RECLAIMING the Waterfront

By Michelle Black, P.E., C.E., Chris Adams, P.E., and Shane McCormick, P.E., S.E.

Pier cantilevering over the Columbia River. Courtesy of the City of Vancouver.

The City of Vancouver, Washington, has a new development along the Columbia River with the Grant Street Pier as its centerpiece. The site, formerly home to a local paper mill, is now home to hotels, restaurants, and a boardwalk. As the focal point for this up-and-coming area known as "The Waterfront," the pier has an iconic form that is sure to attract visitors. The pier's triangular, post-tensioned concrete deck overhangs the water by 90 feet and provides an expansive view of the river. A cable system and 80-foot-tall mast support the deck. Though the structure itself is unique, the reasons behind the form and shape are just as impressive. Developed by an artist and designed to meet environmental concerns, this is not a typical pier.

Master Plan

The master plan for The Waterfront included a gathering area for sightseeing and special events. The City of Vancouver originally planned a platform extending over the Columbia River supported directly on permanent piling. After initial plans were developed, it was discovered that using permanent structures in the river negatively impacted native fish migration. The city needed to create a platform without permanent piling in the river and a structure that was airy enough to allow sufficient light to reach the river to ensure fish migration was not affected.

The city decided to produce a signature structure without permanent piling and respective of the fish migration issue. They contacted Larry Kirkland, international public artist, to design the piece. Kirkland's design included a thin, cable-supported platform. The cables were supported by a structural element resembling a ship's mast, paying homage to the sailing vessels that navigated the Columbia River in earlier eras. Kirkland also created an A-shaped platform that would permit enough light into the river and inherently generate pedestrian circulation. Kirkland also specified white surfaces on the piece, further contributing to its signature design. With this new concept, every design feature, including cable and mast connections, required elegant and creative structural detailing.

Design Concerns

The structure's durability was a primary concern as it would cantilever over the Columbia River. The design team investigated structural steel and post-tensioned concrete deck options, weighing the pros and cons of each system. The structural steel option incorporated a high-performance paint system capable of providing the required durability. The benefits of this system were a lightweight structure with ease of construction; however, maintaining the painted surface over the river was a concern due to regulations and cost. The post-tensioned concrete option inherently gets its durability from a properly designed concrete mix. The benefit of this system is the significantly reduced maintenance cost. Challenges included a heavier structure, an expensive white concrete mixture consisting of white cement and white aggregate, and a complex construction sequence. The city studied these options and chose a post-tensioned concrete deck system because maintaining a painted steel system over the river was too expensive.

The proposed concrete design utilized a bonded, multi-strand post-tensioned system, further addressing durability. Post-tensioning tendons would run inside plastic corrugated ducts cast into the concrete structure. Once the tendons were stressed, the spaces between the tendons and corrugated plastic ducts would be filled with flowable grout to add an additional level of corrosion protection for the tendons. *Figure 1* shows the typical deck section with three post-tensioned beams and hollow areas between. Voids would be placed between the beams, both to rid the structure of unnecessary weight and to provide an area for vibration mitigation equipment to be housed.

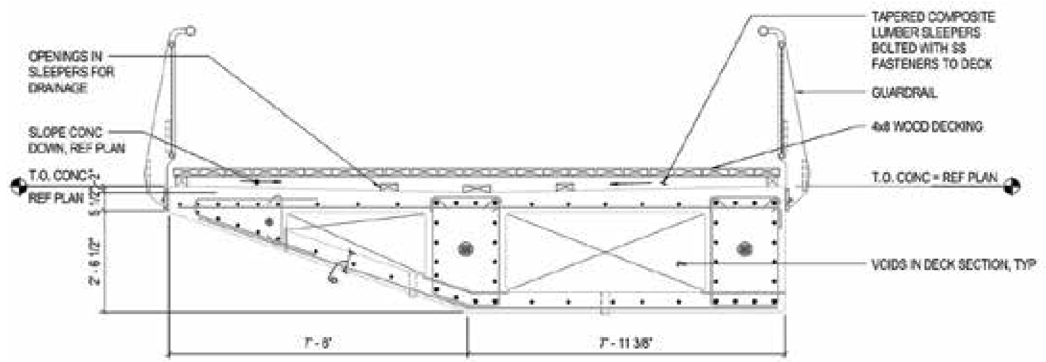

Figure 1. Typical deck section.

Analyses

Once the structural system had been selected, the design team requested a wind report to understand the structure's performance during varying wind speed events. Structural modal information and cable tension values were sent to RWDI Consulting Engineers and Scientists (RWDI) for dynamic analysis. They found the structure to be globally stable and not excitable over a wide variety of wind speeds. RWDI also reported that the cables had sufficient sustained tension load to resist wind excitation and would not require additional dampers to help reduce fatigue loading on their associated connections. Globally, the final structure was designed for an ultimate wind speed of 145 miles per hour with an Exposure Category D.

Adjacent to the west coast, the site is prone to severe seismic events. Mapped spectral response accelerations S_S and S_1 of 94%g and 41%g, respectively, resulted in Seismic Design Category D classification. Because the A-shaped deck inherently had a significant amount of lateral load resisting capability, the design team decided to design the structure elastically using a seismic response modification factor equal to one. This resulted in a base shear equal to nearly 600 kips, and the structure was found to be able to resist this load magnitude without the need for special structural detailing. Shoreside, the soil is prone to liquefaction and lateral spreading during a seismic event. The bulkhead walls separating the shore and Columbia River, designed by BergerABAM, Inc., were designed for additional lateral loading to resist these phenomena. See STRUCTURE magazine's December 2017 issue for a discussion of the pier's foundation system.

Other unique design loadings included flood loading and impact loading from a passing ship. The final concrete deck elevation was below the 500-year flood event, so the deck structure was designed for a 50 psf lateral stream load on each surface expected to be submerged. While unlikely, the deck structure was also designed for impact load from a small passing vessel.

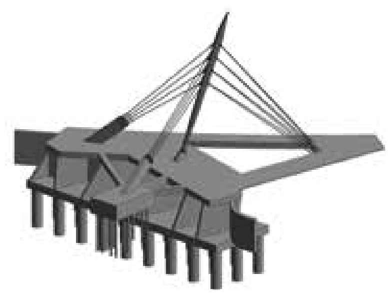

Figure 2. Superstructure and foundations.

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Figure 3. Pier with construction substantially complete. Courtesy of the City of Vancouver.

Figure 4. Cable backstay abutment. Courtesy of the City of Vancouver.

Since the pier is intended for special events such as weddings, a substantial finite element vibrational analysis was performed to understand how the structure reacts to a variety of dynamic loading scenarios. The structure's low fundamental frequency (1.2 Hz) combined with low damping made it prone to movements that may not be acceptable for human comfort. As a result, a pair of tuned-mass dampers were installed in voids in the concrete deck. With these dampers installed and tuned appropriately, the structure's response will meet standard industry acceleration guidelines over a variety of loading scenarios.

Another complex design feature was the sloping concrete on the top surface of the pier. Environmental concerns do not allow water falling on the pier surface to drain into the river; all water must be guided back to drains at the shore. To accommodate this, the pier slopes at one percent from the tip back to shore and has a slightly V-shaped top surface. Though this solved the drainage concern, it made the decking on top of the concrete surface more difficult to install. Composite lumber sleepers were tapered to fit the sloping top of concrete and provide a flat surface for the decking. This wood decking provides a finished walking surface on the top of the pier continuous with the connecting park boardwalks while providing visual contrast to the white concrete and the steel of the mast.

Mast Design

As the mast is the visual focal point of the structure, extra attention was paid to the appearance of the cable connections. Eight forestay cables, with four splaying to each side of the deck, meet at discrete locations along the mast. The 2½-inch-diameter, full-locked, galvanized cables are sized for stiffness to limit pier tip deflection. The cable end clevises are each attached to 2-inch-thick continuous fins protruding from the 24-inch-diameter, schedule 160 pipe mast. Given the cables are under tension, the unstiffened pipe was studied using a finite element model to understand how the prying forces distorted the pipe. The schedule 160 pipe thickness was chosen to withstand the applied forces.

To oppose the force in the eight forestay cables, two pairs of four backstay cables extend from the mast and are anchored at the shore. Each set of backstay cables meets at a common point at the shore, connecting to a large, built-up gusset plate assembly located approximately seven feet off the ground (*Figure 4*). This gusset plate assembly is anchored to a rectangular concrete abutment with ten 1¾-inch-diameter prestressed threaded rods extending below grade into an even larger pile cap. Each threaded rod was prestressed to counteract elastic deformation and to keep the concrete abutment in compression to reduce cracking.

Though the design of the structural elements was challenging, fitting individual elements together in a cohesive construction sequence was perhaps a more significant challenge. Piles were installed in the river to support the weight of the pier under construction, but the piles eventually needed to be removed. The design team developed the following sequence: 1) install temporary formwork and piles in the river, 2) pour and post-tension the concrete deck, 3) set the mast and cables in place, 4) tension the cables to values that caused the tip of the pier to lift off the formwork, and 5) remove the formwork and piles from beneath the pier. The cables were tensioned in stages, with the contractor adding tension to each of the 16 cables in a calculated manner. As the tensioning progressed, the tip of the pier slowly lifted off the formwork. Final cable tension values were within two percent of the design cable tensions.

Unique design criteria including environmental factors, proximity to the river, vibration concerns, and seismic site conditions challenged the design team. Aesthetics provided a second and welcomed set of challenges. Working with an artist focused attention on how to make the structure efficient, yet graceful. In the end, the blending of art and engineering makes a striking product. The Grant Street Pier now stands over the banks of the Columbia, waiting for visitors to come and see The Waterfront.▪

Temporary piles and formwork.

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Foundations EOR: BergerABAM, Inc.
Contractor: Rotschy, Inc.
Landscape Architect: PWL Partnership Landscape Architects, Inc.