PIPELINES HANGING FROM BRIDGES – UNIQUE DESIGN PROBLEMS TO OVERCOME, UNIQUE SOLUTIONS TO CONSTRUCT

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ABSTRACT

The Golden State Water Company (GSWC) serves more than 1 in 20 Californians with drinking water, which is a total of over 1.5 million customers. They serve a diverse number of water systems located all over the state, including Southern California. The Central District includes the cities of Bell and Bell Gardens. The two cities have diverse sources of supply including surface supplies and some groundwater. In order to improve the water supply reliability of both systems, GSWC decided to construct a 12-inch main connecting the two distribution systems.

The distance between the systems is about 1,400 feet (ft); however, it includes several daunting obstacles. A long bridge across the Los Angeles River and another bridge across the 710 freeway are between the two water systems, along with a multitude of utilities including gas, petroleum, communication ducts, water mains, and storm and sanitary sewers. Permits must be obtained from the California Department of Transportation (Caltrans), the statewide transportation agency, both cities, and several utilities with prior rights-of-way.

During 2007 and 2008, a pipeline design was prepared that included special features to overcome the multitude of obstacles. During late 2008 and early 2009, the pipeline was constructed. This paper documents the design decisions that were made and the resulting construction that implemented the design features. Some of the important decisions that will be discussed include:

1. Pipe material selection, for buried segments as well as suspended segments hanging from the two bridges.

2. Design and construction of a 450-ft pipeline span across the Los Angeles River bridge taking advantage of a corridor currently used by a large telephone duct and a gas pipeline, while avoiding these utilities

3. Design and construction of a 150-ft pipeline span across the 710 freeway, one of Southern California's busiest truck routes out of the Long Beach Harbor, so that

night construction was required with lane shutdowns of the freeway to install hangers and piping

4. Consideration for and installation of special pipeline features to account for seismic response and thermal expansion and contraction across both bridges which are exposed pipelines

5. Consideration for thrust restraint in all segments of the pipeline, buried and suspended segments

6. Traffic control on the bridge decks and connecting roadways, including methods, features, and success during construction

BACKGROUND

The Golden State Water Company serves more than 1 in 20 Californians with drinking water, which is a total of over 1.5 million customers. Their service areas are diverse and distributed throughout the State. In the Los Angeles region, Central District, they serve many cities, including Bell and Bell Gardens. Water supplies are almost entirely groundwater. The City of Bell has a population of 38,762, and encompasses 2.64 square miles (mi^2), while Bell Gardens has 44,454 inhabitants and covers 2.49 mi^2. Currently, the entire Southern California area has seen a reduction in surface water supplies normally imported from the northern part of the state. Consequently, in order to improve the reliability of the water supply for these two cities, as well as the water system reliability, the GSWC determined to construct a 12-inch pipeline connecting the two water systems.

Gage Avenue is a minor arterial route (two lanes each direction) that connects the two cities. However, to get from one city to the other, Gage Avenue traverses a bridge over the Los Angeles River and across the major 710 Freeway. The distance between the two systems is about 1,400 ft. The Los Angeles River, entirely concrete lined in this area, has a long bridge 450 ft in length crossing it, and the 710 Freeway crossing is a 150-ft span. As the pipeline finally exits the bridges at each end, it must divert at right angles on to residential streets down steep slopes. Refer to Figure 1 for an overall layout of the route and largest obstacles, which also included a number of utility crossings such as large-diameter oil and gas lines, communication ducts, water mains, storm drains, and sanitary sewers.

During 2007, a preliminary evaluation of the route was made during a field inspection. Initially, horizontal directional drilling was one option considered, but ultimately dismissed because of cost and uncertainties in crossing the L.A. River channel. Attaching the pipe to the exterior rails of the bridge was dismissed early, as the L.A. River Gage Avenue Bridge is a beautiful old style bridge with arches (refer to Figure 2), and a recent project included upgrading the light standards to further enhance the bridge status as an iconic structure, day and night. Recent public expenditures have created a wide bike and walking path with landscaping along one edge of the river, so aesthetic issues were deemed important. Caltrans, which has jurisdiction over the freeway bridge, also prefers that utilities stay within the bridge structure for aesthetic reasons.

Each bridge exhibited some previous consideration for placing utilities. The L.A. River Bridge was built with two large utilities in a central corridor beneath the bridge deck and between the I-beams. A telephone utility duct and an 8-inch gas main were supported by transverse small 4-inch steel beams with a spacing of about 8 ft. The end of the steel beams rested on small corbels built into the legs of the large-concrete I-beams (refer to Figure 3). On the 710 freeway, which is also constructed using T-beams with a deck and an integral end diaphragm abutment, Caltrans placed a blockout 5 ft wide by 18 inches high in the abutments, the middle bent, and the two intermediate diaphragms (refer to Figure 4). The 8-inch gas main took up a portion of the opening, but the rest was available. On the L.A. River Bridge, the two existing utilities provided a formidable obstacle to avoid, and limited the alternate route selection. Interestingly, even though the 8-inch gas main became inactive and was abandoned in place several years ago, the gas utility did not want to relinquish the corridor of the gas main, which would have been an ideal location for the 12-inch water main.

Figure 1. Project Site (Arial Source: Google Earth, 2009)

Figure 2. Sideview Gage Avenue Bridge Over L.A. River

Figure 3. Existing Utilities Resting on Cross Beams

Figure 4. 710 Freeway Bridge Showing Blockouts for Utilities

Permits were identified that must be obtained from both cities (encroachment) and a permit from Caltrans was also required. The United States Army Corps of Engineers (USACE), which has jurisdiction over the L.A. River, did not require a permit as long as material was not stored in the concrete river bottom. They noted that the rainy season officially runs from November 1 to April 1, but most often any significant water flow in the L.A. River is released from upstream retention dams, so there is advance warning. There is a low water channel about 12 inches deep by 40 ft in width that conveys minor irrigation runoff year-round. (Such is the fate of a river running through the nation's second largest city/metropolitan area; all natural runoff is a precious commodity to be intercepted, stored, and percolated into the upstream groundwater aquifers). All of the utility owners along the route were contacted for plans, and special provisions were included in the design to avoid all the competing utilities. Potholing existing utilities provided valuable information that was included in the final design to avoid field surprises during construction.

DESIGN APPROACH

There were a number of key decisions that needed to be made as part of the approach to the final design of the project. These included (1) selection of pipeline materials, (2) design of unique pipe support systems for each bridge, (3) coordination with adjacent and competing utilities, (4) providing a design that meets the design standards of Caltrans for freeway crossings in bridges, (5) consideration of features for seismic response, thermal expansion and contraction and thrust restraint, especially in the exposed bridge segments, and (6) traffic control at each end, exiting the bridges, and for the buried segment between bridges.

Alternate Pipeline Materials

For a 12-inch water main, candidate materials were deemed to be ductile iron pipe (DIP), polyvinyl chloride (PVC), and Steel. The GSWC does have quite a bit of asbestos-cement (AC) pipe in the system but is no longer installing it. For buried pipeline, GSWC in recent years has standardized on DIP, so that was the material of selection for the buried segments. For the bridge segments, since the pipe would need to be somewhat self-supporting, PVC was ruled out. DIP and Steel were both determined to be acceptable materials for the segments that would be supported by pipe hangers on both bridges. Ultimately DIP was favored on the L.A. River Bridge because it is the current standard widely used by GSWC. In addition, with a painted epoxy coating and standard cement mortar lining, the weight was fairly similar to steel pipe, so the bridge hanger design was comparable. Another important piping decision was the type of joint. Flanged pipe was dismissed because it was too rigid for the geometry required for this crossing, and it does not provide any thermal expansion/contraction capability. Restrained joint DIP has been used in a number of locations for bridge crossings because it provides a strong joint, flexibility, and some expansion/contraction capability. Ultimately grooved-end (GE) couplings, with a flexible radius joint, were selected to join the pipe segments. The coupling provides a joint system capable of handling very high pressures, with some ability to move in place allowing for thermal expansion and contraction, and is relatively easy to remove and repair pipe segments if necessary. (This author had prior experience using GE couplings on a 10-inch water main at the South Rim Grand Canyon where pipeline pressures were in the 600 pounds per square inch [psi] range). In addition, the geometry of the L.A. River Bridge crossing included a small vertical curve required over the 450-ft span, as well as a horizontal curve required at each end to move the pipe over to a better location for penetrating the bridge abutment wall (less rebar to cut).

The 710 freeway bridge had several additional requirements that influenced the choice of pipe material. Firstly, Caltrans requires that all water conveyance piping be placed in a steel casing when the main is exposed as it crosses above freeway travel lanes. The concept is to contain a pipe leak, if one occurs, and divert it to the shoulder of the roadway to minimize the danger to continuous traffic. The bridge structure blockouts were 18 inches high, so this limited the steel casing to 18-inch outside diameter (OD), and with a 0.375-inch wall thickness meant that the available space for a water carrier pipe would be 17.25 inches in diameter. Most types of bell and spigot DIP have a bell OD in this range, so it was determined that restrained-joint DIP would not work to be inserted within the steel casing. Further compounding this issue was the fact that the Gage Avenue roadway above, and the T-bridge beams across the freeway, had a slight vertical curve so that fully rigid type piping systems were not going to be acceptable. Ultimately conventional lap-welded steel pipe was selected for the 12-inch carrier pipe, with an epoxy coating inside and out. The outside coating included an epoxy hold-back at the joint for coating in the field. On the inside of the carrier pipe at the joints, it was decided to fully assemble the pipe and install it on the bridge, and then pull a one-piece seamless in situ liner in place from one end to the other.

Design of Unique Pipeline Support Systems

The existing utilities on L.A. River Bridge, a box telecommunication duct and an 8-inch gas main, required a hanger support system that worked around these obstacles as well as the existing support system. It was determined necessary to completely avoid the existing hangers and utility support system. Furthermore, it was necessary to avoid modification to all existing bridge structural elements, since alterations to the bridge structure were not to be considered. The ultimate engineering solution required a great deal of investigation of the unique geometry of the bridge structure. To assist the contractor with understanding the plan, the two bridge concrete I-beams that flanked the utility corridor were dimensioned in plan and section detail on the design plans, showing the route intended. A hanger system was devised (Refer to Figures 5 and 6) that consisted of an HSS 4 x 4 x 1/4-inch structural box element with a flat plate fastened to a leg of the bridge beams (the beams vary between T-beam configuration at the abutment and full I-beam at intermediate bents). Standard U-bolts were used to hang the pipe from the hollow structural sections (HSS). To avoid a full cantilever condition, the hanging end of the HSS was further supported by a 7/8-inch-diameter welded eye rod to the deck of the adjacent concrete beam. The beam attachment for the eye rod is a standard design. All hanger components were either stainless, galvanized, or epoxy-coated to be made suitable for long-term corrosion protection. The spacing of the hangers was dictated in part by the existing support system for other utilities, which was at about 8 ft on center. Consequently, it was decided to mimic the spacing for the new hangers, which would provide at least two hangers per 20-foot pipe joint.

The 710 Freeway Bridge, as noted, had a corridor with concrete blockouts 5 ft wide by 18 inches high. The steel casing pipe was therefore selected to be 18 inches OD. A system of hangers was required to support the casing from the bridge deck.

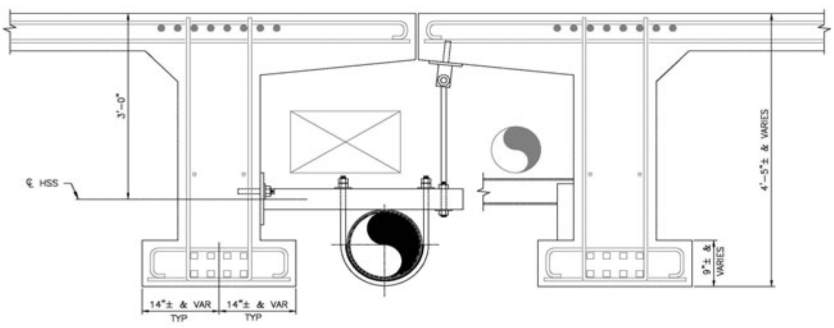

Figure 5. Detail for L.A. River Bridge Pipe Hanger

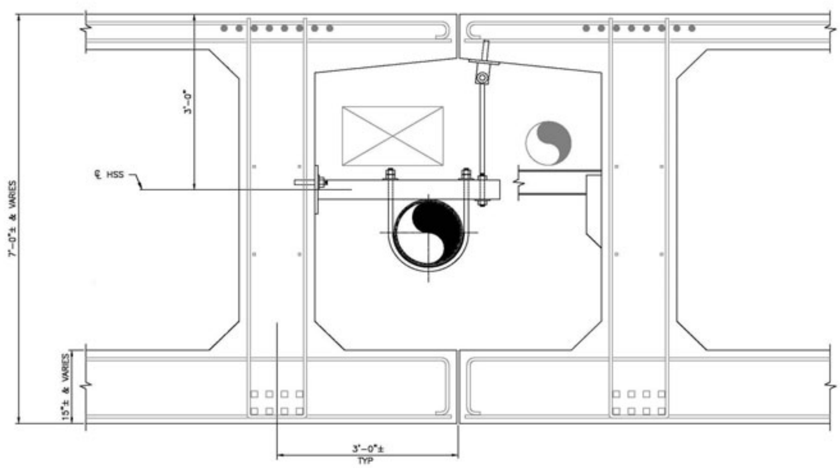

Figure 6. Detail for L.A. River Bridge Pipe Hanger

Standard adjustable steel yoke piperoll hangers were selected to support the casing, as well as the 12-inch water carrier pipe inside (Refer to Figure 7). A 1-inch welded eye rod was to be hung from a concrete clevis plate. Finally, these roller hangers were further stabilized in the lateral direction by a 4 x 4 x 3/8-inch angle fastened to the leg of the bridge beam. The hangers were spaced at 6 ft, 2 inches on center, providing at least three hangers for each 20-foot segment of casing. Grooved-end couplings were specified for the 18-inch casing pipe, in order to facilitate field assembly, provide some flexibility for the vertical curve of the bridge structure, and avoid any field coatings.

Regarding the expansion anchors to be used for fastening the pipe hanger plates to the existing concrete bridge structures, the structural engineer selected an undercut type of expansion anchor as manufactured by Hilti (Refer to Figure 8). This type of hanger was selected because it is available in stainless steel, it has been designed for use in new or cracked concrete, and it comes in a wide variety of sizes and lengths that allow for custom selection of a diameter and embedment depth corresponding to the needs at each location.

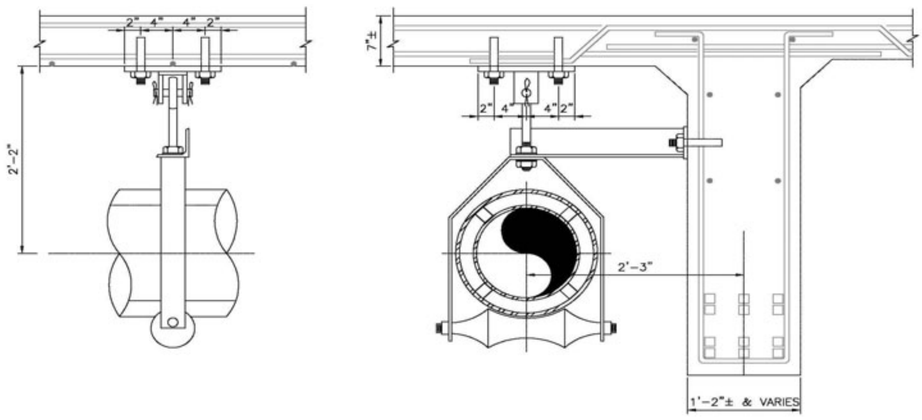

Figure 7. Detail for 710 Freeway Bridge Pipe Hanger

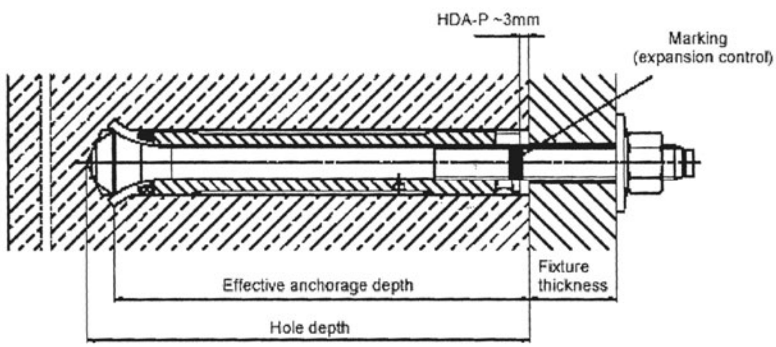

Figure 8. Hilti Insert Stud Anchor

Coordination with Adjacent and Competing Utilities

It has already been described how the telecommunications duct and the existing 8-inch gas main were important obstacles to work around on the L.A. River Bridge. Where these utilities exited the bridge through the abutments, the utilities had to be avoided in the buried environment. In addition, at the west end there was a 36-inch abandoned metal storm drain in the desirable alignment. Initially, it was proposed that this project would remove the old pipe and put the new water main in this location. Ultimately, the City reversed itself and requested that the abandoned storm drain be left in place, so the new water main was moved slightly into an open, but somewhat more restricted corridor near the curb and gutter. Between the two bridges was a segment of roadway about 200 ft in length, which included a number of buried utilities to be avoided and crossed: an 8-inch oil pipe in a 14-inch casing, an 8-inch gas main, a 6-inch oil pipe in a 12-inch casing, a telephone line, and significant overhead power transmission lines. In order to avoid the buried utilities, a segment of the new water main was placed at a sufficient depth to go under all the utilities.

Meeting Caltrans Design Standards

This highway agency has jurisdiction over all the major freeways in California, including the 710 Freeway. Caltrans has reviewed a number of similar utility crossings over the years and consequently has developed some basic design standards for utilities crossing their structures. The bridge at Gage is an end diaphragm type abutment with T-beams. Caltrans has published schematic type drawings to guide the design engineer in meeting their standards. They also require a flexible connection at each end of the crossing as a response to seismic concerns, that is, in the event of a seismic event they expect the bridge and adjacent soil to move differentially; consequently, they require provisions in the water pipeline to accommodate some movement. Therefore a number of design elements were included in specific response to Caltrans requirements including: (1) a casing pipe, as mentioned, to contain any leak in the water carrier pipe and divert it to the outside shoulder of the roadway, (2) a bridge hanger system that can move on rollers, as provided, (3) a flexible coupling at each end of the bridge to allow for differential movement between the buried soil portion of the pipeline and the segment attached to the bridge, and (4) extension of a pipe casing from the outside wall of the abutment to a location 5 ft beyond the approach slab or wingwalls of the bridge. In the case of this bridge there were wingwalls to retain earth for this freeway that is in a depressed position relative to adjacent ground. The wing walls at the west end of the bridge extend about 60 ft into the adjacent bank and on the east end the wing walls extend about 50 ft. For these buried reaches of pipe, 24-inch steel casing was buried to carry the 12-inch restrained joint DIP.

Caltrans was to issue a permit for construction the project. Consequently, the agency was contacted at a very early stage of the design process to obtain requirements and standards, or preferences. Several meetings were held. It became apparent that a traffic control plan would need to be developed for the freeway lane closures required. GSWC does not normally prepare traffic control plans during design, but in this case services were added to prepare a traffic control plan for freeway lane closures as well as a plan for constructing within Gage Avenue that would satisfy the two cities. The final freeway traffic control plan called for temporary closure of no more than two (of the total four) lanes at one time, each direction, and a night time work schedule only (exact start and stop times to be determined at time of construction).

It is fairly common knowledge that a Caltrans permit to construct may take up to 6 months for processing, and for this project that held fairly true to form. It was quite beneficial that the agency agreed to make an early review of the 90 percent complete plans. This allowed the design team to make changes or negotiate the final requirements so that after final submittal it was a relatively smooth process to obtain the final permit. However, after the low bid Contractor put his construction plan together, some additional changes to the permit were requested that required additional Caltrans review (more to be discussed on these issues).

Design Features for Seismic Response, Thermal Expansion and Contraction, and Thrust Restraint

The construction of a pipeline within multiple bridges involved a design response to each of these elements. In order to respond to the seismic movement concern on the 710 freeway crossing, a flexible coupling has been installed at each end of the bridge crossing between the pipe in the buried environment and the segment on pipeline hangers. Several pipe manufacturers have developed such a flexible coupling that will deflect horizontally and and/or vertically in the event of an event. One manufacturer has developed a zero-net-thrust model, which is thrust neutral under normal water service conditions. This unit in 12-inch diameter can expand up to 8 inches longitudinally (in and out), and deflect laterally, during a seismic event. For the L.A. River Bridge crossing, there are no special provisions for seismic response, as a leak would be a nuisance but would not necessarily lead to an accident, property damage, or personal injury (as a leak on the freeway crossing over travel lanes might cause).

The thermal expansion and contraction was estimated for the DIP within the L.A. River Bridge crossing. It was determined that the grooved end couplings could allow for the movement required. The welded steel pipe (WSP) within the 710 freeway bridge also has a need for an allowance for expansion and contraction. The rigid joints of the WSP within the casing on the bridge are directly connected to DIP with restrained joints on each end of the bridge, which can provide some minor response or movement to thermal changes. In addition, it was noted that the flexible coupling at each end of the WSP can provide for longitudinal movement in response to expansion and contraction.

Thrust restraint must be provided at all deflections along the route. In the buried environment, all of the DIP is provided with restrained joints to resist thrust. Furthermore at several key locations, concrete thrust blocks were provided to provide for backup thrust restraint. It should be noted that the restraint provided by the thrust blocks is only available as long as the soil profile behind the thrust block is not disturbed. Because the GSWC may not have direct control of the buried environment around thrust blocks, the thrust blocks were only counted upon for secondary restraint and the primary thrust restraint was provided by individual joint restraint.

Traffic Control

Normally GSWC allows the contractor to prepare his own traffic control plan (TCP) prior to construction and submit it to the affected City for review and approval. However, for this project, both cities wanted to see and review a traffic plan early in the design stage. In addition, Caltrans wanted to review a TCP prior to issuing a permit. Therefore, GSWC authorized the preparation of a TCP for work within Gage Avenue and for the freeway work during design. As pointed out previously, the Caltrans plan includes at most two lanes closed at any one time, and nighttime work only, during hours to be determined at time of construction.