Projects Highlights

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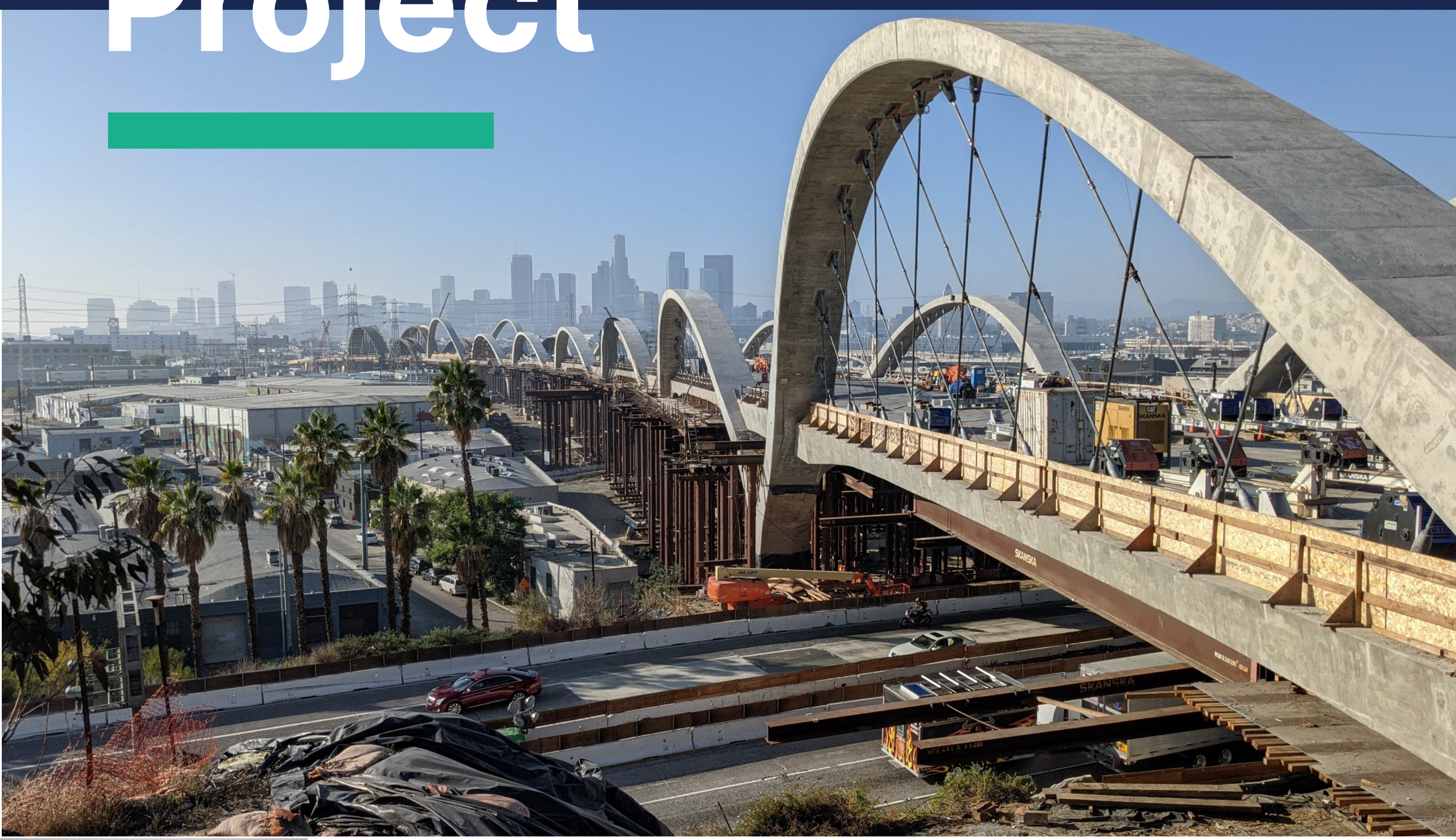
6th Street Viaduct Replacement Project



CANADIAN CONSULTING engineer

COWI

SOCIAL AND/OR ECONOMIC BENEFITS

Built in 1932, the original iconic 6th Street Bridge was the most filmed bridge in LA, featured in various movies and music videos such as Grease, and Terminator 2 and 3. It comprised mainly a concrete viaduct with two pairs of braced steel arches and extended across the Los Angeles River, several railroad tracks, the US 101 freeway, and various local streets. It was demolished in 2016 due to high alkali content in the concrete, resulting in cracks and impairing the viaduct's structural integrity. Although "various costly restorative methods were tried in an ongoing effort to save the viaduct ... all of them failed," explains the Los Angeles Bureau of Engineering's website. In addition, "seismic vulnerability studies concluded that the viaduct had a high vulnerability to failure in the event of a major earthquake."

The new 6th Street Viaduct is the largest and most complex bridge in the history of LA. The 3060-ft-long continuous, and 100-ft-wide structure is comprised of 10 sets of concrete network arches. The wider deck allows for two bicycle lanes and separate pedestrian walkways, including a helical ramp for cyclists which allows access to a planned future park. The goal of this new bridge was not only to be a place for cars, but also a multimodal link for pedestrians and cyclists, and a driving force in transforming the urban landscape bringing a new life to the communities on both sides of the bridge.

For the first time in L.A., the project delivery model was CMGC (Construction Manager/General Contractor) with a total cost of US$588M. A contributing factor to its success was the cooperation between the Owner, Designer, Contractor, and Erection Engineer. Furthermore, Contractor engagement during the preconstruction phase minimized issues during construction.

The economic impact of the 6th Street Viaduct project is such that it created hundreds of jobs during construction which added to the economy of Central L.A. and its neighbors.

This project has been the catalyst for significant investment in the surrounding communities. Over 60 projects collectively representing over $3 billion in value have been recently constructed, are under construction, or have been proposed in and around the project site since the beginning of the 6th Street Viaduct Project. For example, 17 recently developed projects include museums and apartment buildings.

New businesses and restaurants are also moving to the area because of this project. Another eight projects are currently under construction, including several mixed-use developments, and 40 additional projects have been proposed for the area, including hotels, schools, and art facilities.

Furthermore, this new viaduct will improve congestion issues in the area. The planned park underneath will bring people and vitalize this once fairly deserted area.

The 6th Street Viaduct design team which included Michael Maltzan Architecture (Design Architect), HNTB (Engineer and Executive Architect), Hargreaves Associates (Landscape Architect), and AC Martin (Urban Planning), began with the fundamental understanding that the viaduct is more than a simple replacement thoroughfare crossing the Los Angeles River. The project instead foresees a multimodal future for the City, one that accommodates cars and incorporates significant new bicycle connections. It also increases connectivity for pedestrians to access the viaduct, not only at its endpoints, but along the entirety of the span, linking the bridge, the L.A. River, and future urban landscapes in a more meaningful relationship.

The structure's generous spans create large areas of open space below that will become new recreational green spaces. Five pedestrian stairways along the length of the 3060 ft viaduct connect the bridge level with the ground below. This strategy enables a more significant degree of connectivity with the ground plane, and a less prescriptive approach to landscape that will allow for expanded flexibility overtime. A wide range of public activities and open space will be under the eastern portion of the viaduct in what was an industrial zone.

Original 6th Street Bridge

"Infrastructure projects like the Sixth Street Viaduct can be significant contributors to the socioeconomic vitality and attractiveness of communities," said Melissa Peneycad, ISI's (Institute for Sustainable Infrastructure) managing director. "It's exciting to see anticipation building around many new projects that are moving ahead or are proposed for the viaduct area, and also to recognize the immediate benefits — not least, the benefit to existing businesses, non-profit, and community activities from the increased foot traffic in and around the bridge."

Improving Community Safety and Incorporating Alternative Modes of Transportation into the Project's Design

As an important connection between East and Downtown L.A. this bridge corridor is essential to local communities and the regional transportation network. The need for structural rehabilitation and seismic safety of the 6th Street Viaduct was the impetus for this replacement project. Alkali-silica reaction was causing the bridge to deteriorate over time, leading to a significant risk of collapse in the event of an earthquake. The new bridge is built with high quality concrete material and uses the concept of seismic isolation to provide protection from any anticipated future earthquakes.

The new bridge also improves safety and the overall experience for cyclists and pedestrians. For example, the project includes widened sidewalks and protected bike lanes. There are two bike ramps for cyclists, with one ramp to the west and the Arts District, and one to the east and Boyle Heights. A new sloping River Gateway path will link the River to a future Arts Plaza at the terminus of the viaduct in the heart of the Arts District.

Rebuilding an Iconic Structure

In addition to preserving the viability of the 6th Street corridor across the Los Angeles River, the project was also designed to restore the viaduct as a community landmark and riverside space for the public.

To improve overall aesthetics and incorporate public art elements into the design of the viaduct and park, input from local artists and community members within the Cultural Arts Commission was gathered as part of the project's preliminary design through the Design Aesthetic Advisory Committee, and later in the project's final design as part of the Public Art Advisory Committee. Local artist Glenn Kaino, selected as the winner from among five finalists, will be designing public art incorporated into the PARC (Park, Arts, River and Connectivity Improvements). His project for the viaduct will likely explore the role and potential of infrastructure as social context.

The ten pairs of arches and the helical-shaped east ramp are among many of the viaduct's design elements that will add significantly to the area's aesthetics.

Incorporating Resiliency into the Design

The 6th Street Viaduct project has been designed to withstand, at a minimum, a seismic event expected to occur once every 1000-years. Importantly, the viaduct is expected to remain functional after this seismic event, which surpasses the standard for the area. Seismic isolation bearings, typically located within the viaduct columns, allow lateral movement up to 30 in in the case of an earthquake. By using these bearings, three intermediate expansion joints were eliminated from the structure, a design decision that contributed to significant capital cost savings and will lead to reductions in maintenance expenses over the life of the project as expansion joints are typically high maintenance items.

The project eliminates the use of piers on the water which improves the capacity of the Los Angeles River basin and reduces the risk of flooding.

The revitalization of the river ecosystem through the PARC Project will also help create a vibrant habitat and improve overall community resiliency.

It is hoped the new 6th Street Viaduct will have a positive impact to the neighborhoods on either side of the bridge.

The brightly lit bridge and improved transportation should motivate people to use the future park and spur the development of public spaces in an area which is typically deserted at night.

Diversity

Out of the 35 COWI employees who worked on this unique project, 10 were female in the fields of Engineering, Project Management, Finance and Support Services. The 6th Street Bridge construction team on site included 15 women — the most on any commercial project in L.A. and nearly double the Department of Labor's participation goal of 6.9% female crew members.

TECHNOLOGY TRANSFER

In close coordination with the Contractor COWI developed a full staged construction analysis, detailed design for falsework, graphical solutions for complex geometry visualization and comprehensive information for hanger stressing procedures.

The information was summarized in Memos to show the findings of analysis and design. Yet, COWI also showed visualizations from numeric analyses and graphical assessments. In order to provide easier understanding of the complex structural behavior of this continuous structure such as camber and deflection interaction throughout the different construction stages, COWI generated simplified plots showing the elevation change stage by stage for Edge Girders and Crown of the deck. The organization of the data in this way helped not only the Owner but also the workers onsite to better understand the complex behavior of this structure.

Hanger stressing schedules were provided on spreadsheets with graphs to visualize target vs actual stresses during the hanger stressing procedures.

Modelling

COWI used a staged construction analysis developed in the FEM package SOFiSTiK. The analysis considers effects such as post tensioning, long term effects, such as creep and shrinkage, and nonlinear falsework support. The model provided stress checks of the concrete elements at all the construction stages. To achieve the final geometry at 10 years after the end of construction, it was fundamental to consider the movements the bridge is subject to during construction resulting from all the before mentioned effects.

Graphics

3D suite Rhino with Grasshopper was used to resolve complex geometry issues, related to the 9-degree outward canted arches including hangers and the bridge plan curve, which could have led to exceeding the geometry tolerances. Because these are network arches, placing the hangers at the designed geometry within the design tolerances was very important for a successful completion.

Unique Solutions/Analyses

COWI developed camber and produced simplified deflection visualization diagrams to communicate the complexity of the construction phasing and time dependent movements to the Owner. COWI also provided specialty analysis services to resolve potential issues arising during construction.

Base Isolators and Bridge Construction – How was that Achieved?

From the analysis, COWI obtained the required bearing offsets due to the PT and time dependent longitudinal movements of the bridge. COWI's analysis estimated that the bridge would move in certain locations up to 2-5/8" before achieving the target geometry at 10 years after end of construction. COWI therefore evaluated the offset each bearing would need to have during its installation. Furthermore, the triple-pendulum isolation bearings needed to be restrained so they could support the Y-Bent column on top during form removal. That restraint was achieved by the use of unique LUDs made to suit the bridge geometry and construction stages.

Expertise

"Having the opportunity to apply our expertise to projects of this kind reminds you just how important our work is. By exploiting some of the most advanced techniques we can ensure the safe and sound erection of complex infrastructure projects. "

COWI's Senior Project Manager
Tobias Petschke

Longitudinal and Transverse Post Tensioning

Longitudinal PT is continuous over the entire 3060 ft-length of the bridge deck. Couplers were used to connect tendons to achieve this length and not to have tendons with individual length of more than 900 feet. PT Contractor DSI performed the installation and stressing. Transverse PT was used to optimize the floor beam geometry.

Camber and Stresses

As mentioned, COWI performed a camber analysis. The complexity of the analysis contained all durations per stage, PT tensioning effects and timing of the bridge constraints, and time dependent effects so that all different effects could be superimposed to determine the camber. Staging and flexibility of falsework also played a significant role herein.

Hanger Installation and Stressing

Hanger stressing is one of the more complex operations on a tied/network arch. On this bridge the spans were continuous which added further complexity to this task. Each span's hanger forces would affect the next span. COWI determined a sequence that allowed the Contractor to install the hangers, remove the falsework that supported the deck, thereby loading the hangers and then proceeding to final stressing.

Hanger forces were monitored with vibrating wire strain gages supplied by GEO-Instruments and data was recorded with a web interface. Due to the complex interaction between the concrete and steel bridge elements, temperature effects became an issue in the correct understanding of cable force readings. Ultimately, the strain gauge readings were collected at night when the concrete and steel elements reached near-equilibrium temperature to better correlate cable force tensioning with temperature effects.

Innovation

A series of innovations contributed to the success of this unique structure:

- Seismic isolation of the entire superstructure from the ground by use of triple-pendulum isolation bearings
- COWI designed unique and project specific LUDs for stabilization of the triple-pendulum isolation bearings during construction
- The 3060-ft-long Post-tensioning tendons through use of post-tension couplers, to post tension the entire concrete deck between expansion joints
- The grade 80 reinforcing steel in knuckles and arches to increase seismic capacity
- Advanced rebar clash detection by the use of BIM tools
- Assessment of the as-built geometry through LiDAR scan point cloud assessment
- Form finding processes with grasshopper for hanger fin plate geometry optimization
- Hanger force monitoring with vibrating wire strain gages providing a live web interface to check hanger forces at all times during the hanger stressing process
- Development of a hanger stressing sequence for viaducts with continuous spans, where span to span interaction needs to be considered.

ENVIRONMENTAL BENEFITS

This project earned an Envision Platinum award for sustainability, specifically for addressing community needs, adding significant public space and amenities, and improving community safety and resiliency. The project responds to various community needs including the identified need for more park space in the Boyle Heights neighborhood and Central City North. The Sixth Street PARC Project will soon start development now that the viaduct is built. These improvements will respond to community needs gathered through an extensive public engagement process, including a series of meetings and community surveys. Programming elements to be included in the PARC Project include a soccer field, landscaped sitting areas, a children's play area, grilling and picnic areas, flexible play and performance lawns, and a dog park.

Supporting Long-Term Sustainable Growth and Development.

"Infrastructure projects like the Sixth Street Viaduct can be significant contributors to the socioeconomic vitality and attractiveness of communities," said Melissa Peneycad, ISI's managing director. "It's exciting to see anticipation building around many new projects that are moving ahead or are proposed for the viaduct area, and also to recognize the immediate benefits — not least, the benefit to existing businesses, non-profit, and community activities from the increased foot traffic in and around the bridge."

The multimodal transportation pathways and walkways enlarge mobility options for visitors and the community, where car ownership is below the Los Angeles average. Enhanced mobility, together with the new venues that are being developed in the area because of this project, will spur additional long-term economic and cultural value.

"Wow — by earning the Envision Platinum Award, we've not only proven that the substantial sustainability goal was achiev-able, but also shown that the Project First Mindset worked, in that all participants delivered their part for the benefit of the environment," *said Jeff Smith, Project Manager, Skanska-Stacy and Witbeck JV.*

COMPLEXITY

The bridge concept was driven mainly by the architectural form and the seismicity of the site. The columns and arches create the image of a 'Ribbon of Light' connecting the Los Angeles Art's District with the community of Boyle Heights. The 10 sets of arches are not uniform, seven are 30 ft high, one is 40 ft over the 101 freeway, and two are 60 ft over the railroads. Seismic resilience is provided by the use of triple-pendulum isolation bearings installed in the stem of the Y-Bent columns, which are supported on cast-in-drilled-hole (CIDH) concrete piles 10 ft in diameter that extend as much as 165 ft into the ground. Since the isolators are placed in the unusual location within the height of the column, a number of novel approaches were implemented to ensure unseating cannot occur.

While 165 ft deep CIDH piles with a 10 ft diameter are already complex in their installation, the installation of bearings before superstructure erection poses additional challenges for meeting the required tolerances.

The superstructure construction in several stages while supported on falsework is complex enough yet the structural continuity adds span to span interaction to it.

Ultimately, hangers get installed while the deck is still supported by falsework and the falsework removal after hanger installation was considered as a loading stage for the hangers.

Combining Falsework and Erection Engineering Solutions

Erection engineering entails the development of a feasible construction sequence, the design checks of the different construction stages, and the cambering of the structure to achieve the targeted design geometry.

It was extremely challenging for this project to achieve the target geometry as the target geometry was prescribed at 10 years after the end of construction date. As such, COWI needed to take into account the interaction of all different time dependent effects during construction, which was a complicated process given the size of the bridge and the duration of construction.

Stability of the partially erected structure was a main concern for such complex bridge construction. Therefore, COWI designed unique lock-up devices (LUDs) that hold the Y-Bents in place during construction by stabilizing the triple-pendulum isolation bearings, creating temporary fix points for geometry control. The LUDs will eventually serve as shear keys that will accommodate anticipated changes in the alignment of the continuous cast-in-place structure due to creep and shrinkage. Furthermore, COWI analyzed the falsework bridge interaction as the Contractor planned to build the bridge on traditional Californian falsework.

To achieve the required hanger design forces, COWI created an elaborate hanger installation and stressing sequence to minimize the required stressing operations per hanger.

How it was Built

Following demolition of the old bridge, construction commenced by installing the large CIDH pile foundations. The piers were then constructed followed by the bridge deck, starting from west to east to provide easier access. Once the deck was in place construction of the arches began. Hanger installation was performed while the deck was still supported by falsework and the falsework was removed only after initial hanger stressing. This procedure was carried out span by span.

The Contractor used local carpenters to build the forms for the cast-in-place concrete of the superstructure. Columns were formed with aluminum elements.

Cast-in-place concrete was cooled with nitrogen, and cooling circuits embedded in the structure would further serve to control concrete hydration temperatures.

Problem Solving Examples

Problem solving such as hanger fin plate alignments needed to be performed in 3D to meet the tight tolerance of 0.75 degrees. Failing to achieve this tolerance would lead to clashing of crossing hangers and stress exceedance in the fin plates. COWI used Rhino and Grasshopper to find the correct alignment connecting the 3D model with the analysis to consider the geometry impact of camber.

COWI undertook a number of considerations to ensure the safety of both the public and the construction crew during this complex bridge erection, including the specifically designed LUDs to stabilize the triple-pendulum isolation bearings of the bridge during construction.

MEETING OWNER'S NEEDS

Team Interactions

Following the spirit of the CMGC model, a strong focus was made in coordinating our efforts with the Construction Team. COWI held regular meetings with the Contractor, Designer and Owner. We initiated fully electronic submittals, coordinated site visits, and during COVID we communicated via video conferencing during critical site operations.

Tailoring our Work to the Contractor's Capabilities

COWI carefully considered which means the Contractor would use to perform construction in each construction stage, the resulting constraints and support conditions. Information was provided in concise and comprehensive format.

COWI paid great attention to potential schedule impacts and helped the Contractor to stay on track. Proactive issue management helped to identify issues early on and to mitigate them.

Responsiveness

COWI maintained a core team of three engineers throughout the entire construction period. Our engineers switched up tasks between originator and checker to allow each team member to gain knowledge of the individual construction process, and the ability to respond to the Contractor's requests.

Teamwork

"The City of Los Angeles Bureau of Engineering is proud to deliver the largest bridge project in the city's history," said Gary Lee Moore, City Engineer. "The new viaduct looks to the future and will unite the community with a multi-model structure that will be a destination point for both residents and visitors. This project is an example of what future infrastructure projects should strive to achieve through collaboration with stakeholders and the delivery of a project that improves community mobility, quality of life, safety and resilience. The Sixth Street Viaduct has achieved these sustainable goals, as shown by the Platinum Envision award."

"It was a challenging project but the excellent teamwork between Designer, City, Contractor, and Erection Engineer made this project a success story," explained COWI's Senior Project Manager Tobias Petschke.