

CHAPTER 211

ARTIFICIAL BEACH UNITS ON LAKE MICHIGAN

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ABSTRACT

High water levels on Lake Michigan during 1985 and 1986 created substantial erosion of the shoreline and reduced the size and recreational potential of many of the parks and beaches. To prevent further erosion, protect existing properties and structures, and to create and improve recreational areas along the Lake Michigan shoreline, four coastal engineering projects were designed and constructed during this time. Artificial beach units stabilized by offshore breakwaters were used as the main component of each project.

Physical hydraulic model studies were used to determine the orientation, size, and spacing of breakwaters and artificial beach units. Model predictions of beach profiles and plan shapes compare closely with prototype surveys. Surveys completed since construction demonstrate the stability of the beaches and support their use as effective, low maintenance shoreline protection.

Prototype experience has shown that these projects are extremely successful both in their ability to withstand storms on the Great Lakes and to attract people for recreational activities.

INTRODUCTION

Four coastal projects were constructed on the west shore of Lake Michigan during 1985 and 1986 to prevent excessive erosion during a period of record high water levels. Of the four projects discussed in this paper, two are located in Lake Forest, Illinois and the other two are located in Milwaukee, Wisconsin.

Each project has a combination of offshore breakwaters and artificial beaches as the basic component providing both shoreline protection and new recreational areas. In assessing the attributes of various shoreline protection schemes it was evident that the benefits of creating new recreational areas outweighed the additional costs in comparison to the costs associated with simply providing basic shoreline protection.

Physical hydraulic models were used in all four projects to design the shoreline protection, determine optimum beach fill profiles, and to assess the impact of design storms on these projects.

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The final designs are unique to each project depending on the particular recreational requirements and environmental conditions specific to each site. Varied combinations of breakwaters, groins, shoreline revetments, and sand fills have been used. Specific items which were varied between projects are discussed in further detail below:

- The type of beach fill material varies from a coarse sand ($D_{50}=2.6\text{mm}$) to waste rock from a tunneling project. Criteria for selection of beach fill materials included:
 - 1) beach stability - grain size must be sufficiently large to provide stable, low maintenance beaches.
 - 2) aesthetics and recreation - the material had to be acceptable for pedestrian traffic.
 - 3) cost - the total cost of material per unit length of shoreline had to be reasonable relative to providing other forms of basic shoreline protection.
- The length, height, and orientation of steel sheet pile groins between the individual beach cells was varied in all four projects. The groins were used to control the amount of alongshore sediment transport behind the breakwaters. In two of the projects the groins were tapered to match the stable beach profiles estimated from hydraulic model studies. This allows native sand to bypass the projects by moving between the breakwaters and artificial beach. Alongshore currents and waves overtopping the breakwaters move the sand through the projects to the downdrift shoreline.
- The constructed plan and profile shapes of the artificial beaches varied significantly between projects. Depending on the cost of the beach fill and room available for beach profile development, physical models were used to determine the most effective elevations and shapes of the beaches, breakwaters and revetments.
- Breakwater design details including both layout and cross-section (for example, the distance that the breakwaters were constructed offshore, breakwater crest heights, and breakwater gap widths) were varied depending on the bathymetry at the site, size of recreational area required, and environmental conditions.

Literature Review

The large grain size of beach fill materials used in the projects discussed in this paper create stable beaches with unique profiles and plan shapes and make direct comparisons to other projects discussed in the literature generally inappropriate. However, a number of papers dealing with related topics have been published. Most of the published information deals with the construction of offshore breakwaters along coastlines with significant littoral drift. In the majority of cases described in the literature the breakwaters are used to trap sand.

For example, Toyoshima (1974 and 1982), and Nir (1982) discuss offshore breakwaters and their effect on coastlines in Japan, and Israel and Sinai respectively. Both authors report rapid formation of large tombolos behind the structures; the tombolo shape tends to stabilize after several years, following which only seasonal fluctuations occur.

Chew et al (1974) and Silvester et al (1980) discuss the use of offshore breakwaters to provide artificial headland control along beaches with substantial littoral drift. In these cases, construction of the structures is followed by the development of pocket or log-spiral beaches, also known as zeta bays, between the offshore breakwaters.

Theoretical aspects of sedimentation behind offshore breakwaters is discussed by Dean (1978). Dean presents a procedure for calculating beach planforms behind closely spaced offshore breakwaters. Perez and Fernandez (1988) also provide a method of predicting beach planforms based on the analysis of data collected from 33 beaches on the Mediterranean coast of Spain.

Model studies assessing the sedimentological influences of offshore breakwaters were discussed in a number of papers, including Shinohara and Tsubaki (1966), Rosen (1982) and Noda (1984).

Curren and Chatham (1977, 1980) describe model investigations undertaken to assess the performance of various schemes of protecting eroding beaches at Imperial Beach, California, and Oceanside Harbor, California. Both offshore breakwater and groin systems were tested.

The most recent information available on the use of detached breakwaters for shore protection is found in Dally and Pope, 1986. The authors review existing systems in the United States, including four single detached breakwaters and six segmented breakwater systems.

The papers described above generally discuss depositional effects behind an offshore breakwater, assuming a suitable source of sand, such as net alongshore drift. Several other papers discussing the use of offshore breakwaters to protect an artificial beach were also reviewed. These included Tourman (1968) (Larvotto Bay, Monte Carlo), Sato and Tanaka (1980) (Suma and Ito Beaches, Japan) and to a limited extent, Walker et al (1980) (Lakeview Park, Ohio). In addition, information on an artificial beach system, constructed near Cannes, France was obtained from the engineering firm Sogreah in France.

ENVIRONMENTAL CONDITIONS

Environmental conditions specific to each site were determined prior to the preparation of designs. The data has been summarized below for the projects discussed in this paper to allow a general comparison of the environmental conditions to other locations.

Water Levels

The maximum and minimum water levels recorded by the U.S. Army Corps of Engineers for Lake Michigan are summarized in Table 1:

Table 1

Lake Michigan	International Great Lakes Datum (IGLD)	Low Water Datum (LWD)
Record high water level	177.30m (October 4, 1986)	+1.5m
Record low water level	175.18m	-0.63 m

Lake Michigan low water datum (LWD) = 175.8m IGLD

The projects described in this paper were designed for maximum water levels of +1.4 m to +2.5 m. These values include an allowance for storm surge, which may increase water levels up to approximately 1m along the west shore of Lake Michigan. For example, a storm surge of 0.88 m occurred at Milwaukee on February 8, 1987 during a severe winter storm. However, it is unlikely that the maximum storm surge levels will ever occur during the summer months which generally correspond with the period of highest water levels on Lake Michigan.

In summary , it was appropriate to design the structures and land based facilities so that severe damage will not occur with water levels in the order of +1.4 to+2.5 m above LWD. These water levels account for extreme water levels plus storm surge. In addition, the facilities are designed to be functional for recreational purposes with both high and low water levels.

Wave Climate

Table 2 provides the range of maximum offshore significant wave conditions estimated using a 20 year parametric wind-wave hindcast. These results represent typical maximum offshore wave climates for the projects described in this paper.

Table 2 Summary of Typical Offshore Wave Climate		
Direction	Maximum Deepwater Significant	Peak Period
	Wave Height (m)	Tp (s)
N	4.0 to 5.0	8 to 10
NE	4.0 to 4.6	8 to 10
E	3.0 to 3.3	6 to 8
SE	3.0 to 3.3	7 to 8
S	2.7 to 3.0	6 to 7

In all of the projects discussed in this paper the breakwaters are constructed in depths ranging from -1.5 m to -3.5 m LWD. Therefore, the wave climate incident on the breakwaters and beaches is depth limited during storms. For each project the inshore refracted wave climate was estimated and model tests were completed for the range of incident wave directions and water levels. This procedure provided sufficient information to estimate the possible range of beach profiles and plan forms. It also provided data on the effects of storms from different directions.

Beach Materials

Two types of primary beach fill materials were used in the projects discussed in this paper. Waste material from a tunnelling project was used as the main source of material for beach fills in the two Milwaukee projects and a coarse sand was used as the primary fill material in the two Lake Forest projects. Figure 1 provides a gradation curve for the tunnel spoil material used in the Milwaukee projects and the coarse sand fill used in all the projects.

The waste material used in the Milwaukee projects consisted of limestone fragments ranging in size from 0.1mm to approximately 80mm in the largest dimension. The D₅₀ was approximately 3mm. The material is very angular as shown in Figure 2 but stone quality tests and prototype experience since construction indicate that the majority of sharp edges will be removed as wave action continues to move the beach materials in the swash zone. The areas above the swash zone have compacted since construction was completed and can be comfortably walked on by pedestrians.

The two Lake Forest projects used a coarse sand fill referred to as Bird's Eye sand as the primary source of beach fill material. This sand consists of a well sorted natural source of sand with a D₅₀ of 2.6mm. Other finer materials were used in the initial stages of filling the beach cells in areas where it was predicted that the coarse sand would not be removed from the outer face of the beach. Several other types of sand were considered however, model study results and cost/benefit analyses indicated that the Bird's Eye sand provided the optimum solution. The Bird's Eye sand provided a stable beach profile which allowed maximum development of land based facilities without having to construct the offshore breakwaters in deep water.

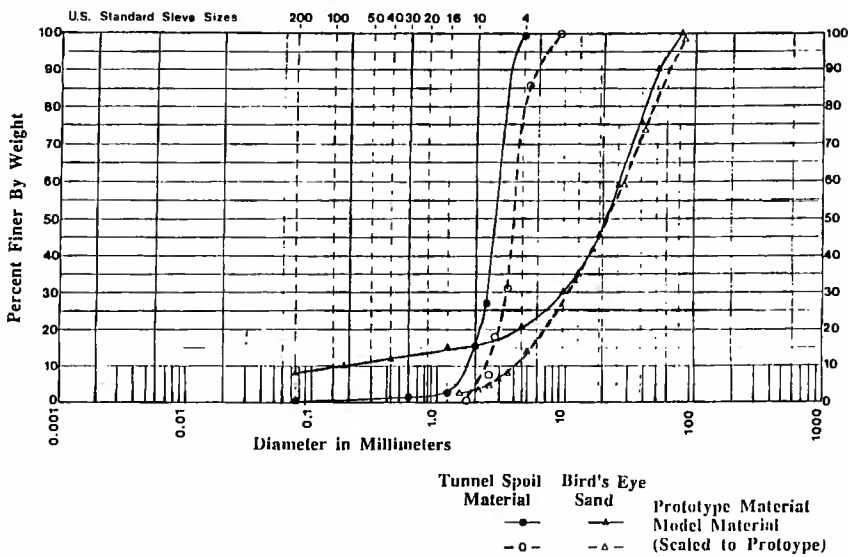


Figure 1
BEACH MATERIAL GRADATION CURVES



Figure 2 TUNNEL SPOIL BEACH FILL MATERIAL

PROJECT SUMMARIES

Of the projects discussed below one was completed in 1986, one in 1987 and the other two in 1988. Information available at this time is provided below. This includes: photographs of prototype structures; survey results of the 'as-built' projects and surveys completed since construction; and photographs showing the public's perspective.

Forest Park Beach Development, Lake Forest, Illinois

The shoreline development at Forest Park extends approximately 1067 m along the Lake Michigan shoreline, and consists of a series of four individual beach cells contained by detached offshore rubblemound breakwaters and shore connected steel sheet pile groins. The project also includes a protected boat launch basin, a shoreline revetment, and considerable greenspace and land based development as shown in Figure 3. Construction of the project started in the spring of 1986, and was completed approximately one year later.

The Lake Forest project was designed using a three dimensional hydraulic model study at a geometric scale of 1:20. Figure 4 shows the Forest Park model study in progress. During the hydraulic model tests it was demonstrated that it would be necessary to separate the beach cells with groins and to use a coarse sand as the artificial beach fill. The selected beach fill consists of sand with a D_{50} of approximately 2.6 mm. The coarse sand was necessary to reduce the amount of material transported between beach cells during storms, and to provide stable beaches within the limited area available.

An extensive review of the history of the shoreline and coastal processes was completed at this site prior to construction. It concluded that the project would have no negative impacts on the shoreline, since the alongshore sediment transport is negligible. A comparison of surveys taken in late April and August 1988 supports this conclusion. Cross sections were surveyed every 15m (50 ft) along the beach and indicate a total net accretion of 178m^3 for the project. Considering the accuracy of the surveys, the net accumulation of sand within the project is considered to be negligible. Figure 5 shows the project in plan view including the locations of the breakwaters, design and August 1988 plan forms, and locations where beach cross sections were completed.

Beach cross sections are presented in Figures 6 and 7 for the following conditions: original beach profile, the as-built profile, April 1988 survey, and August 1988 survey. Profiles 2+00 to 3+00 indicate a net accumulation of sand whereas profiles 12+00 through 14+00 show a net loss between the as-built and August surveys. The elevation of the groins, +2.4 m LWD, is insufficient to prevent movement to the south as evidenced by the net accumulation of sand in beach cell 1.

The project was subjected to several severe storms during the winters of 1986-87 and 1987-88. It was noted during the model studies and during the first winter following construction that the storm profiles included development of a sand berm up to elevation +3.7m LFD. The comparison between model and actual beach plan and profile development under storm conditions was excellent as shown in Figure 8.

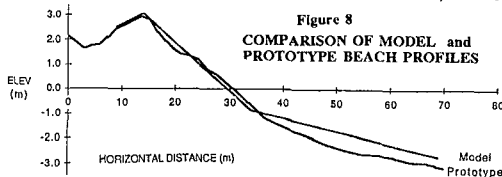




Figure 3 COMPLETED FOREST PARK PROJECT



Figure 4 FOREST PARK MODEL STUDIES IN PROGRESS

FIGURE 5 FOREST PARK PLAN SURVEYS
and LOCATION OF PROFILES

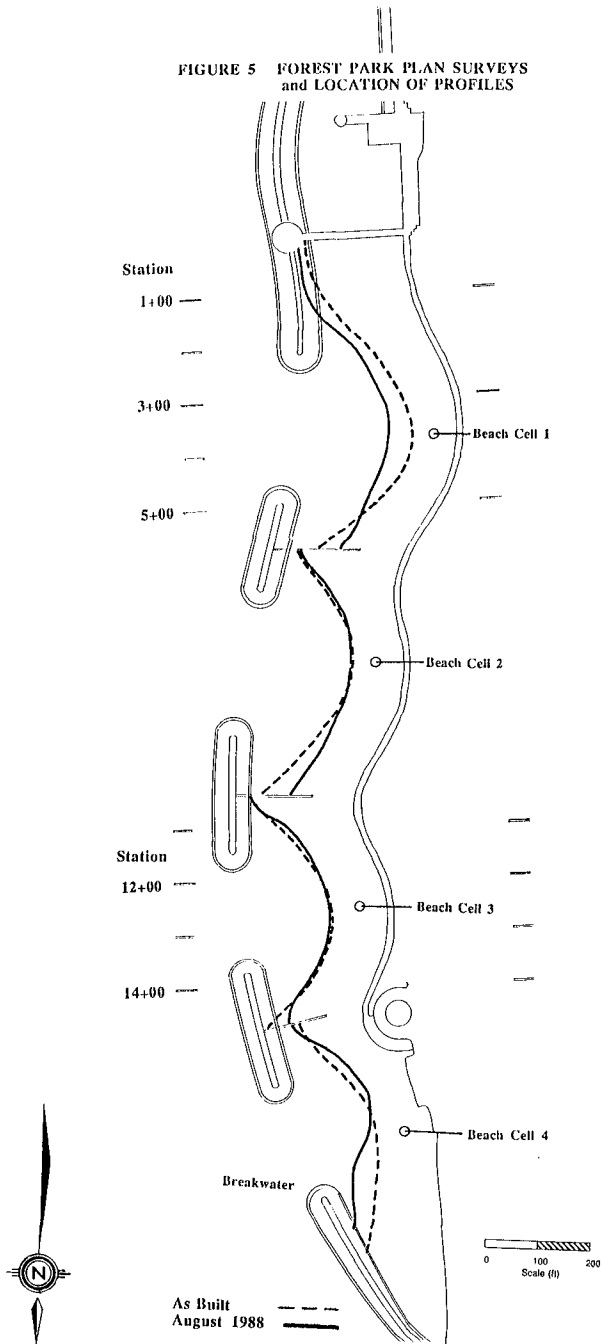
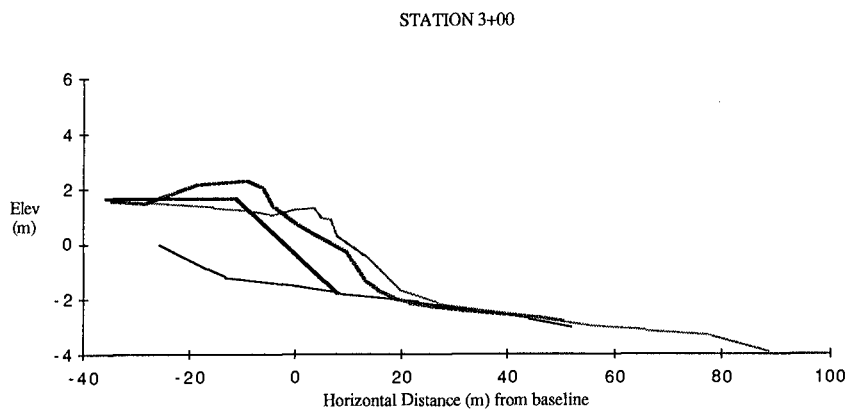
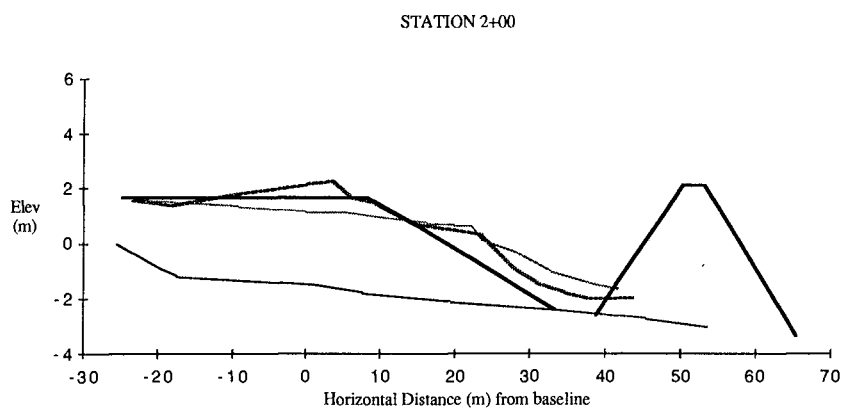
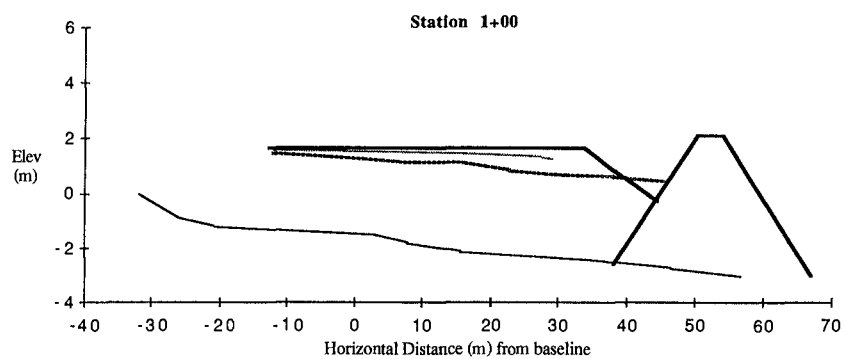
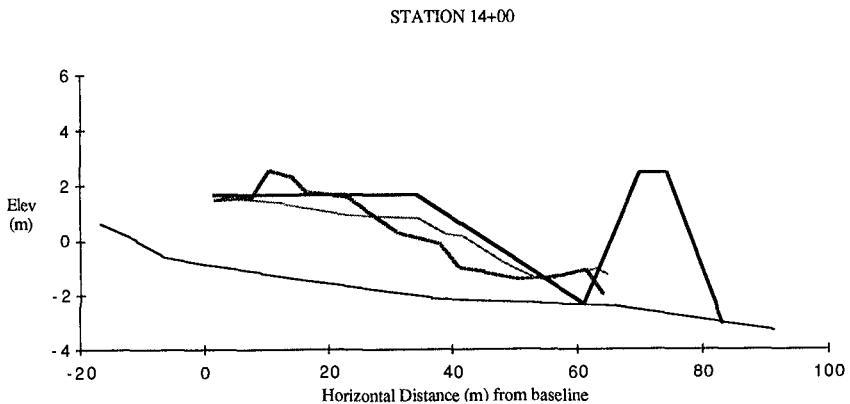
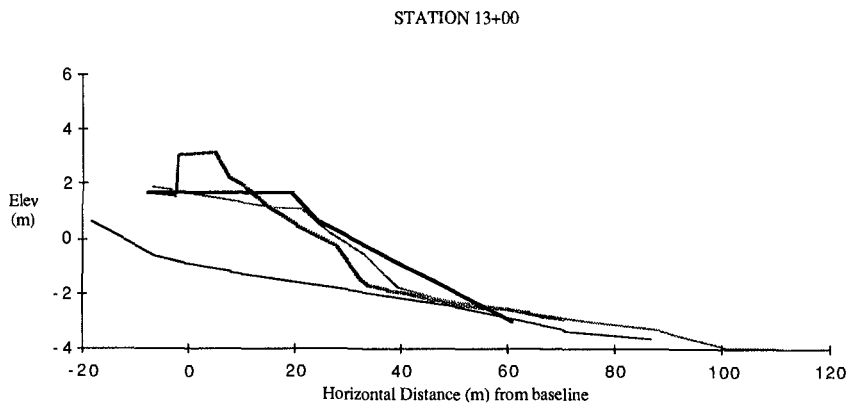
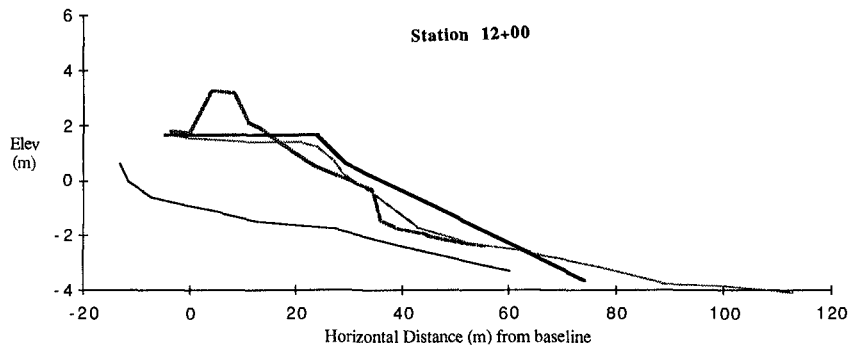


Figure 6 FOREST PARK BEACH PROFILES

— original (y) — Apr 88 — Aug 88 — As Built (y) — Breakwater

Figure 7 FOREST PARK BEACH PROFILES



— original (y) — Apr 88 - - - Aug 88 — As Built (y) — Breakwater

The prototype berm profile is also evident in Figures 6 and 7 in profiles 3+00, 12+00 and 13+00 which are located primarily in the center of the beach cells. The berm is now constructed each fall by pushing the existing beach sand up into the storm profile. This protects the land based facilities behind the beach during fall and winter storms, and each spring the berm is levelled to provide a clear view of lake from the walkways for the summer season.

The Forest Park project has been extremely successful since its completion. Thousands of people visit the beach each day during the summer and the facility is also used for cross country skiing in the winter.

McKinley Park Shoreline Restoration, Milwaukee, Wisconsin

A design to protect a 762m long section of shoreline at McKinley Park was developed using a combination of desk and model studies. The project is located along a main commuter roadway which was frequently flooded during major storms.

The project consists of a series of rubblemound groins, revetments, and offshore breakwaters to contain landfill, a stone beach, and a coarse sand beach. Alongshore sediment transport was not a concern at this site, as the project is immediately north of Milwaukee harbor, which extends much further out into Lake Michigan.

The landfill and stone beach fill consist of crushed limestone produced by a large sewer tunnelling project underway in Milwaukee during construction of the McKinley Park project. This material is very angular, and ranges in size from 0.1 to 80 mm, as mentioned previously. The material was delivered to the site at no cost making it an extremely attractive product to be used as beach fill.

Figure 9 provides a photograph of a 180m wide beach cell which was filled with tunnel material. The photograph was taken in the fall of 1987 immediately following construction. A vertical edge is visible near the top of the beach which was removed during winter storms leaving a smooth beach face as shown in Figure 2.

Figure 9 McKinley Park Beach



There have been no obvious changes in the plan form shape of the tunnel spoil beach since construction. As evidenced in Figure 9 the beach has a very flat plan profile along the majority of its length.

Since construction was completed the McKinley project has prevented flooding and damage to the roadway in addition to adding a significant recreation area for the public's enjoyment. By taking advantage of the free tunnel material it was possible to construct this project for a total sum estimated to be similar to the cost of a conventional revetment using quarried armour stone.

Klode Park Beach Development, Whitefish Bay, Wisconsin

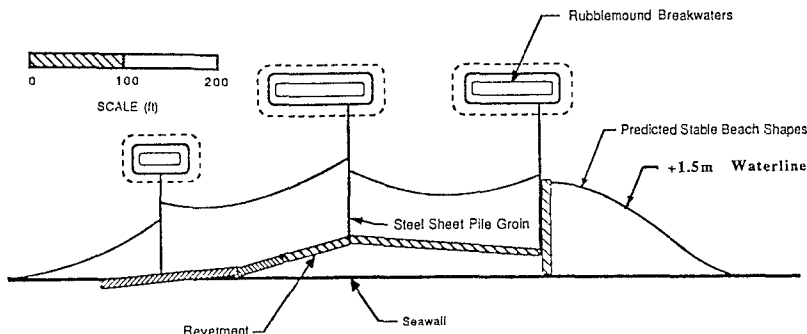
A three dimensional hydraulic model study conducted at a geometric scale of 1:20 was completed to develop a design for a shoreline restoration project to protect the Klode Park shoreline (approximately 200 m long), and to provide increased recreational space. The shoreline at Klode Park has a bluff with a height of approximately 20m. At the time the project was initiated the bluffs and shoreline had been steadily eroding to the point that slope failures were occurring which were threatening a water filtration plant located within the park.

Due to the existence of alongshore sand transport in this area it was necessary to limit the extent to which the project extended out into the lake and to account for sand bypassing the project. This was accomplished by constructing the offshore breakwaters within 60m of the original shoreline and by tapering the steel sheet pile groins which separated the beach cells. The groins were tapered to match the beach profiles to minimize the loss of beach fill during severe storms. The tapered groins also allowed native sediments to bypass the project behind the breakwaters. Because the distance from the offshore breakwaters to the permanent land based facilities is substantially shorter in this park as compared to Forest Park it was necessary to significantly modify the design of the beaches and other shoreline protection measures.

Variations over the Forest Park project include significantly reducing the breakwater gap width, tapering the groins, increasing the breakwater crest height, and adding stone revetments to the upper beach area. The revetments are buried and not noticeable to the public, but become exposed during severe storms at extreme water levels providing protection to the land based facilities and water filtration plant.

The final design, shown in Figure 10, consists of three offshore rubblemound breakwaters, which contain artificial beaches. The beaches consist of either all tunnel material similar to the McKinley project or tunnel material covered with coarse sand fill. The coarse sand has a D50 of approximately 2.6 mm placed over a general fill consisting of tunnel material similar to the McKinley project.

FIGURE 10 KLODE PARK FINAL DESIGN



Public's perspective from the park down onto the beach and from the beach looking down the adjacent shoreline are provided in Figure 11.



FIGURE 11 PUBLIC PERSPECTIVES



Pesch Property Shoreline Protection, Lake Forest, Illinois

Similar to the other projects the high Lake levels in 1985 and 1986 had caused considerable shoreline erosion and bluff retreat along this section of the Lake Michigan shoreline. The project was required to prevent further erosion of a 130 m long privately owned section of shoreline where erosion was threatening the stability of the bluff and the property owner's house.

The project was completed in the winter of 1986 and consists of two offshore rubblemound breakwaters and two steel sheet pile groins which contain small pocket beaches filled with a coarse sand as shown in Figure 12. Rubblemound revetments provide additional protection along the shoreline behind the breakwater gaps where the beach fill is not sufficient to protect the bluff during storms. A physical model study was used to design the combination of offshore breakwaters, steel sheet pile groins and sand beaches.

This project was subjected to several severe storms during the winters of 1986-87 and 1987-88 and similar to the Forest Park project performed as predicted by the model investigation.

FIGURE 12 PESCH PROPERTY ARTIFICIAL BEACH



SUMMARY

Shoreline protection was the basic goal of each of the projects described above. In assessing the attributes of various shoreline protection schemes it was evident that the benefits of incorporating recreational areas into the projects outweighed the additional costs associated with creating them. Prototype experience has shown that these projects are extremely successful both in their ability to withstand storms on the Great Lakes and to attract people for recreational activities. Therefore each of these projects meets the basic criteria of providing effective shoreline protection while also providing excellent recreational areas, and demonstrates the numerous advantages associated with choosing artificial beach units versus standard protection measures.

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