

OPTIMIZATION OF BREAKWATER SYSTEM USING A 3D PHYSICAL MODEL

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INTRODUCTION

Illinois Beach State Park is the only stretch of undeveloped Lake Michigan shoreline in the State of Illinois. The park is approximately six miles long and contains unique habitat features including a well-formed beach-ridge plain coastal landform and freshwater wetlands called pannes. The shoreline was eroding at an alarming rate through the highwater cycle of Lake Michigan in 2019 and 2020, threatening to destroy these distinct ecological features. Given the nature of the site, the Illinois Department of Natural Resources sought to find solutions to the erosion that were non-intrusive to the shoreline and attempted to preserve the aesthetics of the park, intentionally deviating from more traditional approaches to erosion control such as revetments and seawalls.

The client wanted to emphasize a design approach that favored "Working with Nature" and implementing "Living Breakwater design aspects" (Baker et al, 2018). For this reason, the design team employed creatively shaped and formulated breakwater island and submerged reef structures. Additionally, the intent of the plan was to force a new, stable shoreline alignment that was relatively straight and void of salient and tombolo growth. The breakwater dimensions and alignments had to avoid a copy and repeat approach. An example of this previously common approach can be seen at Presque Isle State Park, Lake Erie, Pennsylvania. Instead, the offshore breakwaters were carefully sculpted and positioned to maximize tip diffraction from the structures to achieve a straight beach form. The design also needed to throttle down the magnitude of the transport rate to limit the long-term rate of retreat of the shoreline.

MODELING APPROACH

The first attempt at a design solution was completed numerically. The site's wave climate was analyzed, and the results used to orient and size breakwaters to maximize shoreline protection and balance the various design criteria. However, the design team recognized that this numerical approach would be insufficient to assess the complex diffraction and wave transformation caused by the structures and their effect on the shoreline morphology. Therefore, a 3-dimensional movable bed model was built at the HR Wallingford facilities in the UK. The physical model allowed the opportunity to experiment with different breakwater configurations and make quick adjustments based on the shoreline response.

Modeling proceeded in two phases: geometric arrangement and then design confirmation and stability tests. To first develop an optimal breakwater system

layout, sandbags and anthracite were used to allow for quick changes in breakwater geometry with a corresponding rapid shoreline reaction to any change in configuration. The anthracite is more mobile than sand at this modeling scale and would quickly develop a stable shoreline. After a few runs under a design wave, one could also observe where diffraction around the breakwaters was causing a salient to develop.

These rapid observations allowed for multiple improvements to be vetted in a short time period. By simply changing the length, shape, orientation or freeboard, the corresponding shoreline planform could be straightened or induced to accrete, in some cases locally reversing currents were formed to further slow sediment transport. Additionally, breakwaters were made submerged, emergent, or a combination of both to allow more or less wave energy to pass through the structure. As a result, the shoreline profile changed.



Figure 2 - Two breakwater orientations yielding two different shoreline shapes.

DESIGN SOLUTION

Ultimately, the design team refined and optimized the initial numerical design to best achieve the client's aesthetic criteria and the need to achieve a cost-effective design. The shoreline protection solution devised for this coast was unique when compared to a traditional approach. While numerical modeling was used initially, 3D physical modeling yielded more useful observations that were used to minimize the breakwaters footprint, material costs, and utilize diffraction around the breakwater edges beneficially to develop the type of shoreline desired aesthetically from the client.

REFERENCES

Scott Baker, Pippa Brashear, Paul Tschirky, Joseph Marrone, and Max Lardson, (2018), "Design and Physical Model Studies of Innovative Living Breakwaters", Coastal Engineering