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Figure 1: An example of a Great Lakes revetment

Great Lakes Coastal Shore Protection Structures and Their Effects on Coastal Processes

Introduction

Many Great Lakes private and public shorelines, ports, harbors and marinas are protected from damage by storms, waves, ice and high water levels by a variety of engineered coastal and offshore shore protection structures. Just as there are many types of Great Lakes shorelines and coastal bluffs, there are many shore protection alternatives, and the effects of those structures both on the immediate site as well as farther away along the shoreline can vary. Each location/structure combination could have both positive and negative effects depending upon conditions. Therefore, it is extremely important to understand Great Lakes coastal processes and how coastal structures can affect coastal processes when choosing an engineered solution.

Great Lakes Coastal Processes

Changes along the shoreline are influenced by several things—the marine climate, the geology of the area, the weather and human-induced shoreline changes such as dredging or placement of coastal structures. Certain reaches of shoreline are more exposed to damaging winds and waves by the nature of their orientation. However, the effects of that exposure are more apparent on certain types of shorelines than others. Rock shorelines tend to remain more stable; however, over longer periods, even they will change as the rock is weathered and worn down by ice freeze/thaw or the scour of waves and moving water. Sandy shorelines are dynamic and move along the shoreline and across the beach depending on wave conditions. Between those two extremes are cobble beaches, which are far less mobile than sand beaches and tend to pile up as low berms along the beach edge. Finally, glacial till is very hard and initially resistant to erosion, but once lost, does not recover like sand can.

Coastal processes are mostly thought of as an erosion process, but that is only half the cycle. In many places, sand accumulates in pockets as it moves from areas of higher wave energy to zones of lower energy. These pockets are commonly found at river mouths and any place where a rock outcrop or other type of geologic feature can capture sand, but they can also appear along straight open stretches of shoreline if the conditions underwater cause waves to bend away or soften at some point—a process known as refraction.

Changes in shoreline are often called erosion, but most are actually caused by a process called "sand starvation." Waves usually approach a beach at a slight angle, creating a "push" against the beach in the alongshore direction, which causes sediment to move laterally. As long as the same amount of sand comes into the beach at one end and goes out the other, it doesn't matter how big or small the waves are. It only matters when the ratio of sand coming in to sand going out changes. Different events can change that ratio. A natural structure may appear in the middle of the beach, an artificial one may be built, or a simple curve can develop in the beach that changes the relative angle of the waves to the beach, which increases or decreases the amount of push. If the amount of sand movement changes for any reason, the shoreline will expand or contract depending on whether the amount of sand is increased or decreased at a given location.

Erosion is a term properly reserved for what happens if wave energy is focused on a cliff, bluff or similar feature, causing it to break down beyond what is naturally repairable. In the case of bluff erosion, sediment breaks from the bluff face, causing the bluff to steepen and leading to a bluff face collapse. That collapsed material becomes "food" for part of the beach and may actually relieve the starvation of sediment occurring along that reach for a short time. The efficacy of this "food," however, depends on the grain size and material type of the eroded bluff. A very fine clay material will do little to nourish beaches, while a sandy material will stay in the nearshore and mix with the existing sand along the shoreline. The undercutting of a bluff and bluff collapse onto a beach tend to be episodic, only happening every few years to maybe a decade, so even without any other changes in wave climate, the shoreline may appear to shift from stable, to growing, to retreating. For this reason, the stability of a shoreline should not be viewed on a short timeframe, but rather over a period of both seasons and years.

This understanding of a dry beach, bluff or dune lining a shoreline as being "food" for a beach is an important concept when considering development near a beach. Constructing walls to retain property and protect an area from erosion can be effective on a local basis. However, by armoring that point, that beach "food" is being permanently taken out of the littoral zone, which increases the amount of starvation happening elsewhere.

Other coastal processes can affect sand movement as well. During storms, when waves are big, the shape of the waves is called "steep," i.e., the height of the wave grows taller than its length (the distance between any two consecutive wave crests). Steep waves break more easily so they pick up sand and move some of it higher onto the beach and carry some out into the lake where it deposits at the breaker line. This cross-shore behavior is seasonal, tends to be short-term and is sensitive to the level of the lake water surface. While the storm is occurring, something interesting happens to the growth of the waves. At first, the lengths of the waves are relatively shorter, making the waves steeper. As the storm passes, the distance between wave crests gets farther apart. Once the storm has passed, only longer, flatter waves remain. These longer waves penetrate deeper into the water, often all the way to the bottom of the lake. Once the storm has passed, only the longer waves remain, and they start pushing sand back up onto the beach. Over a period of as little as a few days, a beach can appear to retreat and then re-appear days or weeks later due to the change in wave forms.

In the Great Lakes, other forms of shoreline processes occur as well. One shoreline change, called ice shove or push, is due to the formation and movement of ice during winter. Though ice may grow as a solid sheet across the lake, the stress and friction of the wind blowing across the ice surface force it to move. It will push against the shoreline and frequently ride up, bulldozing shoreline material with it. In extreme cases, it may freeze around an object such as a rock or pile and lift it from its foundation.

Another shoreline process called aeolian transport is the movement of beach sand due to wind, illustrated by the various duned shorelines wrapping Lake Michigan. Wind will actually carry sand off the beach and pile it inland, building tall dunes that can then march farther inland. However, in general, most changes seen on Great Lakes shores are triggered by wave action.

Common Great Lakes Coastal Structures

Great Lakes coastal structures are used for both navigational safety and land preservation. While the structures may appear similar, their functions differ, so the composition and scale of the protection will vary. In addition, virtually no two locations will experience the same conditions, so each application of a protection scheme is unique. There are three types of shore defense structures—shore parallel structures, shore perpendicular structures and offshore structures—and each performs in a different way.

Shore Parallel Structures

The most effective shore parallel structure is the simple beach. Its broad shallow sloping surface causes waves to gradually break until all energy is lost. Although a beach is ideal for providing direct access to the water, it has

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Figure 2: Offshore breakwaters and groin at Presque Isle, Lake Erie

characteristics that limit its use as a shore protection strategy. First, the sand of the beach is highly mobile, so that the beach width and profile are not consistent and frequently not predictable. Second, the footprint of a beach is flat and wide across the shore. It also extends underwater a long distance, so its true width may be two or three times as large as the visible dry beach. To get an area wide enough to dampen waves effectively, especially if there are water-level variations, either significant upland area must be dedicated as a beach, or the same amount of land or more sand must be retrieved from the bottom.

Hardened surfaces are more compact than beaches and are usually a constructed type of shore parallel structure. They are commonly placed somewhere between the high-water limit and the breaker line, and they effectively block any further contact between water and land. Types of these structures range from simple rock rip-rap revetment placed against a slope, to a rock-armored dike built at or near the water edge, to vertical walls of driven sheeting, to crib structures with an interior fill with ballast material to provide weight to resist forces. Figure 1 shows a typical shoreline rip-rap revetment.

All of these systems work in a brute force way to resist the erosive pressures of waves. They do little or nothing to actually change the wave environment. However, some shore parallel structures do trigger wave reflections (the return of part or all of the wave back toward its original direction), which may make the wave climate in front of the wall rougher. The structures can redirect wave energy to adjacent or opposing shorelines. Because shore parallel structures prevent some exchange or movement of sand in a local area, depending on the positioning of the wall, the beach in front of that structure may actually be narrower. That is a result of greater reflection of the wave off the structure. There may also be additional starvation of the beach downdrift of the structure. This behavior is not unique to just human-made structures. Some natural, near-vertical bluff faces also reflect wave energy. Placing wave-absorbing materials in front of these steep bluffs can help reduce shoreline problems caused by wave reflection.

Shore Perpendicular Structures

Any structure built across the beach perpendicular to the shore will block sand movement to some degree—a consequence that may or may not be intentional. Groins or jetties are common shore perpendicular structures, but there are also other forms, such as timber crib piers. The terms groin and jetty are often used interchangeably, but correctly applied, a groin is a structure that extends out across the beach but does not extend past the normal limit of wave breaking, leaving some sand free to leak around the end. Groins are usually used to retain a

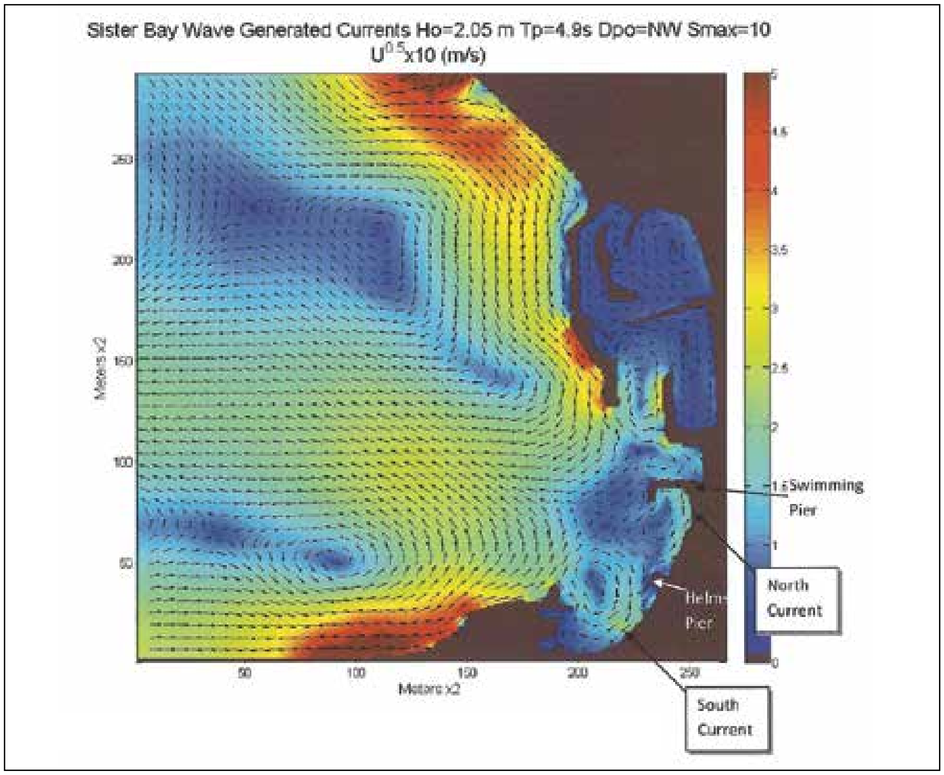

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Figure 3: A numerical model showing current patterns near a marina and shoreline

minimum width of beach in a certain area. In contrast, a jetty extends well past the limit of wave breaking so virtually no sand can leak past. It is more often used as a navigational aid, directing the discharge of water from a river mouth or outfall, or defining a port or harbor entrance. The shore-connected arm of a breakwater is a form of a jetty.

In all cases, shore perpendicular structures trap sand on the side of dominant wave action. In this area, the shoreline may even grow out into the lake as sand accumulates. However, immediately to the downdrift side, the beach is starved of sand, so the shoreline retreats. (See the groin in Figure 2 for an illustration of this process.) Note that in many cases, wave action can move in either direction, depending on wind direction. It is common to find some sand piled up against both sides of the shore perpendicular structure, but typically, one side will still extend farther out into the lake.

Offshore Structures

The third type of shore protection structure is built offshore or occurs naturally as an island. Rather than just absorbing the brunt force of the wave attack or blocking the sediment that moves along shore, this method works by creating a shadow of itself on the shoreline. Waves are greatly reduced in the shadow, which reduces the driving push to move sand or the erosional forces of the sand. An offshore or detached breakwater is a common type of offshore structure. Figure 2 shows two offshore breakwaters with a short groin between them and the accompanying sand build-up behind the breakwaters and alongside the groin. These offshore structures can be used to improve navigational safety, to cause a beach to grow locally without touching the shore, or to reduce the wave energy level at the shore for environmental or recreational benefit. They can also be sized and positioned to allow sand to continue to migrate, or to agitate and induce water circulation for improved and refreshed environmental quality.

Submerged reefs and floating wave attenuators are invisible versions of offshore structures. Such systems do not fully block the waves but can lessen the impacts. Their successful application is site-specific and should not be presumed suitable or appropriate without taking the wave environment and the limitations inherent to their use into consideration. In general, offshore breakwaters offer the greatest versatility, but they are typically more expensive to build and implement and require much more length than just the area to be protected, perhaps 50 to 100 percent more.

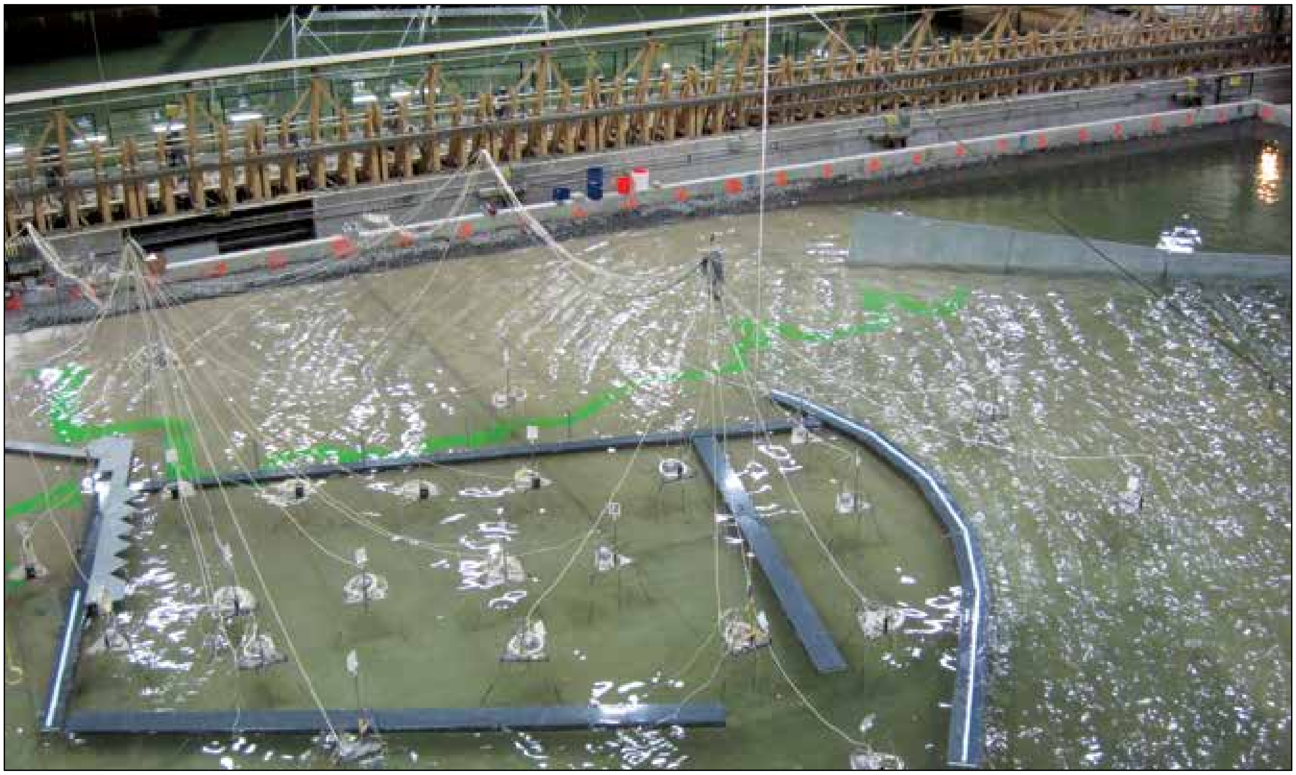

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Figure 4: A physical model of a marina design with floating breakwaters

Coastal Structure and Shoreline Monitoring and Modeling

Coastal engineers often use both site monitoring and modeling as tools to design a coastal structure. The tools estimate both the effectiveness of the structure and any adverse coastal processes it may cause. Monitoring typically includes gathering site condition information before any work is done as well as monitoring conditions after the structure is built. Monitoring could include sediment sampling; bluff, beach surveying and nearshore bathymetry measurements; and wave and/or current measurements. All of these can assist the coastal engineer in designing the appropriate structure and monitoring its effectiveness.

Sometimes numerical and/or physical modeling is part of the design of a coastal structure. Numerical models use computer programs that allow the coastal engineer to "test" many different structure sizes, shapes, configurations, etc., along with a wide range of waves and currents. The models can also indicate sediment movements to predict how a selected structure may affect the natural coastal sediment movement. Figure 3 shows the results of a numerical model simulation of a potential marina entrance design. Numerical models are a convenient and relatively inexpensive way to examine many conditions. However, these models only approximate what may be occurring and should not be considered absolute answers.

To arrive at more accurate and detailed answers, physical models are also sometimes employed by building and testing a scaled version of potential designs in a wave tank where the marine environment is reproduced. This allows engineers to modify structure designs and examine questions not easily answered in the numerical model. Although the cost to do a physical model is often at least three times that of a numerical model, a combination of both types of testing is usually performed to find the best solutions. Figure 4 shows a physical model of a harbor designed with floating outer breakwaters for wave protection.

Conclusions

Every Great Lakes coastal site has unique features and potential interactions with waves, currents and sediment movement. Therefore, any Great Lakes coastal or offshore structure design requires the services of a professional coastal engineer with significant experience in Great Lakes coastal processes and structure design. Often, the design will include modeling and monitoring as part of the process.


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For Additional Information

- *Living on the Coast, Protecting Investments in Shore Property on the Great Lakes*, University of Wisconsin Sea Grant Institute and the U. S. Army Corps of Engineers, 2003.
- *Stabilizing Coastal Slopes on the Great Lakes*, University of Wisconsin Sea Grant Institute fact sheet, WISCU-G-05-003.
- *Working with Engineers and Contractors on Shore Protection Projects*, University of Wisconsin Sea Grant Institute fact sheet, WISCU-G-05-002.

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