PROJECT

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE

Curved, post-tensioned structure links Seattle campus to downtown

by Claudio Osses and Richard Patterson, Buckland & Taylor, and Orin Brown and Huanzi Wang, AECOM

The Montlake Triangle Pedestrian (MTP) Bridge is a highly-curved, 427-ft-long, cast-in-place (CIP), post-tensioned concrete pedestrian bridge spanning over Montlake Boulevard between the Sound Transit light-rail station and the University of Washington (UW) campus in Seattle, Wash. A number of challenges to bridge design and construction were presented by the unique geometry, curved post-tensioning, dissimilar foundations, and the need to interface with several structures and utilities, both new and existing. It is anticipated that this daring bridge will become a landmark for both the UW and the city of Seattle.

Project Overview

The MTP Bridge was designed and constructed as part of Sound Transit's University Link project to extend light-rail from downtown Seattle to the UW campus. The new station is located on the east side of Montlake Boulevard directly across from the UW Triangle area. This Triangle area is being revitalized by the UW, enhancing the view of Mount Rainer from campus with new landscaping and improving pedestrian and bicycle access. The Headhouse is a building structure that forms the above-ground portion of the

Montlake Triangle Project. Rendering: LMN.

profile

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE / SEATTLE, WASHINGTON

BRIDGE DESIGN ENGINEER: AECOM, Seattle, Wash.

ARCHITECT: LMN, Seattle, Wash.

PRIME CONTRACTOR: Hoffmann Construction, Seattle, Wash.

POST-TENSIONING CONTRACTOR: Schwager Davis Inc., San Jose, Calif.

Montlake Triangle Pedestrian Bridge project. Photo: Sound Transit.

new, underground light-rail station. The MTP Bridge provides a direct connection for pedestrians and bicyclists between the Triangle area and the Headhouse.

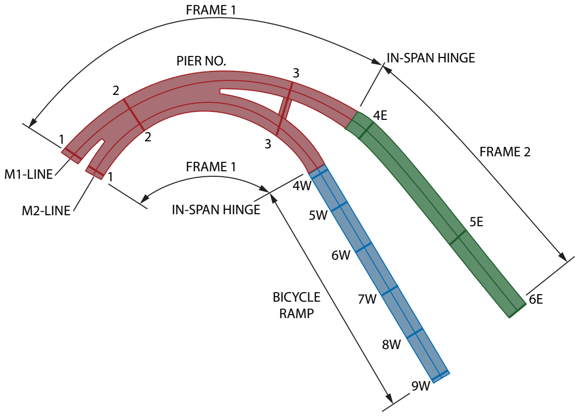
Bridge Layout

The layout of the bridge consists of two horizontally curved alignments:

- The northeast outside curve (M1-line) with a 152-ft radius
- The southwest inside curve (M2-line) with a 94-ft radius

Both alignments begin with pier 1 on the UW Triangle and curve to the right with span 2 of both alignments crossing over Montlake Boulevard. The M1-line has a deck width of 16 ft and consists of five spans with lengths of 55, 131, 76, 100, and 65 ft, ending with a 5-ft cantilever past pier 6E inside the Headhouse. The M2-line has a deck width of 14 ft and consists of eight spans with lengths of 49, 115, 40, 47, 30, 36, 36, and 36 ft, ending at pier 9W as a bicycle access ramp along the east side of Montlake Boulevard. From the middle of span 1 to the middle of span 2, the bridge decks of the two alignments merge into one, making the horizontal geometry resemble a highly curved "X" in plan view, including a forked superstructure at each end of the two spans.

In-span hinges were added to the bridge to divide the bridge into three more-regular bridge segments, which improved the overall static and seismic bridge behavior and simplified the analysis and design. The entire M1-line and the M2-line up to the span 4W hinge are 5-ft-deep, cast-in-place, post-tensioned, concrete single-cell box girders, which become a three cell box in the area where the two lines meet. The M2-line beyond the span 4W hinge is a cast-in-place, reinforced concrete slab girder with a minimum depth of 2 ft and a cross-sectional shape that matches the



Bridge layout. Drawing: AECOM.

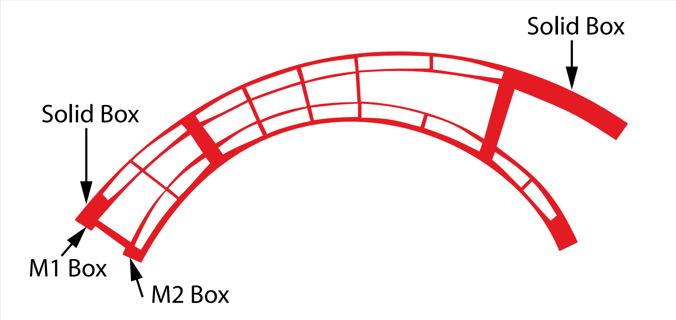
SOUND TRANSIT, OWNER

REINFORCEMENT SUPPLIER: Harris Rebar, Tacoma, Wash.

FORMWORK: Peri Formwork Systems Inc., Woodland, Wash.

PROJECT DESCRIPTION: 427-ft-long by 12- to 35-ft-wide multispan, curved, 5-ft-deep, cast-in-place, post-tensioned concrete box girder bridge founded on drilled shafts, spread footings, and an underground light-rail station

BRIDGE CONSTRUCTION COST: $11.4 million



Framing plan. Drawing: AECOM. Photo: Sound Transit.

overhangs of the box girder. Beyond pier 9W there is a 16-in.-thick approach slab resting on soil sandwiched between two mechanically stabilized earth walls that are about 60 ft long.

Vertical design constraints required the bridge to meet stormwater runoff requirements and match predetermined elevations for three sets of stairs, an escalator, three elevators, temporary and permanent vertical clearances for traffic, and permanent clearances for pedestrians and bicycles. The Headhouse escalator 1 and stair 1 are side-by-side structures that are supported by, and join the end of, the M1-line bridge girder near pier 6E.

Superstructure

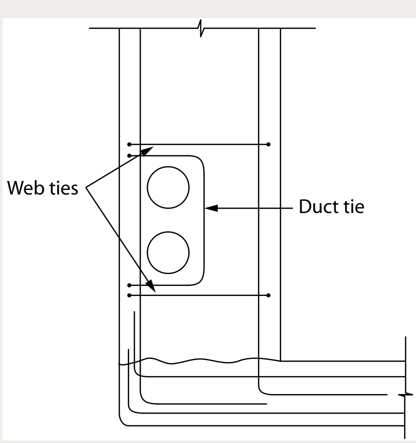
The uneven span arrangement (end-span to main-span length ratio of 0.4) required the use of special design techniques, including the use of a vertical tie rod, a hinge, and mass concrete at selected end-span box cells to control live load uplift reactions at pier and in-span hinge bearings.

Typically, post-tensioning is avoided in highly curved bridges due to difficulties associated with the large out-of-plane forces induced. However, post-tensioning was chosen for this bridge because it allowed a shallow section that met the vertical clearance requirements and produced a high-level architectural finish without the normal cracking associated with typical reinforced concrete bridges.

In order to better resist the girder torsion due to gravity loads and the lateral bending due to horizontally curved post-tensioning, the two box girder alignments were transversely connected by a soffit slab. This soffit slab is located where the decks merge together and by integral bent cap crossbeams at piers 1 and 3. The soffit slab between the box girders where the decks converge is recessed 9 in. upward from the soffit of the box girders for aesthetic reasons.

With such a complex geometry, simplified straight line models are incapable of capturing important aspects of the structural behavior of the bridge such as the effect of the post-tensioning on the global bridge response and the concrete stress and load distribution across the bridge section. A more sophisticated three-dimensional, structural, finite-element model was used to capture the static and dynamic behavior of the bridge.

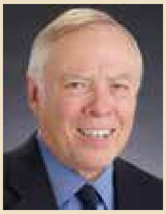
The tight horizontal bridge curvature required special post-tensioning analysis, detailing, and construction. Post-tensioning a structure with such a tight horizontal curve produces variable concrete stresses across the bridge section and causes transverse tension in the slabs between the webs and undesirable torsional effects if the tendon forces are not distributed properly. Using prestressing forces at each web that were roughly proportional to the span length of each web minimized these undesirable effects. Additionally, a construction analysis by stages was used to determine the optimal jacking sequence to minimize any undesirable post-tensioning effects.



Duct-tie and web-tie reinforcement. Drawing and Photo: AECOM.

AESTHETICS COMMENTARY

by Frederick Gottemoeller



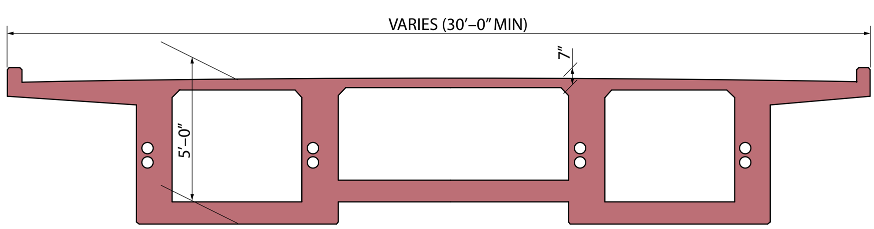
This bridge reminds me of the old television advertisements for Perdue chickens. In those advertisements, Frank Perdue would talk at length about chickens, and then end his spiel with, "It takes a tough man to grow a tender chicken." This bridge demonstrates that it takes excellent engineering to make a complicated bridge look so simple. And that's important because this bridge's aesthetic appeal is based on the simplicity with which its complex geometry is addressed. The bridge is an interesting shape, and it is unencumbered by pier caps, straddle bents, expansion joints, or any of the other details that may be distracting.

The girders are relatively shallow, giving the pedestrian areas under the bridge a feeling of spaciousness. They curve to follow the curve of the deck, creating a generous and constant-width overhang that contributes a consistent shadow line, making the girders seem even thinner. The smooth undersides of the girders provide a clean and light-colored ceiling for this outdoor space; space that pedestrians and bicyclists can occupy without worrying about birds and debris overhead.

The circular piers have no axes or planes that would conflict with the curves of the girders floating above. They also allow the myriad paths of pedestrians and bicycles to flow past them with a minimum of interference. The straightforward railing allows the overall geometry of the bridge to dominate, creating no secondary rhythms or panelization that would distract. The light poles serve their function without attracting the eye away from the bridge itself.

Once the Sound Transit University link is in service, the Montlake Triangle will be filled with the activity of pedestrians, bicyclists, and transit riders. This bridge will provide a dignified and memorable setting for all of them.

Frederick Gottemoeller is an engineer and architect, who specializes in the aesthetic aspects of bridges and highways. He is the author of Bridgescape, *a reference book on aesthetics and was deputy administrator of the Maryland State Highway Administration.*



Typical section at frame 1. Rendering: AECOM.

The girder web stirrups also needed to be designed to resist vertical shear and lateral web bending caused by the horizontally curved post-tensioning. The strut-and-tie method was used to analyze and design the duct-tie and web-tie reinforcement to resist the local out-of-plane lateral post-tensioning forces. Special attention had to be paid to the placement of the duct-tie and web-tie reinforcement during construction, as this reinforcement was critical in resisting the post-tensioning, out-of-plane forces.

Two measures incorporated to enhance the durability of the bridge were the use of epoxy-coated reinforcement in the 7-in.-thick deck, and the use of high-density polyethylene corrugated ducts for the post-tensioning tendons.

Substructure

The girders are integral with 4-ft -diameter columns at piers 2, 3, 4E, and 4W, and with 2-ft 6-in.-diameter columns at piers 5W through 8W. The girders are supported on expansion bearings at piers 1, 5E, 6E, 9W, and at the span 3E and 4W hinges.

Another unique feature of this bridge is that the foundations are dissimilar between piers. Pier 1 is founded on two, 4-ft-diameter drilled shafts, one under the centerline of each box girder alignment. Piers 2 and 3 are founded on two-column combined spread footings 4 ft 6 in. thick. Pier 4E is founded on top of a large roof beam within the underground light-rail station. Piers 5E and 6E are part of the Headhouse building frame. Pier 4W is supported on a single-column spread footing 4 ft 6 in. thick. Piers 5W through 8W (supporting the bicycle ramp) are all founded on single-column spread footings 2 ft 6 in. thick. Pier 9W is an abutment bearing wall with wingwalls, which all bear on a spread footing that is 1 ft 9 in. thick.

Because piers 4E, 5E, and 6E are all founded on the building frame of either the Headhouse or the station roof, the bridge engineers provided all design loads and displacements to the station designer, and included the Headhouse frame in the bridge analysis model. A special seismic design criterion was developed to satisfy bridge (displacement based) and building (force based) code philosophies for the spans supported by the Headhouse.

Final Remarks

The design of the MTP Bridge has pushed the limits for the use of post-tensioning in highly curved bridges, demonstrating that with the proper analysis and detailing, durable and low maintenance post-tensioned concrete bridges can be used for bridges.

Claudio Osses is a bridge engineer and Richard Patterson is the Washington practice lead with Buckland & Taylor in Seattle, Wash. Both Osses and Patterson were formerly with AECOM. Orin Brown and Huanzi Wang are bridge engineers with AECOM in Sacramento and Oakland, Calif., respectively.

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