staged) rock revetment, half "capped" with armor stone of medium size (11 to 16 inch [27.5 to 40 cm]).	50	164
		LAKE MICHIGAN			
11	Michiana	Open coast area with 30-foot (9.1 meter) sand bluff. Shoreline immediately north and south of project area have seawall construction and narrow beach.	Revetment composed of rock and asphalt mastic (a European technique new to the Great Lakes).	70	230
12	Lincoln Township	Open coast area with a 20-foot (6.1 meter) sand dune and a narrow beach.	Groin system with 2 groins 240 feet (73.2 meters) on center composed of:		
			40-inch (101.6 cm) diameter Longard tube, 120 feet (36.6 meters) long	30	98
			Timber pile, 90 feet (27.4 meters) long	50	164
13	Charles Mears State Park	Open coast area with low sandy beach area in front of high dunes. Study area is immediately north of Pentwater navigation structure	Groin system with 3 groins about 150 feet (45.7 meters) on center. Each groin is composed of gabions in beach area and giant sandbags in the water area.	*	*
14	Pere Marquette Township	Open coast area with 20-foot (6.1 meter) sand bluff and narrow beach. The Pere Marquette navigation structure (jetty) is 1 mile (1.6 km) north of the site.	3 precast reinforced concrete, zig-zag breakwaters about 70 feet (21.3 meters) long with 50-foot (15.2 meter) gaps between structures.	70	230

TABLE 2

PROJECT DESCRIPTION

PROJECT NUMBER	PROJECT LOCATION	SITE DESCRIPTION	METHOD OF PROTECTION:	TEST CONSTRUCTION COST ($ per foot)	($ per meter)
15	Ludington State Park	Open coast area with low, wide sand beach in front of high sand dunes.	2 steel pile groins, 125 feet (38.1 meters) on center to stabilize beach. Groins are periodically filled with sand removed from an adjacent parking area.	*	*
16	Big Sable Point	Open coast area with 10-foot (3.0 meter) sand dunes and an existing damaged seawall; no beach.	Tie backs installed on existing seawall; return and cutoff gabion groins constructed from existing seawall landward. Land area behind the seawall and between return walls and cutoff walls sand filled.	*	*
17	Empire	Open coast area with 5-foot (1.5 meter) sand bluff and little to no beach. This area has been experiencing extremely high (30 feet/yr [9.1 meters/yr]) recession rates.	40-inch (101.6 cm) diameter Longard tube placed on filter cloth parallel to the shoreline near the waterline.	30	98
18	Moran Township	Open coast area with 30-foot (9.1 meter) sand bluff and narrow beach.	3 40-inch (101.6 cm) diameter Longard tubes placed pyramid fashion (1 on top of 2) on filter cloth parallel to the shoreline near the waterline. Giant sandbags placed in 4 different stacking patterns parallel to the shoreline along the waterline.	60	197
19	Manistique	Open coast area with 5-foot (1.5 meter) sand bluff and narrow beach.	Gabion mats placed over bluff face in revetment fashion.	20	66

Note: Cost figures given are determined over the length of shoreline the structure was designed to protect.

* Exact cost figures are not available.

TABLE 3

PROJECT RESULTS THROUGH FALL, 1975 FOR SITES UTILIZING SURVEYS

PROJECT	NUMBER OF STORMS (BREAKING WAVE OF 6 FEET [1.8 METERS] OR GREATER) AT THE SITE SINCE TIME OF CONSTRUCTION (INCLUDES ALL MONTHS)	STRUCTURE CONDITION	NEARSHORE ENVIRONMENT CONDITION
Site 5, Lakeport 40-inch (101.6 cm) diameter Longard tube on bar	3	Unchanged.	Beach area has increased greatly in the vicinity of the tube (unrelated to the tube's performance) to such an extent that it is no longer a breakwater. This site is no longer part of the extended field program since the tube is not required for shore protection.
Site 6, Sanilac 26 2 40-inch (101.6 cm) diameter Longard tubes.	1	Minor differential settlement in tubes.	Sand has been trapped by the groin. Recession at top of bluff is about 10 feet (3.0 meters) in the immediate vicinity of this groin. This recession could be caused by factors other than wave attack.
69-inch (175.3 cm) diameter Longard tube	2	Unchanged.	This groin has heen effectively trapping sand, particularly to the north. Top of bluff recession has been minimal.
Gabion	1	Unchanged.	Sand is being trapped, especially on north side of groin.
(Site 6 continued)			
Sandbags	2	Approximately the outer 15 feet (4.6 meters) of this structure have been lost through bag destruction.	Sand has been trapped by this structure. Top of bluff recession has been minimal.
Asphalt mastic	2	Small section (about 3 feet by 3 feet [.9 meter by .9 meter]) of groin has broken off at outer end.	Sand has been trapped by structure. Minimal top of bank recession has been recorded.
Timber crib	1	Unchanged (installed late summer 1975).	No data available.
General		Spacing between groins has been effective to date.	Some areas of localized top of bluff recession.
Site 7, Sanilac 11 69-inch (175.3 cm) diameter Longard tube	2	Structure has remained stable. The center section of the structure has lost sand.	Area of minor bluff recession.
Site 8, Tawas City Sand nourishment	1	Only minor shifting of the sand nourishment.	No change.
Site 9, East Tawas Sand nourishment	2	Totally dispersed.	No apparent effect from sand.

TABLE 3

PROJECT RESULTS THROUGH FALL, 1975 FOR SITES UTILIZING SURVEYS

PROJECT	NUMBER OF STORMS (BREAKING WAVE OF 6 FEET [1.8 METERS] OR GREATER) AT THE SITE SINCE TIME OF CONSTRUCTION (INCLUDES ALL MONTHS)	STRUCTURE CONDITION	NEARSHORE ENVIRONMENT CONDITION
Site 11, Michiana Asphalt mastic revetment	5	Revetment collapsed on beach after 5 critical storms. The sand behind the revetment's slope has been flattened. Small portions of the revetment are completely destroyed.	Bluff erosion has continued. Remaining revetment is an inconvenience to bathers at this beach.
Site 12, Lincoln Township 40-inch (101.6 cm) diameter Longard tube	18	Outer portion (1/3 of tube) has been lost. The remainder of the tube has settled from 0-2 feet (0-.6 meter).	Tube has trapped and held sand. Slope on dune near tube has flattened to some extent.
Timber pile	18	Unchanged.	This groin has trapped and held sand. Slope on dune near this groin has flattened to some extent.
General			Structures have protected site by trapping sand and raising the beach profile.
Site 13, Charles Mears State Park Gabion and sandbag groins	13	Some settlement detected in all groins. One or 2 sandbags lost from each structure.	System has helped stabilize beach area with artificial nourishment added each spring.
Site 14, Pere Marquette Township Precast concrete breakwater	18	All three structures have settled about 1 foot (.3 meter). Two panels have been lost off the north end of the north section and 1 panel has been lost off the south end of the center section.	Bluff recession has continued. Bathhouse that this installation was meant to protect has been destroyed.
Site 15, Ludington State Park Steel pile groins	14	North groin had to be repaired once (lake portion pulled, straightened, and redriven).	Deep holes have scoured in the lake bottom around the outer edge of the groin. System has required periodic sand maintenance.
Site 17, Empire 40-inch (101.6 cm) diameter Longard tube	-	Destroyed within 1 month.	Rapid bluff recession has continued.
Site 18, Moran Township 40-inch (101.6 cm) diameter Longard tubes	8	Some minor differential settlement. The top tube had to be wedged in place to avoid being pushed off due to back pressure from sliding sand.	Sand bluff has flattened some.
(Site 18 continued) Sandbags	8	A number of sandbags have been lost, partly due to vandalism. Some differential settlement has been detected.	The sand bluff has slumped in some areas.

TABLE 4

PROJECT RESULTS THROUGH FALL, 1975 FOR SITES UTILIZING PHOTOGRAPHIC MONITORING ONLY

PROJECT NUMBER	PROJECT LOCATION	STRUCTURE CONDITION	NEARSHORE ENVIRONMENT CONDITION
1	Little Girls Point	Some change in revetment position due to sliding clay. Rings have filled with sand and small rock.	Some sliding of clay bluff.
2	Keweenaw Peninsula	Unchanged.	Unchanged.
3	Marquette	Groin has remained unchanged; as expected a large amount of sand has shifted.	No apparent effect from structures.
4	Whitefish Township	Unchanged.	Stable.
10	Tawas Point Coast Guard Station	Some shifting in the rocks is evident.	Unchanged.
16	Big Sable Point	(Construction problems were experienced at this site which hampered the study.) All the sand filled behind the wall has been washed out, exposing improperly installed tie backs. The south return wall which was poorly installed has failed.	In spite of these failings, the original seawall is still in place. Bluff recession has continued at a very low rate.
19	Manistee	Structure has been "paved" over and area is now a parking lot.	No longer applicable.

TABLE 5

GROIN SYSTEMS INSTALLED AT SANILAC 26

Type	Structure Length Feet	Structure Length Meters	Test Construction Cost Per Foot	Test Construction Cost Per Meter
2 40-inch (101.6 cm) diameter Longard tubes	100	30.5	$30	$98
1 69-inch (175.3 cm) diameter Longard tube	50	15.2	$25	$82
Gabion	70	21.3	$30	$98
Giant sandbags	60	18.3	$30	$98
Asphalt mastic	60	18.3	$45	$148
Timber crib	50	15.2	$30	$98

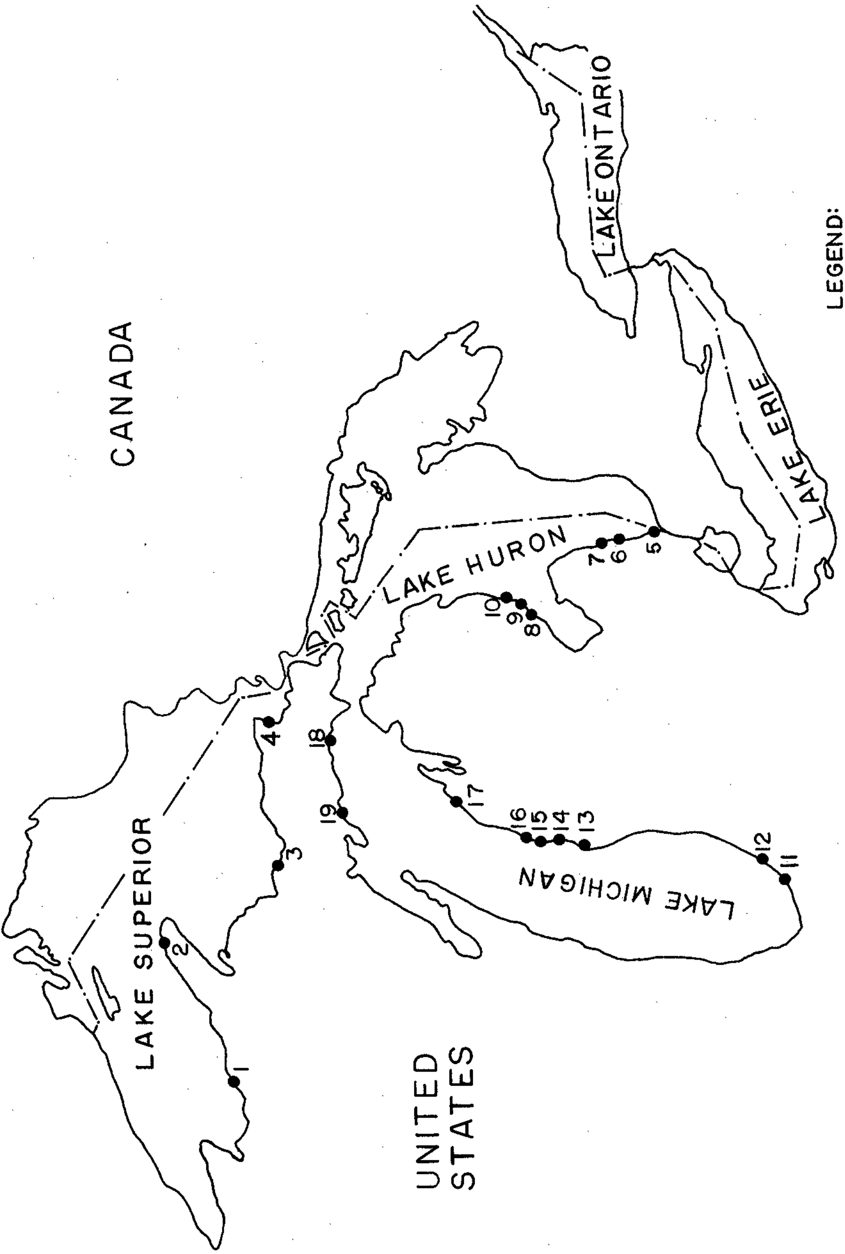

FIGURE 1
SITE LOCATIONS

Figure 2 Sanilac 26 April 27, 1975

The sandbag groin can be seen in the foreground with the gabion, 69-inch (175.3 cm) diameter Longard tube and the two 40-inch (101.6 cm) diameter Longard tube groins is succession behind it. The group of structures in the far background are not part of this project.

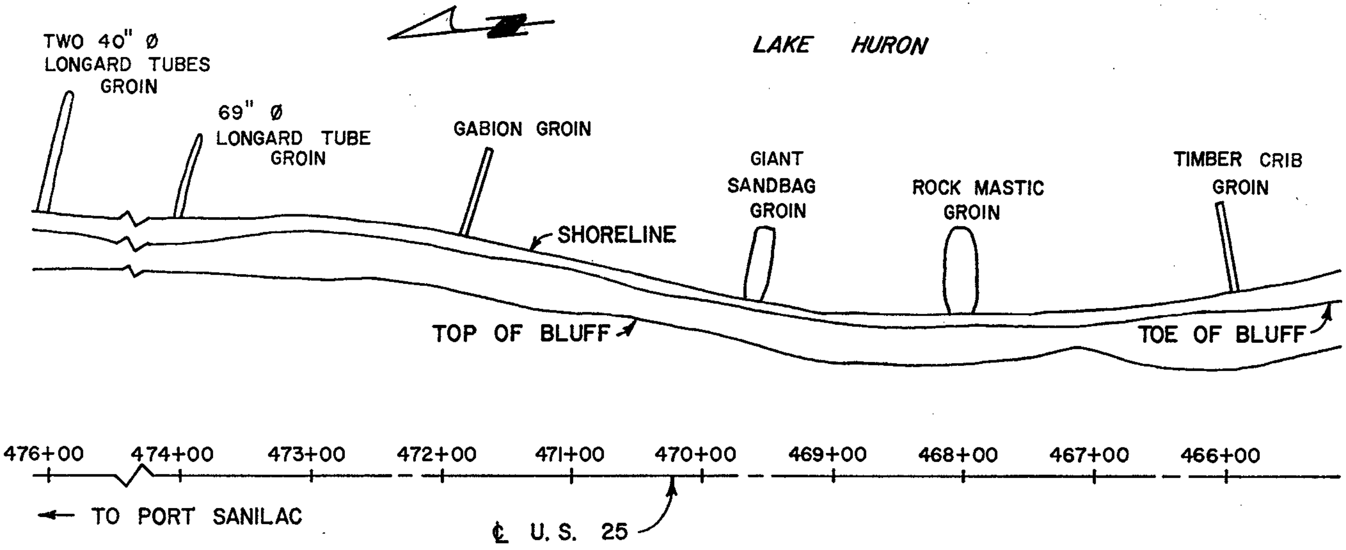

FIGURE 3

PLAN VIEW OF SANILAC 26

SANILAC TWP., MICHIGAN

Figure 4 Sanilac 11 April 27, 1975

This view shows the 69-inch (175.3 cm) diameter Longard tube used as a seawall at Sanilac 11. The very active and slumping clay bluff is evident in the photograph.

Figure 5 Michiana September 23, 1973

The revetment can be seen one month after completion of construction in the fall of 1973.

Figure 6 Michiana October 20, 1975

Large portions of the sand behind the structure have been washed out causing the structure to collapse. Despite its collapsed condition the revetment has maintained its integrity. Emergency fill operations are evident at the south end of the project near the concrete seawall. The entire beach area has been eroded as is evident by the exposed steel pile foundation beneath the concrete seawall.

Figure 7 Lincoln Township April 20, 1974

The timber pile groin, installed in the winter prior to this photograph, is evident in the foreground. Part of the Longard tube, constructed the previous fall, can be seen in the background (near the tripod). Settlement in the tube is particularly evident at the shoreline.

Figure 8. Pere Marquette Township April 29, 1974

This view shows the south and north set of panels (looking north) shortly after construction. The center panels were installed in the fall of 1973. The newer set of panels were placed at a higher elevation (with more freeboard) than the center section. As is evident, these panels were initially very effective in trapping sand.

Figure 9 Pere Marquette Township October 12, 1975

In this photograph (looking north) it is evident that the north and south sets of panels have settled considerably. Effectiveness of the structures has been reduced and the bluff behind the structures (not shown) has been considerably damaged by storms.

Figure 10 Empire November 3, 1973

This picture was taken shortly after construction was completed. The filter cloth foundation and the low sand bluff to be "protected" by the tube is evident.

Figure 11 Empire March 7, 1974

As evident in this photograph, a large portion of the structure has settled out of site. Bluff recession has continued at a high rate.

Figure 12 Moran Township November 4, 1973

The Longard tube structure and one of the stacking patterns of the sandbag structure, both used as seawalls, are shown here. The short stub groin protruding lakeward from the Longard tubes was removed. The active sand bluffs to be protected by the seawalls are evident.

Figure 13 Moran Township October 12, 1975

This is a view of the site two years later. Many sandbags have been lost and the tube has remained stable. Recession activity is evident as shown by the number of trees and vegetation scattered along the face of the bluff. This action is a result of erosion damage prior to the installation of the test projects. The shoreline in front of these structures has stablized as well as the shoreline in the adjacent areas (no cause and effect relationship is apparent).