LIVING BREAKWATERS: DESIGNING FOR RESILIENCY

Paul Tschirky, Geosyntec Consultants, ptschirky@geosyntec.com
Pippa Brashear, SCAPE Landscape Architecture DPC, pippa@scapestudio.com
Ido Sella, SeArc Ecological Marine Consulting, ido@searc-consulting.com
Todd Manson, COWI, tpma@cowi.com

BACKGROUND

In the aftermath of Hurricane Sandy, the Rebuild by Design competition was born to encourage cross-disciplinary collaboration and resilience planning in coastal and flood protection design. The Living Breakwaters project is a layered resilience approach to promote risk reduction, enhance ecosystems, and foster social resilience. Following the competition, the project was awarded $60 million by HUD (US Department of Housing and Urban Development) in June 2013. It is currently in final design and permitting with construction anticipated to begin the summer of 2019.

The Living Breakwaters Project is a unique design of an offshore breakwater system to promote coastal resilience in Tottenville, Staten Island, New York (Figure 1). It combines physical risk reduction through wave attenuation and erosion prevention functions with ecological enhancement and habitat creation as an integrated part of the design. This paper explores the modeling and design of these unique coastal engineering and ecological structures.

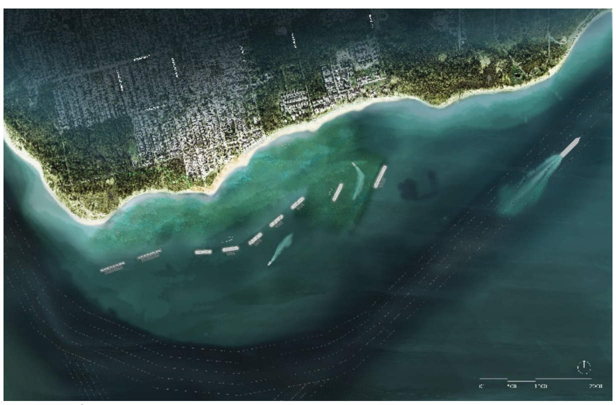

Figure 1 – Living Breakwaters Layout

THE LIVING BREAKWATERS

The Living Breakwaters system is comprised of 9 breakwaters totaling 3,200 linear feet and over 3,000 linear feet of reef ridges. The reef ridges extend perpendicular from the breakwater trunk on the offshore side of the breakwaters. Gaps between these ridges, “reef streets”, mimic natural systems creating diverse and complex reef habitats (Figure 2). There are 3 types of breakwaters including low crested breakwaters with crenelated crests, a field of tighter spaced breakwaters to protect the most critical infrastructure and two larger breakwaters in deeper water to provide protection from the dominant wave direction while allowing sediment transport into the system. Water depths range from 6 to 12 feet and crest elevations from 5 to 14 feet. The reef streets, various ecological treatments targeted toward fish and oysters, and control areas are being incorporated in the breakwaters to test and evaluate their effectiveness.

ECOLOGICAL FEATURES

In addition to the reef ridge and reef street features themselves, some of the armor stone units throughout the breakwaters will be replaced with bio-enhancing concrete armor units and tidepools (Figure 3). These units will maintain the structural stability of breakwaters acting as replacements to the armor stone, while enhancing the ability to recruit marine organisms and promote diverse and vibrant aquatic ecosystems. These will include, ECOncrete® concrete armor units, cubed-shaped armor units with chamfered edges and faces specifically contoured (textured) to create complex surfaces that attract biological organisms and allow them to settle and stay on the units. Oyster disks and spat can be installed after construction. ECOncrete® tide pool units are designed to mimic the form of natural rock pools. They are basin-shaped and capable of holding water between tides. These units will be placed within the intertidal zone of the breakwater to provide additional habitat and will be flushed with the tidal fluctuations.

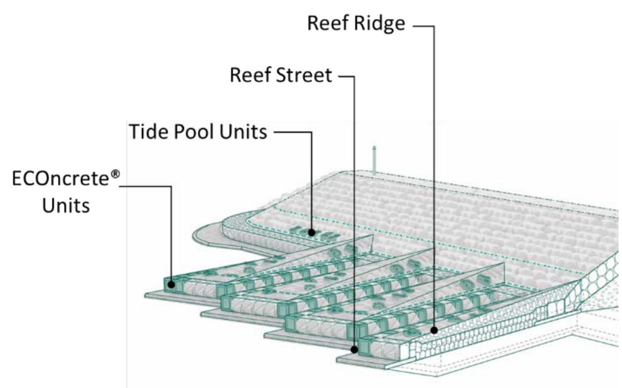

Figure 2 – Living Breakwater Section with Reef Streets

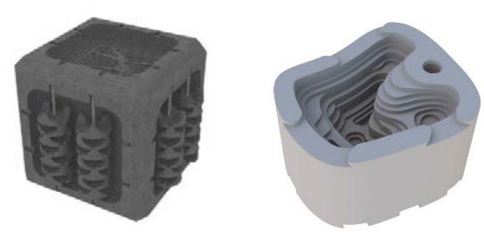

Figure 3 – ECOncrete® Armor Units and Tide Pools

MODELING AND DESIGN INTEGRATION

Design of the breakwaters required consideration of the physical performance to attenuate waves and reduce erosion under rising sea levels and the threats posed by coastal storms. It also required understanding of the ecological elements and their performance under the hydraulic conditions to which they are exposed.

Multiple numerical models were used throughout the design process. Early modeling focused on relatively rapid assessment of concept layouts, impacts on waves and shoreline change. Long term wave climate hindcasts were developed at the site and shoreline change assessed using 1-D models. More than 15 alternative layout configurations were modeled. The shoreline change modeling informed the placement and spacing of the breakwaters.

Risk reduction through wave attenuation is another key goal of the project. Numerical model simulations (Figure 4) were performed to evaluate the impacts of varying crest elevations and a fully nonlinear Boussinesq wave model was applied to evaluate the wave attenuation performance and impacts of waves acting on the shoreline. The preferred alternatives were further evaluated with more detailed hydrodynamic and sediment transport modeling to assess the potential impacts of the project on water quality and dredging in the nearby navigation channel.

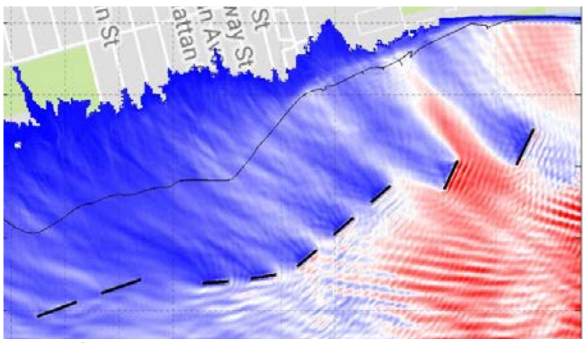
Figure 4 – Wave Attenuation Modeling

Detailed modeling of the flows and potential sediment movement around the breakwater and reef streets was performed using a 3-D computational fluid dynamics (CFD) model (Figures 5 and 6). These model results were used to aid the ecological design of the reef streets by examining variations in the length, spacing, orientation and position of the reef ridges. The model was used to assess the predicted mobilization of sediment within the reef streets and around the breakwaters.

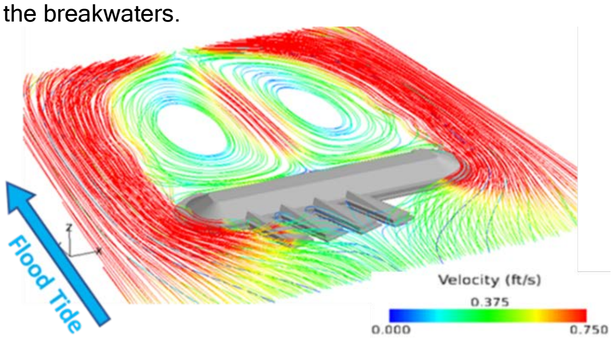

Figure 5 – Flow Modeling Around Breakwater

The flow and sediment patterns immediately around the Living Breakwaters are important to the ecological design and performance with the objectives of minimizing sedimentation within reef streets; minimizing local scour along the reef ridges; reducing inequities between flood and ebb currents and performance between reef streets; and allowing adequate flushing of streets and ridges for nutrients.

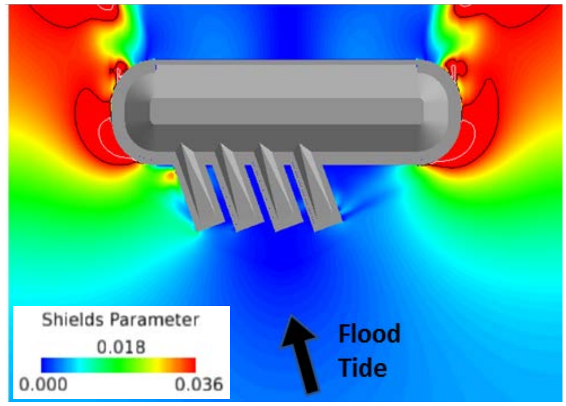

Figure 6 – Sediment Transport Potential Around Breakwater

In addition to numerical modeling, a series of physical model tests were performed to assess stability of the breakwater design and confirm the overall wave attenuation performance of the Living Breakwater system under varying wave and water level conditions. Some of the key concerns addressed in the physical model were evaluation of the stone sizing and gradation for the breakwater and reef ridges (within the ridges smaller stones were used for the armor layer to promote diversity in habitat spaces), testing of crenelated crests, and experimenting with the bio-enhancing armor unit and tide pool placement locations. Both 2-D and 3-D features and sections models were used to assess stability and breakwater section design. A 3-D layout model was used to verify the overall performance of the entire project comprised of the system of multiple living breakwaters.


Figure 7 – Physical Modeling Testing of Breakwater Section

SUMMARY

Modeling aided the design at many levels from the use of simple models to quickly screen initial alternative layouts to detailed 3-D models to assess complex details. Various numerical and physical model simulations were integrated with the design process resulting in an effective approach to achieving the overall project goals to reduce shoreline erosion trends, maintain the shoreline, reduce wave energy in front of residential areas, and benefit the local marine ecology. The project from its inception embraced the planning, engineering, ecological, and social elements required for resilient design with landscape architects, engineers, and ecologists working collaboratively.