A Boon for Beantown

Award-Winning Cable-Stayed Bridge is Newest Attraction in Boston

By Sena Kumarasena, P.E

The Leonard P. Zakim Bunker Hill Bridge was presented an Outstanding Project Award (Bridge Project with Multi-span or Single Span over 150 ft.) in the NCSEA 2002 Excellence in Structural Engineering Awards program.

The new Leonard P. Zakim Bunker Hill Bridge solidified its stature as the city of Boston's newest landmark and destination – long before a single vehicle could cross it. At 183 feet, the structure is the widest cable-stayed bridge in the world.

The $100 million bridge measures 1,407 feet in length and is designed to carry 10 traffic lanes over the Charles River. Its first four northbound lanes opened to traffic in March 2003; the remaining six lanes will open in phases during the next two years.

Photo Credit: Phil DeJoseph, Central Artery Tunnel Project

"…a new structural icon"

Physical constraints, including an underground subway tunnel, double-decked truss bridge, Charles River locks and dams, 36-inch water main and numerous surrounding structures were among the major challenges that designers faced.

The public voiced opposition to numerous proposed schemes until a concept developed by Swiss bridge engineer Christian Menn was accepted in 1994. A year later, the Massachusetts Turnpike Authority selected HNTB Corporation, assisted by subconsultant Figg Bridge Engineers, to lead the bridge's final design.

Structural Solutions

The Zakim Bridge epitomizes the philosophy of form following function. Constrained by the Massachusetts Bay Transportation Authority's Orange Line subway tunnel on one side and an existing six-lane bridge on the other, the tower width at deck level can accommodate only eight of the bridge's 10 lanes. As a result, a secondary two-lane roadway is cantilevered 45 feet to the eastern side of the main roadway, making the bridge asymmetric in cross-section.

Its 745-foot steel composite main span is supported with two cable planes along the longitudinal edge girders. Because the existing bridge overlapped the new bridge at the end of the south back span makes, designers found that anchoring cables along the median of the roadway was the only viable solution for the back spans. The site's geometric limitations necessitated a relatively short south back span to allow the bridge to tie into the depressed I-93 tunnel as it emerges at the bridge's south end.

The positioning of back span cables along the median and the relatively small span ratio led to the decision to design torsionally rigid, heavy concrete box-girder back spans. This combination of steel main span and concrete back spans makes the Zakim Bridge the first hybrid superstructure layout for a cable-stayed bridge in North America.

The resulting cable geometry led to the design of inverted-Y towers. Widest at the roadway level, the towers bend back below the deck to form a diamond shape due to foundation footprint constraints.

Technical Challenges

Cantilevered roadway

Within the steel main span, two trapezoidal box edge girders and transverse floor beams at 20-foot centers form the steel framing. A longitudinal fascia girder frames into the outer ends of the floor-beam extensions. Cables attach to the outer fascia web of the box edge girders between the floor beams. Precast concrete panels are made composite with superstructure steel framing through cast-in-place closure strips.

Eccentric loading

The eccentrically placed cantilevered roadway results in higher tensions on the bridge's eastern cables than on its western cables, creating torsion and lateral bending in the tower spire. The net transverse cable forces made bridge erection analysis highly complex. A minimization procedure was developed: First, lightweight concrete was used for the cantilevered lanes, reducing the difference in forces between the eastern and western cables to about 60 percent. Then, compact cable anchorage details were used to minimize the transverse cable spacing and reduce the torsion leverarm. Finally, the main span cables were placed at a small eccentricity from the tower centerline to produce a counteracting moment, eliminating the residual torsion. The minimization procedure reduced the eccentric cable offset to just 3 inches, making the visual effects of the adjustment insignificant.

Geometry issues

The bridge's unique cable arrangement, inverted-Y towers and wide roadway section produce a structure with a very high degree of three-dimensionality. This increased the complexity of framing and detailing of bridge elements, particularly the anchoring of cables in the towers and geometry control.

Compact details

The compact tower elements and several other issues led HNTB to design a composite tower with a steel inner core. Serving as a cable anchor box, the steel inner core also provided a convenient means to control the complex cable geometry with the precision of a shop-fabricated steel box, eliminated post-tensioning in the tower walls to resist tensile forces due to cables, and acted as reinforcing steel in the vertical direction. The design allowed a considerable reduction in the cross-section of the tower spire, improving the overall visual quality of the tower.

Impacts to existing facilities

Transmission of lateral bridge loads to existing underground facilities, including the MBTA subway tunnel, ventilation building and water main, through surrounding soil was determined to be unacceptable. The drilled shafts nearest to these facilities were encased in an outer steel shell, isolating them from the surrounding soil.

Interface coordination

Numerous Central Artery/Tunnel Project construction activities under the bridge's north back span left little room for falsework for cast-in-place concrete construction. As a result, the north back span was designed to provide an option for incremental launching. The south back span's length was shortened an additional 45 feet, avoiding interface with a tunnel ramp, by employing an underground spline extension to anchor three affected cables. Heavyweight concrete ballast was used in select cells of the south back span to counter the effects of the loss of superstructure weight.

Proving its worth

With its striking lighting schemes and visibility from key sections of the city, the Zakim Bridge has provided Boston with a new structural icon. Going forward, the bridge will ease gridlock that has plagued Boston's elevated highway system for decades. Even those who aren't driving across it will benefit, as a series of parks and recreation areas, encompassing 44 acres, are planned for the riverbanks at its base.

This record-setting and award-winning structure also is testimony of the ability of the bridge engineering community to deliver efficient, economical, no-frills "form follows function" designs that meet the public's highest aesthetic standards.

Sena Kumarasena, P.E., served as deputy project manager and project engineer for the final design of the Leonard P. Zakim Bunker Hill Bridge. Kumarasena, who has been with HNTB for nine years, is an associate vice president in the firm's Boston office.
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