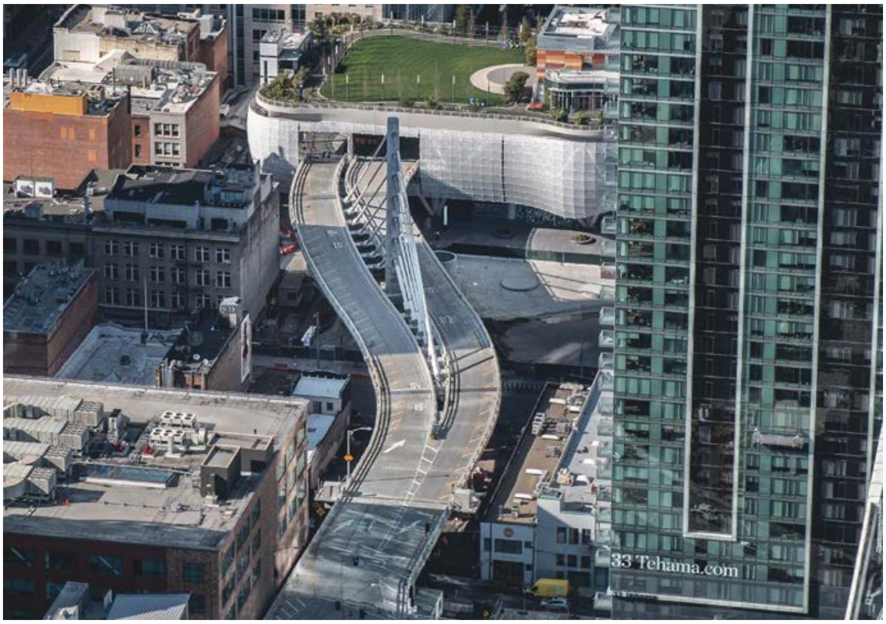
SALESFORCE TRANSIT CENTER BUS RAMP BRIDGE

by Qiyu Liu, Arup

The Salesforce Transit Center (STC) is a regional transit hub located in the heart of San Francisco, Calif. The multilevel hub connects San Francisco with the Bay Area counties through 10 transit systems and will be a station for California High-Speed Rail. As part of this visionary, $6 billon project that is transforming downtown San Francisco and the Bay Area regional transportation system, a new 1849.0-ft-long Transbay bus ramp bridge system was built to provide bus transit access to the STC from the East Bay via the San Francisco–Oakland Bay Bridge exit ramp. The Transbay Ramp Bridge is the first vehicular cable-stayed bridge built in California.



Aerial view of Salesforce Transit Center (STC) and the cable-stayed bridge that connects the second level of the STC to the viaduct-style bus ramp bridge system leading to the East Bay. Photo: Steve Proehl..

Urban Congestion and Seismic Risks

The STC is located in a densely populated area surrounded by high-rise buildings. The bus ramp bridge connects to the second floor of the STC multilevel building and spans over a multistory underground structure composed of a local street roof, a vehicle/bicycle ramp at the first below-grade level, a concourse at the next level, and the future California High-Speed Rail underground station at the lowest level. This configuration severely limited the location of the bridge piers and foundations.

The high seismicity in the Bay Area also posed design challenges. The bridge piers and foundations were located outside of the STC structural footprint to avoid dynamic seismic interactions between the STC underground structure and the bridge and to eliminate any interference between the bridge and STC structure and foundations.

For the connection between the viaduct and the STC, a cantilever cable-stayed bridge was determined to be the best design option in terms of costs and aesthetics. With this configuration, large columns and foundations for the bridge in the STC underground structure were eliminated, and the seismic behavior and design of the bridge were greatly simplified. This article discusses the design of the cable-stayed bridge portion of the bus ramp bridge system.

Aesthetic Compatibility with the STC

Project leaders wanted the bus ramp bridge to have an aesthetic design that would complement the perforated steel,

profile

SALESFORCE TRANSIT CENTER BUS RAMP BRIDGE / SAN FRANCISCO, CALIFORNIA

BRIDGE DESIGN ENGINEER: Arup, San Francisco, Calif.

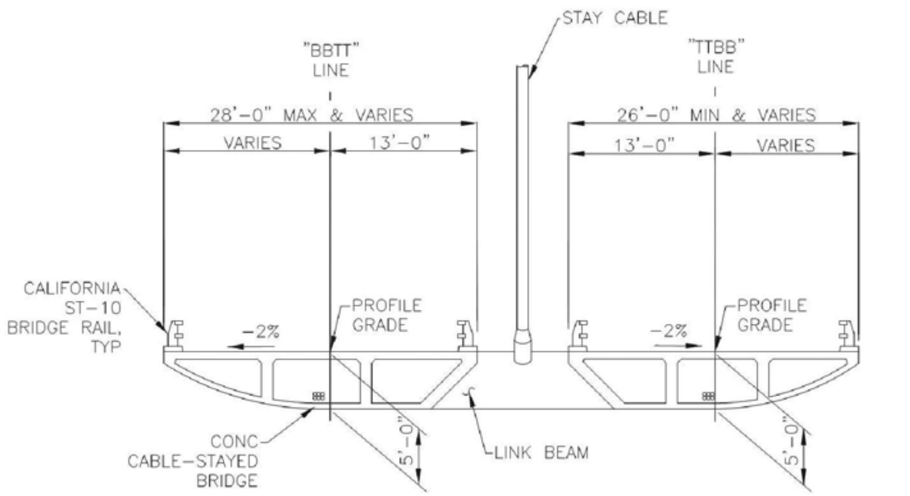
CONSTRUCTION ENGINEER: OPAC Consulting Engineers Inc., San Francisco, Calif.

PRIME CONTRACTOR: Shimmick Construction, Oakland, Calif.

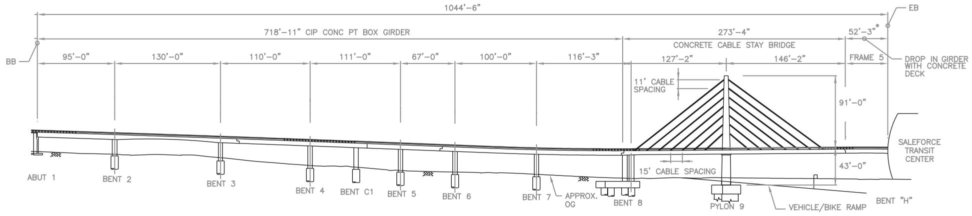
STAY-CABLE CONTRACTOR: VSL/Structural Technologies, Fort Worth, Tex.

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

The bus ramp cable-stayed bridge at night with box girders, link beams, and stay anchorages visible. Photo: Arup.



Typical cross section of the cable-stayed bridge deck showing the ladder-beam system, link beams, and stay anchors. All Figures: Arup.



Elevation of the bus ramp bridge system with the cable-stayed bridge and Salesforce Transit Center at the right end.

curved facade of the STC. To avoid overpowering the appearance of the STC building, a single plane of stay cables supported by a slender concrete tower was proposed for the cable-supported bridge. The bridge deck is a ladder-beam system supported by stay cables anchored in the middle of the transverse link beams. A curved outside web surface in the box girders was adopted so the ladder beams would match the curved facade of the STC. The cable-stayed bridge design allowed for a flexible superstructure with shallow box girders that enhance the bridge's overall aesthetics.

The cantilever bridge was designed to support a maximum of four lanes of fully loaded bus traffic. It was necessary to strictly control the deflection of the cantilevered end to provide comfort for bus passengers. Relatively large stay cables were designed to control the required deck deflections—109 parallel 0.6-in.-diameter strands were used. To achieve a slender tower design, cable saddle boxes were used instead of typical individual stay anchorages, thus avoiding the need for access space inside the tower.

TRANSBAY JOINT POWERS AUTHORITY, OWNER

BRIDGE DESCRIPTION: A 1849.0-ft-long viaduct and cable-stayed bridge to provide dedicated bus transit access between the Salesforce Transit Center and the San Francisco–Oakland Bay Bridge. The 273.33-ft-long cable-stayed bridge consists of a 127.17-ft-long back span and a146.17-ft-long concrete cantilever span with a 52.25 ft simply supported drop-in span that connects the bus ramp viaduct to the second story of the Salesforce Transit Center structure. Post-tensioning was used in the transverse direction in all link beams.

STRUCTURAL COMPONENTS: The cable-stayed bridge has a dual concrete box-girder superstructure connected transversely with concrete link beams. The link beams are supported by stay cables and a solid concrete pylon that extends 91 ft above the deck. Stay saddles were used at the pylon, which is supported by two 200-ft-deep slurry walls founded on bedrock. The end bent at the backspan is supported on four 5-ft-diameter drilled shafts founded on bedrock.

BRIDGE CONSTRUCTION COST: $59.7 million

AWARD: *ENR* California Best Projects 2018: Airport/Transit.

Another aerial view of the cable-stayed bridge as it enters the Salesforce Transit Center. Photo: Steve Proehl.

Innovative Structural Arrangements

The cable-stayed bridge is a side-by-side deck, single-tower structure. The main span consists of a 146.17-ft cantilever span over a park above the future underground train station. A 52.25 ft drop-in span over a local street was used to further reduce the weight imposed by the bridge on the SCT's supporting columns. The 127.17-ft-long back span is positioned over Howard Street. To limit live-load deflection of the cantilever span, a 91-ft-high concrete tower (from the deck to the top) is used with a single plane of cables along the centerline of the bridge deck.

The ladder-frame system of the bridge deck was constructed from two concrete box girders rigidly connected by a series of concrete link beams. To provide sufficient torsional rigidity of the ladder frame, the spacing of the link beams is set at 15 ft in the back span and 16.5 ft in the cantilever span.

The tower and the end pier are monolithically connected to the deck. This arrangement not only minimizes future maintenance work in this area but also enhances torsional rigidity of the ladder frame, which provides additional resistance to unbalanced live load and lateral seismic load in the transverse direction of the bridge.

The tower is supported on two 200-ft-deep slurry walls founded on bedrock. The end pier is supported on four 5-ft-diameter drilled shafts. Post-tensioned bars are used in the end pier columns to resist tension from the stay cables during different loading conditions.

Technical Challenges

The structural isolation of the cable-stayed bridge from the STC added complexity to the design of the expansion joint between the cable-stayed bridge and the drop-in span. The expansion joint should allow for movement in all directions, and the free end of the bridge is expected to move more than 2 ft in the transverse direction during a seismic event. A modular type of expansion joint with dovetail-shaped joist boxes was chosen so that the free end can move in both longitudinal and transverse directions.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

According to the project profile, the Salesforce Transit Center is intended to be a visionary project that will transform downtown San Francisco. Thousands of people will be moving through the center every day on foot, or by bicycle, car, or bus on their way to or from their bus or train. The quality of their experiences will be an important factor in whether they judge the center to be a success. They will be moving through sidewalk and street spaces whose "ceiling" is the underside of the bus ramp bridge. Therefore, the bridge's appearance from below is its most important aesthetic feature.

The designers have recognized this fact in both their overall conception of the bridge and in the structure's details. The choice of a cable-stayed structural system was driven largely by the limited space for foundations, but it also constrained the number of vertical supporting elements below the bridge. That keeps open the sight lines through the structure, making the area below seem safer and more spacious. The concrete box girders conceal all of their internal bracing and provide a smooth, light-colored reflective surface overhead, while their curved outer webs allow daylight to penetrate under the bridge. The curved webs also make it difficult to judge the actual depth of the structure, so the bridge seems thinner than it really is. Finally, using cable saddle boxes instead of individual stay anchorages at the tower keeps the tower relatively thin and in proportion with the rest of the bridge.

But the designers' real stroke of genius was leaving the median open and exposing the ladder-frame system of the bridge deck. This design brings daylight into the space under the bridge, while showing off the structural elements of the system. The role of the tower in supporting the stays and the roles of the stays in supporting the deck are crystal clear. The elegant stay-link beam intersection and simple stay-anchorage detail make their roles even more obvious.

Inserted among numerous 50-story skyscrapers, and adjoining the five-block-long Salesforce Transit Center, the bus ramp bridge can't compete with its neighbors on size. However, by borrowing from the curved-surface vocabulary of the transit center, the bridge's dramatic and carefully detailed shape certainly competes on elegance. The bridge will become a well-known and popular landmark in this urban scene, and a captivating lesson on how bridges work.

Underside of the bridge showing box girders, link beams, and stay anchorages. Photo: Arup.

Another challenge was managing the curved alignment of the bridge. Given the site constraints, the alignment of the bridge is an S-curve, which is extremely rare in a cable-stayed roadway bridge.

A third challenge was the design of the pylon. The stay cables at the highest elevation created significant bending moment in the tower because of the long moment arm. Every effort was made to straighten the bridge alignment; however, when the curve could not be removed, the tower and its foundation were designed to have high flexural strengths in the transverse direction.

Conclusion

When faced with significant design challenges related to the bridge's location and tight right-of-way, engineers and architects collaborated to find innovative solutions that could meet the project requirements. The bridge was completed and opened to bus traffic in September 2018.

Qiyu Liu is an associate principal with Arup in San Francisco, Calif.

Aerial view of the cable-stayed bridge deck, soffit, and pylon during construction. Photo: Arup.