PROJECT

Sixth Street Viaduct in Los Angeles Creatively Melds Past and Present

by Michael Jones, HNTB

Aerial view of the Sixth Street Viaduct at sunset, with the downtown Los Angeles, Calif., skyline to the west and San Gabriel Mountains to the north. Photo: HNTB, © Core-Visual.

The Sixth Street Viaduct was the longest and best known of the 15 historic concrete bridges built in Los Angeles, Calif., between 1909 and 1934. This viaduct and the other 14 bridges represented some of the finest examples of the City Beautiful movement that swept across the United States from the 1890s through the 1920s. An icon beloved by the community, the Sixth Street structure served as a backdrop for numerous movies, TV shows, commercials, and music videos, as well as countless personal stories.

Unfortunately, the Sixth Street Viaduct had an alkali-silica-reactive aggregate. When a seismic retrofit project was intiated to improve the viaduct's seismic resiliency, the project team found that arresting the deterioration in the cement paste was not possible. Thus, the project scope evolved into a full bridge replacement.

The lead agency for the replacement, the City of Los Angeles Bureau of Engineering (BOE), held an international design competition to find a worthy replacement for the popular bridge. The winning design resembles the architecture of the original historic bridges, complete with a concrete tied-arch design and efficient thin profiles made possible by a network of hangers that support the bridge deck beneath.

Dubbed the "Ribbon of Light," the new viaduct opened in July 2022 with a three-day celebration held on the bridge deck. It was instantly accepted by the community as an elegant and worthy replacement of its predecessor. It is a unique structure to be sure. No other bridge in the world is designed with 10 contiguous, tied network arches that interact as a single unit through an uninterrupted, continuous edge girder tie. The final 12-span design includes two continuous cast-in-place, post-tensioned concrete box-girder approach spans and measures 3058 ft long, abutment to abutment. The 100-ft-wide bridge is supported on concrete Y-bents. The deck includes two lanes of traffic in

profile

SIXTH STREET VIADUCT / LOS ANGELES, CALIFORNIA

BRIDGE DESIGN ENGINEER: HNTB Corp., Los Angeles, Calif.

OTHER CONSULTANTS: Architectural consultants: Michael Maltzan Architecture, Los Angeles, Calif., and Dissing+Weitling, Copenhagen, Denmark; construction engineer: COWI North America, North Vancouver, BC; construction management: T. Y. Lin International, Los Angeles, Calif.; geotechnical engineer of record: Earth Mechanics Inc., Fountain Valley, Calif.

PRIME CONTRACTOR: Skanska USA Civil West and Stacy and Witbeck Joint Venture, Riverside, Calif.

CONCRETE SUPPLIERS: Primary supplier: CEMEX, Los Angeles, Calif; backup supplier: Robertson's Ready-Mix, Corona, Calif.

POST-TENSIONING CONTRACTOR: DYWIDAG-Systems International, USA Inc., Long Beach, Calif.

OTHER MATERIAL SUPPLIERS: Isolation bearings: Earthquake Protection Systems, Vallejo, Calif..; reinforcing steel fabricator: LA Steel Services, Corona, Calif.; expansion joints: DS Brown, North Baltimore, Ohio; cast-in-drilled-hole pile foundations: Condon-Johnson & Associates, Los Angeles, Calif.

each direction along with two Class IV protected bicycle lanes, as defined by the California Department of Transportation (Caltrans), and two 8- to 14-ft-wide walkways along both edges of the bridge. The nominal distances between Y-bent centers vary from 240 to 313 ft. The actual arch span lengths are shorter due to the use of a jump span over each Y-bent between the arch spans, with a minimum arch span of 191 ft and a maximum of 250 ft.

The new viaduct carries traffic over the Los Angeles River, two railroad corridors, U.S. Route 101, local city streets, and a future 12-acre park that will be constructed beneath the viaduct. To fully integrate the viaduct with the park and surrounding community, five sets of stairways and two pedestrian ramps, including an intriguing helical ramp, provide direct access to the park and surrounding community.

The new Sixth Street Viaduct provides multimodal transportation with separate travel ways for vehicular, bicycle, and pedestrian traffic. The arch ribs are canted outward at 9 degrees and provide picture-perfect views of the downtown skyline. Photo: HNTB, © Core-Visual.

Why Cast-in-Place Concrete?

The BOE made the decision to move forward with a concrete bridge to be consistent with the original historic bridges while minimizing maintenance costs. Cast-in-place concrete also facilitated the aesthetics of the design concept because the material could be effectively used to achieve the structure's complex geometry. The arches needed to flow seamlessly into the Y-bents to integrate the viaduct with the surrounding community and the park below by providing perfect geometric support for the descending stairways. The varying shapes and sizes of the arches were anything but repetitive, and concrete can be formed into any shape desired.

Cast-in-place concrete also offered other practical benefits. The concrete could be batched at a plant located within 3 miles from the project site. In contrast, the nearest steel bridge fabricators with the expertise to fabricate complex bridge components are located outside

Helical bicycle/pedestrian ramp. Two ramps and five sets of stairways are provided to fully integrate the viaduct with the future park planned below the viaduct. Photo: HNTB, © Core-Visual.

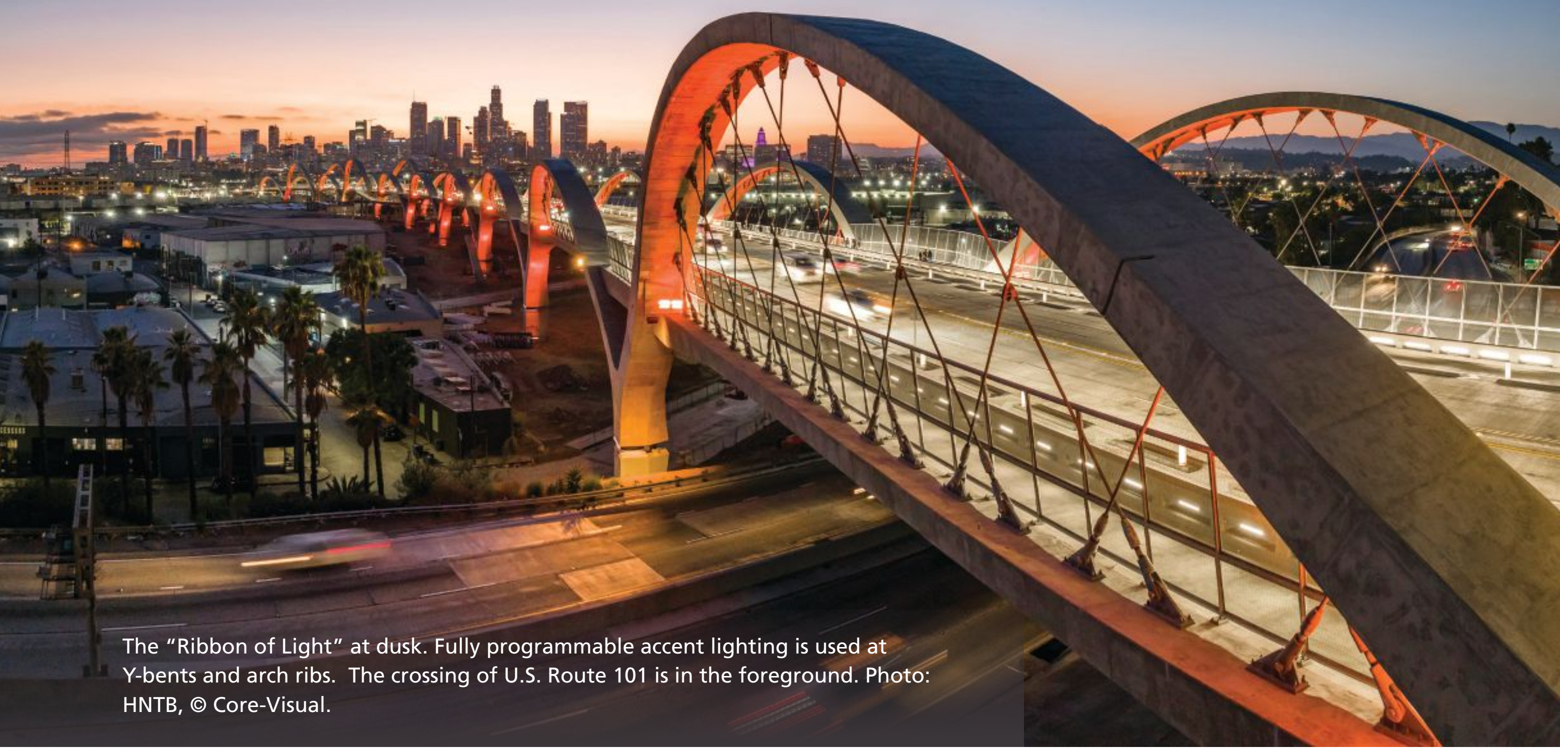
CITY OF LOS ANGELES BUREAU OF ENGINEERING, OWNER

BRIDGE DESCRIPTION: 12-span, 3058-ft-long, 100-ft wide bridge consisting of 10 continuous concrete tied arch spans supported on concrete Y-bents and two continuous post-tensioned, cast-in-place concrete box-girder approach spans

STRUCTURAL COMPONENTS: Ten-span continuous cast-in-place tied network arch with nine cast-in-place jump spans, two-span cast-in-place post-tensioned box girders, five cast-in-place concrete stairways, two cast-in-place box-girder pedestrian/bicycle ramps, one cast-in-place concrete helical pedestrian/bicycle ramp, cast-in-place Y-bents, columns, and abutments, cast-in-drilled-hole pile foundations

BRIDGE PROGRAM CONSTRUCTION COST: $588 million

AWARDS: American Concrete Institute Southern California Chapter's 2022 Charles J. Pankow Jr. Award; American Council of Engineering Companies (ACEC) Grand Award Winner; ACEC California 2023 Engineering Excellence Honor Award and Golden State Award (the highest honor); American Public Works Association's Southern California 2022 BEST Award for a transportation project in a city with a population greater than 200,000; *The Architect's Newspaper*'s 2022 Best of Design, editor's pick for infrastructure; Civil + Structural Engineer Media's 2022 most popular infrastructure project (voted on by the public); Envision Platinum Award for Sustainability; Los Angeles Business Council 2022 Architectural Awards – Civic Award; *Roads & Bridges*' top 10 bridges list for 2022; WTS International: 2022 WTS-LA Innovative Transportation Solutions Award; Post-Tensioning Institute's 2023 Award of Excellence, Bridge Category



The "Ribbon of Light" at dusk. Fully programmable accent lighting is used at Y-bents and arch ribs. The crossing of U.S. Route 101 is in the foreground. Photo: HNTB, © Core-Visual.

of California. Additionally, the hoisting necessary to construct a cast-in-place structure could be performed with a fleet of truck cranes that were easier to mobilize and maneuver than larger crawler cranes. The shorter booms of the truck cranes would also be more appropriate for work around the power transmission lines that run along the river and for operations within the restricted working areas throughout the project site.

Nevertheless, the project team studied the use of steel floor beams to ascertain whether they would offer any potential cost savings. Given the 100-ft width of the bridge, steel floor beam framing would be about 70% of the total superstructure steel if the entire superstructure, except for the concrete deck, were framed in steel. In the end, studies determined that cast-in-place concrete was the best choice for the viaduct in terms of both cost and aesthetics. Additionally, the expected reduction in dead load between steel and concrete options was not as significant as first expected due to the efficiency of the tied-arch superstructure combined with the Y-bent substructure. The dead load of a typical arch span section with 3-ft-deep edge girders was 195 lb/ft^2, compared with approximately 360 lb/ft^2 for a comparable cast-in-place box girder spanning 300 ft between foundation elements.

Seismic considerations were another concern, particularly when considering the use of steel arch ribs in combination with the concrete substructure. In that type of design, the steel-to-concrete transition connections would have been inordinately complex, in large part due to the high seismicity of the project site. One option was to place the transition some distance above the deck level, to avoid possible seismic hinging locations, but that option lacked the desired aesthetics.

The design team also considered the use of precast concrete floor beams, but they determined that the cast-in-place option was more economical. Cast-in-place edge girders were clearly advantageous for economy,

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

The original Sixth Street Viaduct was a rare bridge, recognized by millions of people around the world as the background of memorable scenes in dozens of movies and TV shows. However, almost no one knew its name; all they knew was that it was somewhere in Los Angeles. What made the bridge so recognizable was the paired half-through arches spanning the Los Angeles River that were joined in gull-wing fashion. When it became necessary to replace this memorable and unique bridge, the city's Bureau of Engineering set out to create an equally noteworthy replacement. It succeeded.

The design of the new bridge extends the gull-wing half-through arch theme to 10 of the 12 spans. The spans vary in length, but the span-to-rise ratio is kept roughly the same, so the arches vary in height. The result is a new, lively, blocks-long scalloped ribbon within the Los Angeles skyline. The arches are continuously lighted, so that the scalloped ribbon stays visible at night. In a final stroke of genius, the arches are unbraced and lean back from the edge of the roadway at a 9-degree angle, seeming to open up the driver's view of the Southern California sky.

The designers left the arches themselves and their gull-wing Y-bents as pure concrete shapes generated by the fundamental geometry of the bridge. There is no additional embellishment, and none is required, but some remarkable engineering innovation was necessary to make the whole thing work in this active seismic area. As a final touch, the designers attached the stairs and ramps as clearly separate elements, differentiated from the bridge itself by material and shape.

This bridge is a masterpiece. I predict that it will become the background of memorable scenes for numerous new movies and TV shows. All who were involved in its design and construction have the right to be proud.

Because Isolation bearings are located within the vertical portion of the Y-bents, the team developed a new seismic isolation design methodology. Photo: HNTB, © Core-Visual.

Steel plate expansion joints developed by the California Department of Transportation and modified for the viaduct are provided at each abutment, making the viaduct a 3058-ft-long continuous structure. The joints allow seismic movement of up to 30 in. in any direction. There is a sacrificial rubber seal at the back of each plate joint. Gaps to accommodate seismic movements can be seen between the arches and abutment. Photo: HNTB.

constructability, seismic integrity, and aesthetics. Once falsework was needed for edge girders, the practical construction option was to connect opposing edge-girder falsework to provide a falsework platform across the entire bridge width to support cast-in-place floor beams.

Seismic Challenges

Although cast-in-place concrete was the preferred material and construction technique, designing the viaduct to withstand a 1000-year seismic event in a high seismic area was a formidable challenge. A particular concern was the arch ribs. Arch rib bracing was not an option given the width of the structure and the architectural goal of opening up the deck, which included canting the arch ribs outward at 9 degrees. As one crosses the viaduct, whether by bus, automobile, bicycle, or on foot, the arch ribs provide picture-perfect views of the downtown skyline to the west and the San Gabriel Mountains to the north.

Computer models revealed that the arch ribs above the deck would respond with unacceptably large lateral displacement when subjected to anticipated seismic ground motions. These concerns led the project team to investigate seismic isolation. They noted that the viaduct's architecture prohibited following standard practice of placing the isolators at the top of the substructure, just below the superstructure. The arch

Stairways are supported from the superstructure deck and a lower canted stairway column. The bottom of the stairway is cantilevered and floats above finish grade, permitting unrestricted seismic displacements in any direction. Photo: HNTB.

ribs needed to flow continuously into the Y-bents, which provide geometric support for the stairways. The bearings would have severed the continuity between the arch ribs and the upper arms of the Y-bents.

Instead, the team chose to place the isolation bearings within the vertical portion of the Y-bent columns. Placing the isolators within the vertical height of the supporting columns was unprecedented for a bridge, but this novel approach led to a fundamental change in the application of seismic isolation by the design team and a new seismic-isolation methodology.

Seismic isolation is used to reduce or eliminate expected damage from seismic events and therefore will vastly improve the post-earthquake functionality of a structure. However, there are no guide provisions that specifically address protection of the bearings themselves. The new approach selected by the design team is succinctly described as "the isolation bearings protect the structure while the structure protects the bearings." This new methodology requires the structure to also be designed as a nonisolated structure. Should seismic displacements within the isolation bearings exceed the 1000-year seismic event displacements by a factor of about two, the bearings stiffen rapidly and activate a secondary earthquake-resisting system. The isolation bearings were reconfigured to facilitate this new methodology. This is a "belt and suspenders" system that makes bearing failure and/or unseating within the column virtually impossible.

The use of isolator bearings allowed the viaduct to be configured as a continuous structure with expansion joints only at each abutment for a continuous length of 3058 ft. This led to further innovations, including the first use of Grade 80 concrete reinforcement on a California bridge. Caltrans had been studying Grade 80 reinforcement but had not yet approved its use pending further verification of ductility performance in plastic hinge regions. For the Sixth Street Viaduct, its use was limited to capacity-protected members that form the secondary earthquake-resisting system—that is, the Y-bent members above and below the isolation bearings. Because the secondary system would only be engaged as a backup to the isolation system, this project was an optimal opportunity to introduce Grade 80 reinforcement in a California bridge. Importantly, the use of Grade 80 reinforcement resulted in cost savings because larger member sections and more reinforcement would have been required if Grade 60 reinforcement had been used.

Now open to the public, the new Sixth Street Viaduct has exceeded BOE's goal of delivering an iconic replacement for the original beloved Sixth Street Bridge that provides unprecedented seismic safety. The replacement viaduct, which is already a recognized backdrop for the city's bustling film and music industry, is expected to be an iconic presence in Los Angeles for the next 100 years. A

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