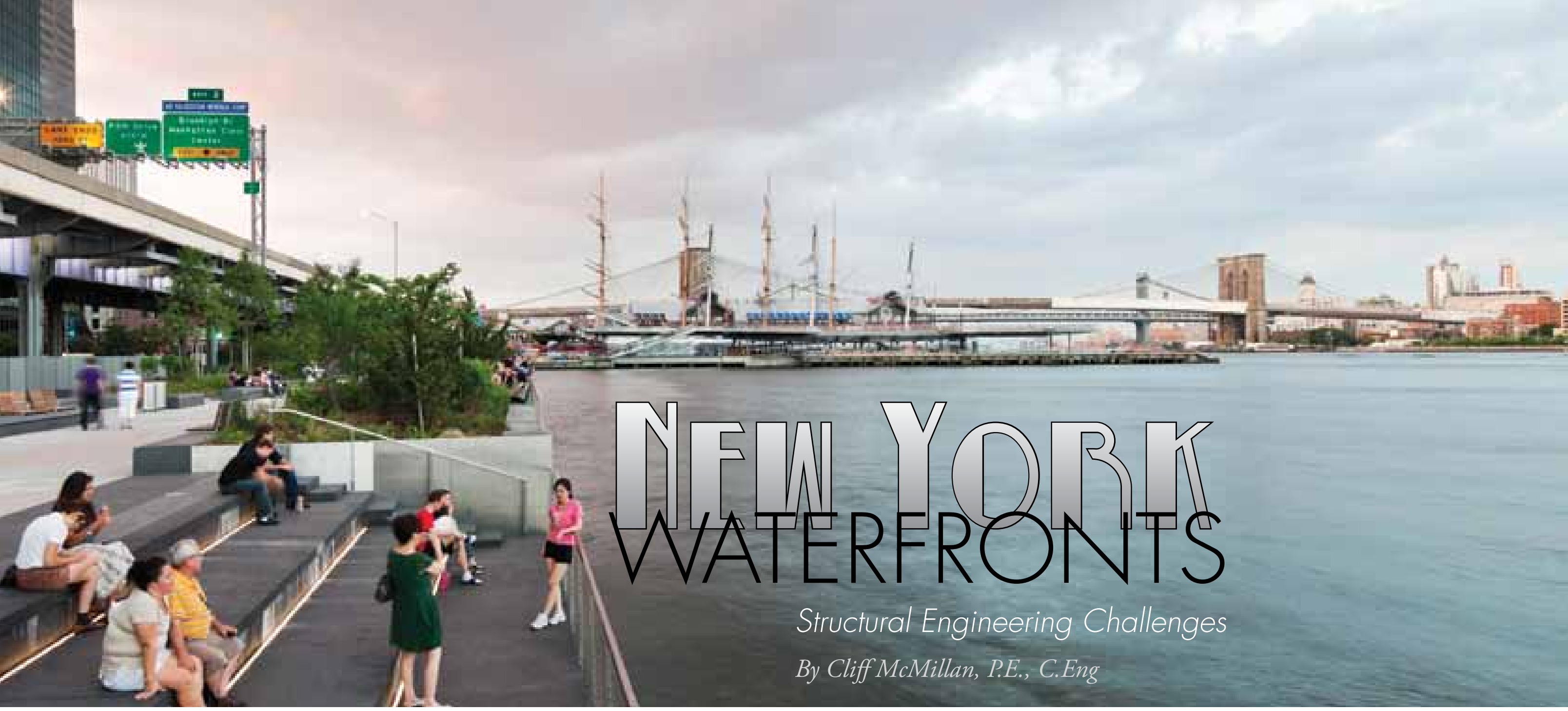

New York Waterfronts

Structural Engineering Challenges

By Cliff McMillan, P.E., C.Eng

A look at the completed waterfront project.

With 500 miles of shoreline, New York's waterfront is the largest of any city in the world. After decades of neglect, the waterfront has again become a place of intense interest for government and civic organizations. With the 1992 *New York City Comprehensive Waterfront Plan* and 2001's *Vision 2020: New York City Comprehensive Waterfront Plan*, the city government took stock of the needs and opportunities of the waterfront and laid out plans to transform it for the benefit of all New Yorkers.

Arup has been involved in this process for over a decade, with six discrete waterfront projects covering almost nine miles in total, including Hudson River Park, the East River Waterfront, Teardrop Park, Pier A in Manhattan, and Hunter's Point in Queens.

Structural engineering plays a vital role in waterfront projects in supporting clients and design teams to achieve durable and cost-effective results. Construction efficiency, longevity and cost-effectiveness all rely upon intelligent structural solutions that take into account a project's full lifecycle. Structural elements such as piers and seawalls often consume a large proportion of a project's initial budget, and repairs and maintenance can lead to significant costs down the road.

Figure 1: Hybrid steel concrete pile. The design adopted a hybrid steel and concrete pile to manage the poor soils above the rock. Courtesy of Hudson River Park Trust.

For these reasons, close attention is paid to structural design on all waterfront work, with particular challenges arising in relation to longevity, pier design, materials selection, and flooding.

Longevity

The harsh marine environment of Manhattan's waterfronts – with their damp, salty atmosphere, intense solar exposure, constant cycles of wetting and drying due to splashing and tide range, and damage caused by skateboarders and vandals – can lead to the untimely deterioration of even the hardiest materials.

These factors are considered at a particular site to develop a design that avoids the need for maintenance as much as possible. In targeting a 50-year lifespan or more for all park structures and permanent exterior elements, sustainable, durable materials matched to the particular demands of their setting are all considered.

Pier Design

Meeting the goal of a 50-year lifespan represents a particular challenge for pier design due to the forces they have to resist and the extent of their exposure to corrosive elements.

Piers have to be designed for a wide range of structural loads, including 1) self-weight, 2) dead loads due to the make-up to achieve surface treatments and soil for planting and trees, 3) live loads arising from the planned activities on the pier, and 4) lateral loads from wind, seismic effects, currents, ice and possible vessel mooring forces and impacts. All these have to be considered in relation to the particular circumstances and to provide flexibility for possible future changes – for instance, the type of vessels likely to be moored in the future, or the depth of soil needed to accommodate possible tree layouts.

Geological conditions along New York's shoreline and rivers can be variable over short distances and are often unfavorable for foundations, thereby presenting major challenges. New York City river silts, sands and clays vary greatly in composition and depth. At some points around Manhattan, rock begins at riverbed level; at others, such as several of the Hudson River Park piers, piles had to be driven to over 300 feet below the surface. Seismic considerations then become a significant factor. Providing sufficient lateral support to the piles, and the depth of water and poor material below the pier deck before such lateral support is achieved, can become a dominant factor in the design.

At Hudson River Park, the very long piles founded on rock at up to 350 feet deep and the poor soils above the rock, presented a particular challenge. The design adopted used a hybrid steel and concrete pile. For the upper approximately 70 feet – through the water and weakest soils – pile stiffness, bending strength and corrosion resistance are most critical. A high quality 24-inch-square precast, prestressed concrete pile section was used. Cast in a controlled environment and tensioned to minimize cracks provides high strength and durability. Below that, corrosion and bending resistance are not a critical issue, and the loads in the pile are primarily axial. There, a steel HP section, up to more than 200 feet long, transfers the load to the rock. The connections between the concrete and the steel section, and between successive steel sections, were designed to ensure simple construction in the field (*Figure 1*). This hybrid pile was less expensive than an all-concrete pile; by minimizing the concrete, its weight was reduced substantially, which was beneficial during the lifting and splicing process, and costs were saved. It was felt that the high-quality concrete section in the vulnerable upper zone provided better corrosion resistance and durability than corrosion-protected structural steel.

To provide further protection, the concrete specification was designed to prevent reinforcement corrosion, usually caused by chloride ion inward migration. A concrete blend suited to preventing this phenomenon was selected, and epoxy-coated rebar was used for all reinforced concrete structures, as epoxy stops moisture and chlorides from corroding the steel.

Another issue with pier design is the form of superstructure construction and how to accommodate the form needed by the landscape design, program design and also the often extensive utilities and services required on the pier – water, electricity, gas, fire and waste disposal. Because of the constraints of over-water construction, the most cost-effective structure usually employs a rectangular pile grid and a flat or uniformly sloping deck. This facilitates the use of precast concrete pile caps and longitudinal beams with precast concrete slabs spanning between the pile caps. The build-up above the pier deck to create the surface shaping, necessary for the landscape design program and to accommodate services and utilities, can then be achieved in a number of ways. To reduce dead loads, styrene foam and lightweight fill were used on the Hudson River Park pier to create the shaping. The services were accommodated within the void above the structural deck (*Figure 2*).

Figure 2: Plate at the bottom of the concrete which connects to the steel section. The connections use a simple detail to facilitate construction in the field. Courtesy of Hudson River Park Trust.

Figure 3: The installation of new concrete pile caps over the new precast concrete piles. Pile caps are elevated to avoid contact with river water. Courtesy of Hudson River Park Trust.

To drain the space above the deck, and avoid saturation and damage to plants and utilities when the tide rises, non-return valves were provided at the underside of the structure to allow any water to drain out when the tide is low but to prevent inflow when the tide is high.

On Pier 15 at East River Waterfront, a utility trench runs the length of the pier within the structure to accommodate the utilities that serve the buildings out on the pier and provide maintenance access. For this two-level pier, the structural columns supporting the upper deck are located to coincide with the piles below.

These designs minimize interaction between the structure and the harsh water environment to the fullest extent possible. Pile caps, for example, are elevated so as to typically avoid contact with river water (*Figure 3*).

Often new piers are built over or among the remains of the timber piles from previous piers. This means careful mapping of the old piles to minimize conflicts when the new piles are driven. Some of the old piles can be retained to provide a visual connection to the history of the park, as well as a habitat for fish, wildfowl, and other marine life.

Sometimes new over-water esplanade areas are constructed on existing but deteriorated platforms. This requires careful study of the existing conditions, and the load capacity and state of deterioration of the existing piles and structure. Often strengthening of the existing structures becomes necessary.

Materials Selection

A key objective throughout the design was to ensure low maintenance and operational costs, partly through the choice of sustainable, durable materials. Common structural and non-structural elements that require consideration are: railings, paving, lighting, benches and other outside furniture.

For instance, for the extensive length of railing on the Hudson River Park pier, Grade 317 stainless steel was selected to improve corrosion resistance. Even with this material, a coating of Adsil, a commercial coating product, proved necessary to minimize "tea-staining" in the harsh, salty environment. FieldTurf grass, a synthetic grass that is designed to mimic real grass, was selected to provide a maintenance-free surface for sports fields and picnic areas on piers. For timber rails and benches, selected tropical hardwood Ipe, farmed from forests

Figure 5: East River Pier 15 deck had to be raised to the flood elevation to accommodate the small pavilions below the code requirement of the FEMA flood elevation. Courtesy of Arup.

certified to meet sustainability requirements, were specified. For the esplanade, granite and blue stone paving were selected.

Where structural steel is used for marine structures, such as pier piles or floating structures, several methods of corrosion prevention were considered. Some piles were coated with glass flake epoxy. Others were covered in fiberglass jackets and epoxy. Cathodic protection has been used for protection on projects, but this has limitations in the splash zone, and is considered by some clients to be a maintenance burden because of the need for an electric current (*Figure 4*).

Flooding Resilience

An important factor in the design of the piers and esplanades is the flood elevation under the 100-year Federal Emergency Management Agency (FEMA) extreme flood conditions. This would involve overtopping of existing piers and esplanades around Manhattan, sometimes to the extent of 3 feet. The typical finished esplanade elevation is fixed in relation to the historic bulkhead elevations, as well as the finished grades utilized in the reconstruction of the roads such as Route 9A which runs along the Hudson River waterfront. As a result, the esplanade elevation at Hudson River Park and East River Waterfront is set generally around three feet below the FEMA 100-year flood level. By this approach, buildings on the esplanade or piers would generally be subject to occasional flooding in extreme circumstances.

Figure 4: Corrosion of steel piles in intertidal splash zone, without protection. (Instead of showing cathodic protection, this photo shows what happens when the pile is not protected.) Courtesy of Hudson River Park Trust.

This means that the park buildings would either have to be raised to meet the code stipulated FEMA requirement, or be designed to withstand flooding and be "drip dry" after flooding. All electrical and mechanical equipment and critical services are elevated to above the 100-year flood level.

For the East River Waterfront, it became necessary to obtain a variance through the Board of Standards and Appeals in order to build small pavilions below the code requirement of the FEMA flood elevation. This variation was granted specifically for the unusual headroom constraints under the existing Franklin Delano Roosevelt Drive. The elevation of the East River Pier 15 deck had to be raised to the flood elevation to accommodate the small buildings (*Figure 5*).

Creating a Legacy for New York City

Until the 90s the city of New York turned its back on its waterfront. Hudson River Park, East River Waterfront, and other recent developments mark a dramatic shift in attitude towards the water and waterfront amenity. Mayor Michael Bloomberg and his administration's strong commitment to the issue, along with public demand for waterfront access, and the extent of the shoreline, present countless opportunities for the city.

While the 500 miles of New York City waterfront pose a tremendous opportunity, they also create a tremendous design challenge. The waterfront is not an infinite resource; it is often narrow and fragmented and is subject to competing interests such as marine habitat preservation, public demand for amenity, and commercial demand for prime locations. They also present a range of engineering challenges, including dealing with an aggressive, salt-laden physical environment that makes material selection critical for providing durability, resisting aging and deterioration, and satisfying regulatory and permitting requirements. The waterfronts referred to above have responded to these special challenges with unique solutions that demonstrate success in improving quality of life and also in expanding our expectations of what waterfront spaces can become.▪

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