Construction Driven Design
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The Design and Construction of the Governor Mario M. Cuomo Bridge

Key Points

- To minimize risk to safety, productivity and cost a key strategy was to minimize work within or over the river.
- Module construction - by using repeatable operations in controlled off-site environments, higher quality construction at lower costs can be achieved with scalable solutions.
- The use of standard, repeatable designs also allows for an efficient and a streamlined procurement process.
- The scalability and modularization philosophy of the design methods employed throughout the project were critical to achieve the aggressive project schedule.

Introduction

The Governor Mario M. Cuomo Bridge is a 3-mile long, twin bridge crossing of the Tappan Zee portion of the Hudson River north of New York City. With signature cable-stayed main spans and modularized approach structures, this $4 billion Design-Build project is the largest bridge project in New York's history. It required planning, design and construction on a macro-scale. This significant investment utilized a performance-based approach where practical and mandated a 100-year design life, structural health monitoring system, and a special design for robustness and resilience to manmade and natural threats. Integrating several innovative design and construction features on a large scale represents both the challenge and success of the new bridge. Virtually every aspect of the project – from the design to the construction techniques to the inspection and asset management – was intended to be repeatable and scalable. This Insight describes the challenges and solutions of the project given various constraints including an aggressive construction schedule.

Increasingly heavy traffic, along with exponentially rising maintenance costs and functionally obsolete features, were cause for a timely replacement of the 1950’s-era Tappan Zee Bridge. The Governor Mario M. Cuomo Bridge replaces the ailing structure with twin bridges, each over 3 miles long, crossing the Tappan Zee portion of the Hudson River. One of the few crossings of the river and the first north of New York City’s George Washington Bridge, the Governor Mario M. Cuomo Bridge is a critically important structure for both regional and interstate commerce. Delivered as a $4 billion design-build project, the new crossing features signature cable-stayed main spans, 1700 footlong approach units, multiple adjoining maintenance facilities and demolition of the existing bridge.

Project Overview

The Owner of the bridge is the New York State Thruway Authority (the Thruway), a governmental toll agency operating more than 850 miles of highway connecting New York City to the state capital in Albany, Buffalo and several neighboring states. The Design-Build team, Tappan Zee Constructors, LLC (TZC), includes a joint venture of contracting partners Fluor, American Bridge, Granite and Traylor Brothers. HDR, Buckland & Taylor, URS and GZA provide the principal engineering for the entire project in concert with TZC. Additionally, HNTB serves as the Owner’s Engineer assisting the Thruway and construction quality assurance is provided by GPI under the TZC contract.

Figure 1 – General view of the Rockland Approach of the Governor Mario M. Cuomo Bridge over the Hudson River, NY

Figure 2 - General view of the main span of the Governor Mario M. Cuomo Bridge over the Hudson River, NY

The obvious challenge facing the project is the sheer size of the Hudson River. Deriving its name from a local Native American tribe and the Dutch word for *sea*, the Tappan Zee section of the Hudson can display ocean-like conditions. Three feet swells are common. Tides are swift and vary by approximately 4 feet. Large ice flows and widespread freezing are also possible. Winter storms are common place.

The less obvious but no less significant challenge to overcome is a mix of geotechnical conditions not far below the river's surface. Most of the river is shallow but covered by a deep layer of poor-quality organic clay. The layer is so weak that steel pipe piles sink through this layer from their own self-weight. Beneath the clay exists better material including mixed silt and clay, lenses of sand, shattered rock, and glacial till in varying depths. The distance to reach bedrock varies from 50 feet to hundreds of feet. At most locations, bedrock is greater than 150 feet below the waterline. Where impractical depths exist, friction piling was required. See Figure 3.

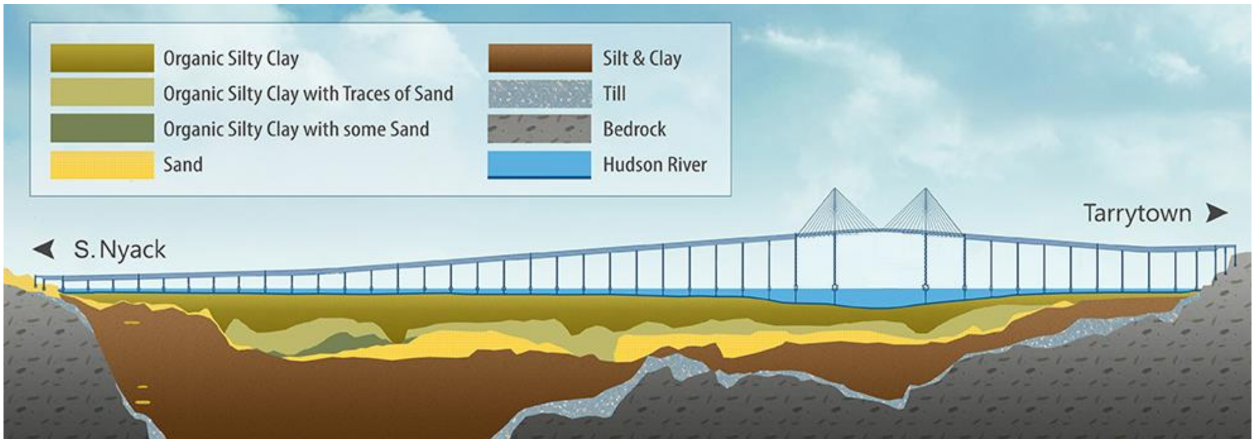

Figure 3 - Representation of geotechnical conditions along the bridge alignment

Meeting stringent project requirements adds to the design and construction challenges. These include managing work around endangered fish species, noise and emissions restrictions, extensive public outreach, monitoring the existing bridge for vibration, settlement and tilt, a 100-year service life requirement, and designing for seismic, ship impact and security threats. The final design features water, compressed air and fiber optic utilities; "turnaround" bridges connecting the two spans; state-of-the-art security, traffic management, structure health and asset management systems; and a 12-foot wide path for pedestrians and cyclists with multiple overlooks spaced across the bridge. The eastbound/southbound span is 87 feet wide while the westbound/northbound span is 96 feet wide. The foundations and substructure are designed for the weight of an addition of a future passenger rail.

The structural design is particularly influenced by several extreme loading requirements. Scour analysis and ice loading are incorporated into the foundations. The final design is based on 100-year scour predictions while estimates are made for 500 years. A site-specific seismic assessment considers both 1,000-year and 2,500-year return periods. The performance criteria requires minimal damage and an immediate return to service (following inspection) for the lower level event. The upper level criteria permits repairable damage with the expectation of allowing emergency or defense vehicles on the bridge within 48 hours and a full return to service within two months. The wind design is also site-specific and considers two levels of performance. Serviceability is required for 100-year return events and stability is guaranteed up to the 10,000-year return event. The structural responses, including satisfying acceleration criteria, are confirmed by analysis as well as wind tunnel testing. Classified as a critical structure, the bridge is additionally designed for site-specific vessel impact loads and all piers are designed for the code-specified drifting barge impact load. Lastly, the project requires a threat analysis to identify any other natural or manmade hazards and the incorporation of corresponding mitigation measures.

These considerations comprise a project not only of scale but of complexity as well. A primary goal of any successful strategy is that of minimizing work within or over the river. Such an approach minimizes risk to safety, productivity and cost. TZC proposed a cost-effective plate girder and substringer cross section which maximizes span lengths using the largest commonly available American steel (12 feet) for its webs. Typical spans are approximately 350 feet. The bridges each have 43 total piers, 41 of which are within the river. The cable-stayed main span uses a steel edge girder superstructure and concrete towers to provide over 1100 feet of horizontal and 137 feet of vertical clearance for ships.

While this configuration reduces the total number of foundations, it consequently concentrates large reactions. To combat this problem, horizontal loading is minimized by way of isolation bearings beneath the superstructure. The vertical reactions are taken by driven steel pipe piles, stiffened within the soft clay zone by concrete infill. End bearing is typically achieved within the glacial till while friction piles are nearly 400 feet long.

Minimizing work within the river also means driving fewer but larger piles and expediting the pile cap construction. Main span piles are 6 feet in diameter while typical approach piles are 4 feet in diameter. Nonetheless, the bridge and its provisions for future rail loading require nearly 1,000 piles total. The pile caps are built at water level using extensive precast concrete elements. The permanent and structurally integral precast units serve as forms, keeping out the river and allowing massive concrete infill pours in the dry.

The scale of the new bridge makes precast and modular construction important for other elements as well. There are two principle rationales. First, this strategy continues the approach of reducing the risks and cost associated with working at height, over water with limited land-based access. Second, by using repeatable operations in controlled off-site environments, higher quality construction at lower costs can be achieved with scalable solutions. A brief example, with more discussion later in this paper, includes the precasting of approximately 6,000 deck panels while using no more than 18 adjustable forming beds.

Many aspect of the new bridge is designed and constructed considering the need to scale solutions according to the range of challenges presented. The major need for this tactic lies in the lengthy approach structures rather than the main span. For this reason, much of the discussion herein focuses on the approach spans.

Project Organization

The scalability and modularization of the design methods are noteworthy, particularly in the case of the long approach structures. At first glance, the bridge is essentially a causeway style structure and appears repetitive. However, a multitude of unique conditions exist throughout making the scalability of the design critical.

A bridge “unit” is bounded by expansion joint locations, most typically 1750 feet apart. Within the unit, the same overall concepts and geometry are applied: a uniform deck design, plate girder superstructure, isolation bearings and concrete substructure. Each unit is designed essentially the same except that the designers can adjust for the unique conditions that may exist at any particular location. The effects of height, curvature and super-elevation, and appurtenances like overhead sign structures and the turnaround bridges are accounted for as discrete inputs. These are applied into a standard set of design tools at which point the designers can maximize material savings by adjusting variables such as number of reinforcing bars or flange size. However, the overall size, shape and resulting construction methods remain the same.

After the preliminary proofing of the design, material procurement can also begin for those elements that will be standard throughout. This includes items such as forms, some of the concrete reinforcement, piping for the piles and web plates. This efficiency allows for an expedited design and a streamlined procurement process. More discussion of these and the scalability of other elements is provided in the following sections.

Pile Foundations

As described earlier, the foundation design plays an outsized role within the project not just in terms of design complexity and cost but also with respect to safety and schedule risk. A preliminary pipe pile performance test had been conducted by the Owner and the results were provided to bidders for consideration. The final design utilizes 3-, 4- and 6- foot diameter pipe piles with capacities determined by the Design-Builder's own load testing.

Nearly all piles are fabricated from 1-inch thick steel. The piles are vibrated or allowed to sink through the organic clay and then driven the remainder of their length. Piles founded within the glacial till or bedrock require reinforced shoes. To achieve the required lengths, the majority of splicing is conducted at the point of fabrication and barges are used to bring the material to the project site, resulting in delivered typical lengths of about 140 feet and the need for one or two field welded splices.

For the most common situation on the bridge, 4-foot diameter piles are used, with the designer selecting from 10-, 11- or 12-pile layouts depending on the geotechnical capacity at the pier in question. After driving, the piles are excavated to a predetermined depth, cleaned out with a specially developed wire brush suspended by crane, and video inspected for damage, cleanliness and water infiltration in preparation of the concrete infill. The reinforcement cages are another standardized element, preassembled offsite, barged to the piers and dropped in by crane. At the main span, the cage design is scaled up, adding a third bar to the bundled primary steel.

Substructure

The twin bridges have a total of 60 precast pile caps. These "tubs" are built from four sets of forms at a fabricator with water access. The 9-foot difference between the widths of the Eastbound and Westbound caps are accommodated by dropping in or removing a section of tangent form. Block-outs for the piles are laid out according to the specified configuration. The general reinforcing steel patterns are identical however. A heavily reinforced bottom slab serves both as the soffit form and the bottom mat steel for the finished pile cap. Shear reinforcement is terminated with couplers at the precast facility and spliced together after being installed over the piles and dewatered. The tub walls are 4 feet-9 inches tall and 9 inches thick.

Cycling through each pile cap in as little as 5 days, the precast caps are brought to the site, four at a time, by barge. Set over the piles by crane, the tubs are hung from four piles temporarily. Pre-installed forms are pulled up the piles and snugged against the bottom of the pile cap in order to place concrete within the annular spaces. Once these develop strength, the tubs are dewatered and the permanent pile connections are completed. The infill reinforcement is installed immediately after finishing the pile reinforcement and concrete work. The

Figure 4 - Setting a precast pile cap "tub"

infill is comprised of additional bottom mat bars, shear dowels, a top mat and the starter steel for the columns. The roughly 650-cubic yard concrete pours require mass concrete thermal control. A combination of high slag content mix design, insulating blankets and cooling tubes pumping river water keep peak and differential temperatures within the allowable requirements.

While pile caps are being cast, another fabricator follows shortly behind in the production of precast pier caps. Like the pile caps, a single cross section is used with the length varied for the Eastbound and Westbound bridges. The pier caps are 13 feet deep and over 10 feet wide. The caps are erected on site with openings in the soffit to receive the column steel. Shims support the caps temporarily until a flowable grout can be placed to seal the interfaces and openings. Prestressing strands in both the walls and bottom slab as well as interior diaphragms provide the necessary support for the wet concrete during infill. A portion of shear reinforcement is contained in the walls and additional bars are doweled into couplers within the precast member.

Figure 5 - Jump form tower construction in progress

In this manner, the Design-Builder advances construction of both Eastbound and Westbound bridges across the river, bringing in large assemblies from offsite and quickly linking them together. As pile driving nears completion, crews are already setting pile caps and advancing from both shorelines simultaneously. Another set of crews responsible for the columns follow them. Lastly, several more crews follow, placing pier caps, completing the infill and pouring pedestals.

The columns are square and traditional in their design and construction. By maintaining consistent dimensions, a limited number of forms are necessary. The main span towers can additionally be considered to reflect the scalable and repeatable philosophy employed throughout the project. The height of the towers is 419 feet and they are 25 feet by 26 feet at their base. The towers taper but maintain their rectangular shape. All eight towers have symmetric design details with the exception of minor provisions for access. The schedule demands require concurrent construction but because of their uniformity a single, adjustable jump form design is possible. The tower construction and operation of the forms, lift by lift, is repetitive. Work crews are therefore interchangeable and the progress of each can be adjusted as necessary to compensate for any issues that may arise.

Superstructure

The steel plate girder and substringer arrangement is a very efficient cross section. The bridge features five girders and four substringers supported by the diaphragms. As already noted, the girder webs are selected based on the largest commonly available plate size in the US. The substringers are a widely available rolled section. Thus, the fabrication required is generally unremarkable and readily accomplished by a range of capable steel fabrication plants. However, the incredible size of the project necessitates not one but two large fabricators to work simultaneously in order to meet the aggressive schedule set by the Design-Builder.

The rapid erection schedule, an important factor in the selection of the winning bid, was made possible because of one of the world's largest cranes. This super crane, owned by TZC, was christened the *Left Coast Lifter* for its role in a major bridge construction project in the San Francisco Bay area. Standing 328 feet tall and with a lifting capacity of up to 1,900 tons, the crane enabled the design development of long approach span units. While expediting construction over the river, it also optimized safety and quality as the workers were able to assemble and perform quality control and quality assurance in the yard rather than over the river. Two- and three-girder assemblies measuring more than 425 feet in length can be lifted and set within the course of two hours. The steel assembly process perhaps best exemplifies the scalable and modular approach to constructing the new bridge.

Girder segments and other members are brought from the fabricators to an offsite location on the banks of the Hudson River. Here, an assembly line readies the steel for shipment to the bridge. The assembly is made possible by a series of sliding hydraulic jacks that are adjusted to achieve the required girder geometry. In the first stage of the assembly line, the girders are spliced and diaphragms are installed. The girders are then slid over toward the river where bolting continues along with installation of secondary members such as the catwalk and utility supports. Sliding further toward the river, painters set to work touching up the connections and electricians ready as much conduit and bridge-supported equipment as possible. The final slide extends onto piers within the river, allowing the completed assemblies to be staged on barges for transport downriver to the bridge.

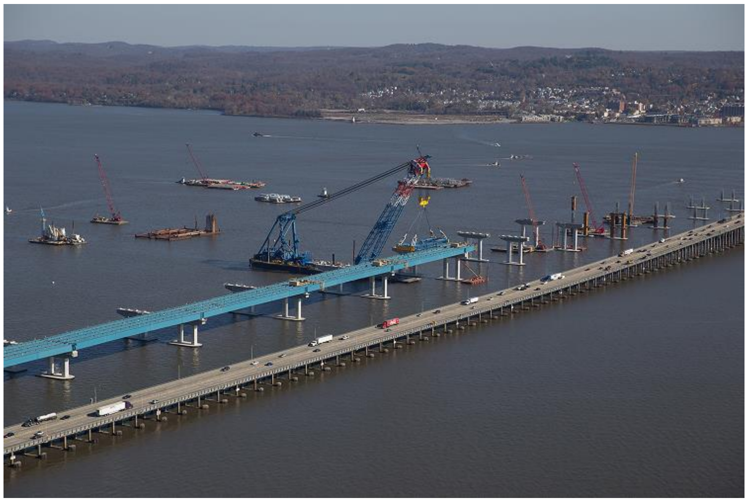

Figure 6 - Steel erection progresses with various stages of substructure seen advancing to the right and the old Tappan Zee bridge in the foreground

This process can be exceptionally efficient and minimizes the expense and risk of splicing high over the water. Multiple trades can work side-by-side without hampering each other's operations as opposed to a more linear approach that would have been necessary on site. Additionally, the sliding jack system is scalable to accommodate the smaller superstructure tie-in units. A few of these are stick-built but the pre-assembly still allows some advance splicing and the erection of otherwise larger than normal girders at the project.

Finally, the deck system for the main and approach spans feature precast decks with both longitudinal and transverse closure pours. One of the two precast facilities hired to produce the deck works nearly around the clock for close to two years in order to build up the inventory needed for the bridge. This fabricator is able to produce the roughly 6,000 approach deck panels with the use of just 18 adjustable casting beds. In curved sections of the bridge, the deck width is split into four panels while in tangent regions two long panels are specified. The casting beds are adjusted accordingly while also compensating for changes in super-elevation and the inclusion of drainage scuppers and utility openings.

The size of the panels, 12 feet by up to 44 feet, restricts trucking of panels to only one at a time from the precast facility. Therefore, the panels are brought to the nearby steel pre-assembly yard and stacked onto barges. The stacked panels can then be received at the bridge several dozen at a time for rapid installation. While an extra handling step is added, the on-site installation efficiency is much greater than would occur if trucks had to bring in panels individually. Also, this approach permits the installation of panels at multiple headings and in portions of the bridge lacking land-based access.

Conclusion

The design and construction of the Governor Mario M. Cuomo Bridge demonstrates the value of well thought out scalable, modularized solutions. Although the general principle of limiting onsite work applies to many situations as a method of reducing risk, increasing quality and productivity, and minimizing cost, it is all the more true when faced with demanding design requirements and challenging site conditions, such as those on the Hudson River. The importance of flexible and easily repeatable solutions is further magnified on projects that combine aggressive construction schedules with massive scale.

About the Author

Jamey Barbas was elected to the National Academy of Construction in 2018. Jamey is Project Director, New York State Thruway Authority. She is known in the industry as one of the first in developing and advancing a methodology in suspension bridge cable condition assessment. She co-founded the International Cable Supported Bridge Owners Committee, which provides a resource for bridge owners in working together to share knowledge and expertise.

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