Technical Memorandum
Bridge Structure Evaluation

Downtown/Riverfront Streetcar Studies

City of West Sacramento

December 20, 2006

HDR

2365 Iron Point Road, Suite 300
Folsom, CA 95630

Contents

Figures

BRIDGE STRUCTURE EVALUATION

The "Downtown/Riverfront Streetcar Studies" Project involves two existing bridges along Capitol Mall/West Capitol Avenue: the Tower Bridge over the Sacramento River (Tower Bridge) and the Capitol Mall Separation, which carries Capitol Avenue (formerly State Route 275) over Interstate 5. This study included a preliminary investigation of both structures to evaluate their ability to carry streetcar traffic along with the current mix of motor vehicle, bicycle and pedestrian traffic. The investigation, documented in the following sections, considered issues related to lane configurations, clearances and structural capacities for each structure, as well as potential approaches for addressing them.

Tower Bridge

Bridge Description

The Tower Bridge (Br. No. 22 0021), constructed in 1934, is a seven-span steel truss and plate girder bridge with lightweight concrete deck spanning a total of approximately 737 feet 7 inches over the Sacramento River (measured between paving notches at the abutments). It consists of four steel plate girder deck spans on the west approach (each between 34 feet and 35 feet in length) and an asymmetrical arrangement of three simple-span, through steel Pratt truss spans over the river. The main river span is a vertical lift span measuring 209 feet 6 inches. The lift span is flanked by truss spans of 192 feet 6 inches and 167 feet 5 inches on the west and east, respectively.

The overall bridge width is 68 feet 8½ inches including a 52-foot wide roadway and 4-foot wide sidewalks cantilevered outside of the trusses, which measure 56 feet 6 inches center to center. The through truss spans provide vertical clearance ranging from 15 feet 0 inches at the curbs to 23 feet 0 inches at the bridge centerline. The grades on the bridge range from level over the easterly portion of the west truss span and the westerly portion of the lift span to approximately 3.9 percent on the east approach.

The approach spans are supported by concrete piers founded upon concrete and timber piling. The lift span is supported on concrete piers founded upon large diameter, deeply embedded, concrete spread footing blocks.

The bridge originally carried a single electric interurban railway line along the center of the bridge flanked by four lanes of traffic, two on either side. Eventually, the interurban trains ceased operation, after which freight trains used the bridge for a number of years before the tracks were paved over and ultimately removed.

The Tower Bridge, which is owned by Caltrans, is listed on the National Register of Historic Places. According to the EIR/EIS for the sidewalk widening project, there are eighteen character-defining features of the bridge, including the trusses, certain railway features and the lightweight concrete deck.

Prior Modifications

The tracks were abandoned and paved over in the early 1960s, and were removed when the deck was rehabilitated in 2004.

The bridge was repainted in the late 1980s. This project added approximately 15,000 lbs of dead load to the lift span.

A project to widen the sidewalks is currently underway. In spite of significantly widening both sidewalks, this project is expected to reduce the overall dead load of the lift span.

Existing and Proposed Lane Configurations

Currently, the bridge accommodates four 11-foot traffic lanes (two each, eastbound and westbound) and two 4-foot shoulders within the 52-foot roadway, along with two 4-foot sidewalks outboard of the main trusses, as shown in **Figure 1**. This configuration was established by the deck rehabilitation project, which narrowed the lanes to 11 feet to accommodate bicyclists on the 4-foot shoulders in anticipation of the planned establishment of Class II bike lanes on the approach roadways. There is no opportunity to widen the roadway to accommodate the streetcar because the roadway is constrained by the 56-foot 6-inch spacing between centerlines of the trusses. Consequently, any proposed lane configurations must fit within the 52-foot roadway. A project to widen the existing sidewalks to 10 feet is expected to begin construction within the next year.

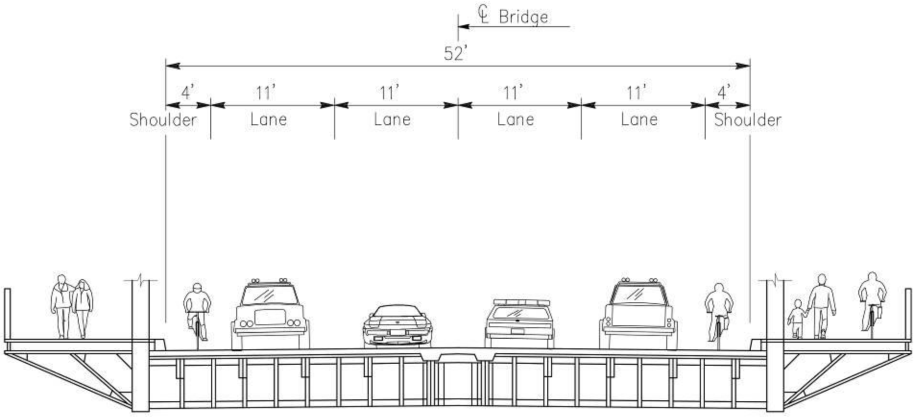

Figure 1 - Typical Section of Tower Bridge showing existing lane configuration (and proposed sidewalk widening) -two through traffic lanes in each direction with shoulders.

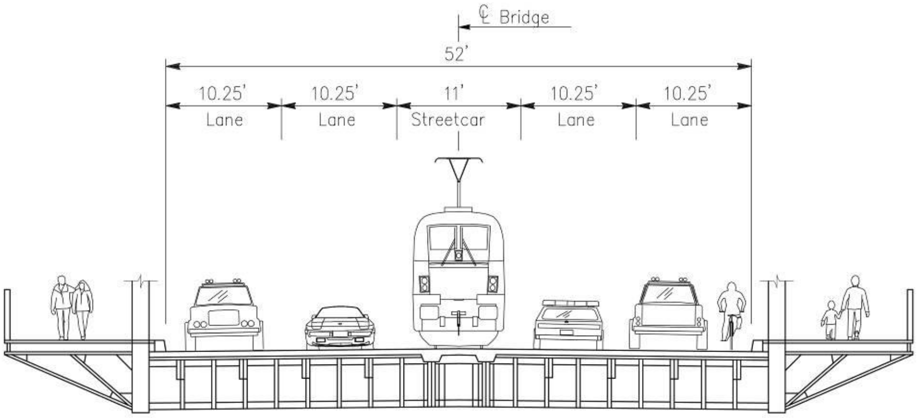

Figure 2 – Typical Section of Tower Bridge showing lane configuration Alternative 1 – two through traffic lanes in each direction and one dedicated streetcar track with no shoulders/bike lanes.

Three alternative lane/track configurations were investigated for accommodating the streetcar on the Tower Bridge:

Alternative 1: Four Traffic Lanes with One Dedicated Streetcar Track

In this alternative, a single, two-way, streetcar track would run along the centerline of the bridge in a dedicated right of way between two eastbound and two westbound traffic lanes, as shown in **Figure 2.** This is the lane and track configuration for which the Tower Bridge was originally designed. However, in this configuration, the traffic lanes would be only 10 feet 3 inches wide with no shoulders. Because of the high volume of truck and bus (100 buses per day) traffic on the bridge, and the importance of the bridge to commuter bicyclists, Caltrans has indicated that neither reducing the lane widths below 11 feet nor eliminating the 4-foot shoulders would be acceptable. Consequently, no further analysis of this lane configuration alternative was performed.

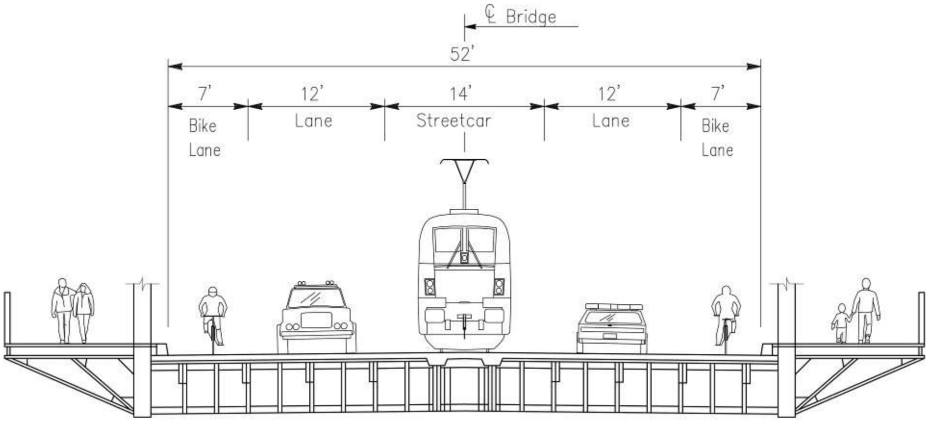

Figure 3 – Typical section of Tower Bridge showing lane configuration Alternative 2 – one through traffic lane in each direction and one dedicated streetcar track with shoulders/bike lanes.

Alternative 2: Two Traffic Lanes with One Dedicated Streetcar Track

In this alternative, as with Alternative 1, a single, two-way, streetcar track would run along the centerline of the bridge in a dedicated right of way. However, in this alternative, there would be only one eastbound and one westbound traffic lane, along with wide shoulders on each side **(Figure 3)**. This configuration would accommodate standard lane widths of 12 feet alongside a 14-foot dedicated streetcar right of way (ROW), and 7-foot shoulders.

Further study of the traffic implications of reducing the number of traffic lanes from four to two will be required, but, based on discussions with Caltrans, preliminary indications are that a reduction from four to two lanes may be feasible given that the primary traffic congestion along the Capitol Mall results from its intersection with 3rd Street, although bridge openings, particularly during the summer, are also significant contributors to congestion.

Alternative 3: Two Traffic Lanes and Two Mixed Flow (Traffic and Streetcar) Lanes

This lane configuration would be essentially the same as the existing one – four 11-foot traffic lanes with two 4-foot shoulders – but with two of the lanes (one in each direction) serving as mixed-flow lanes of highway and streetcar traffic. In this alternative, the mixed-flow lanes could either be the two interior lanes or the two exterior lanes **(Figure 4).**

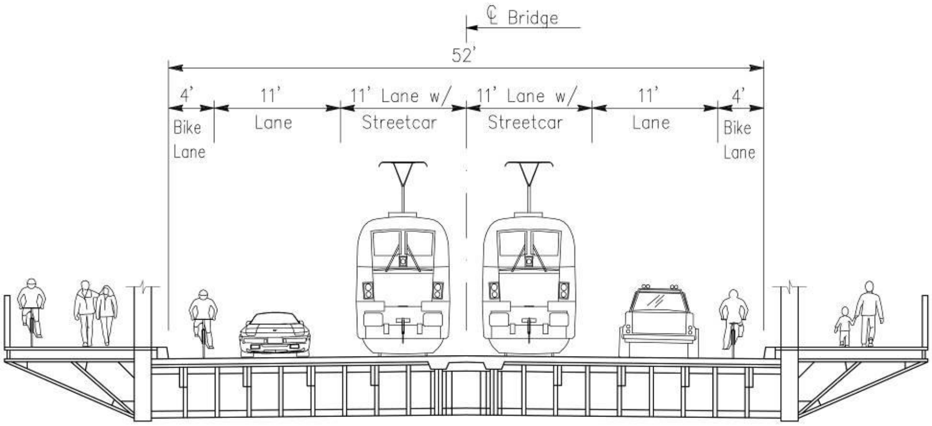

Figure 4 - Typical Section of Tower Bridge showing lane configuration Alternative 3 - one through traffic lane and one mixed-flow traffic/streetcar lane in each direction, with shoulders/bike lanes.

Original Design and Proposed Loads

Original Design Loads — Electric Railroad

The Tower Bridge was originally designed to accommodate four lanes of highway traffic and a single electric rail line. However, rather than being designed for typical electric railway loading of the time, the rail line was designed (according to the as-built plans) assuming a much heavier Cooper's E 50 loading representing a pair of 18-axle, 176.5-ton locomotive and tender combinations followed by a linear load of 3 tons per linear foot representing a train of freight cars, as shown in **Figure 5**. The maximum axle loads (four spaced on 5-foot centers for each locomotive) for the Cooper's E 50 loading are 25 tons.

The centerline of the track was placed at the centerline of the bridge. Two heavy steel stringers were designed for the E 50 loading and constructed directly under each rail of the track. Generally speaking, all of the rail vehicles being considered for the streetcar system are lighter than the Cooper's E 50 loading, but heavier than the H 15 trucks.

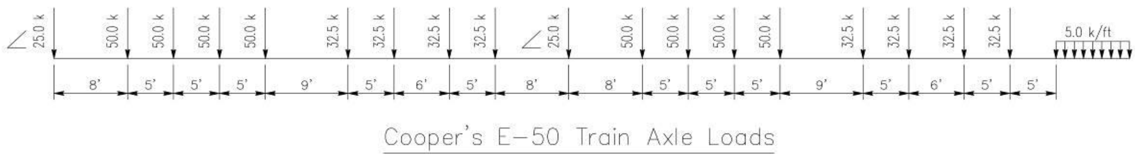

Figure 5 - Cooper's E-50 locomotive loading used for design of Tower Bridge.

Original Design Loads — Highway Loading

According to the as-built plans, the design load for the four traffic lanes was a 15-ton, two-axle truck (H 15 loading). For spans less than 60 feet, this loading consisted of a single 15-ton truck (3 ton front axle and 12-ton rear axle spaced at 14 feet) preceded and/or followed by a series of 11.25-ton trucks spaced 30 feet apart (measured between closest axles). For spans greater than 60 feet, the H 15 loading consisted of a uniform load of 480 lbs per linear foot with a 13,500-lb concentrated load for moment, and a 19,500-lb concentrated load for shear, as shown in **Figure 6**. Note that the linear lane loading is the same as for the current H 15-44 loading, but less than the current standard highway loading, which is HS 20-44.

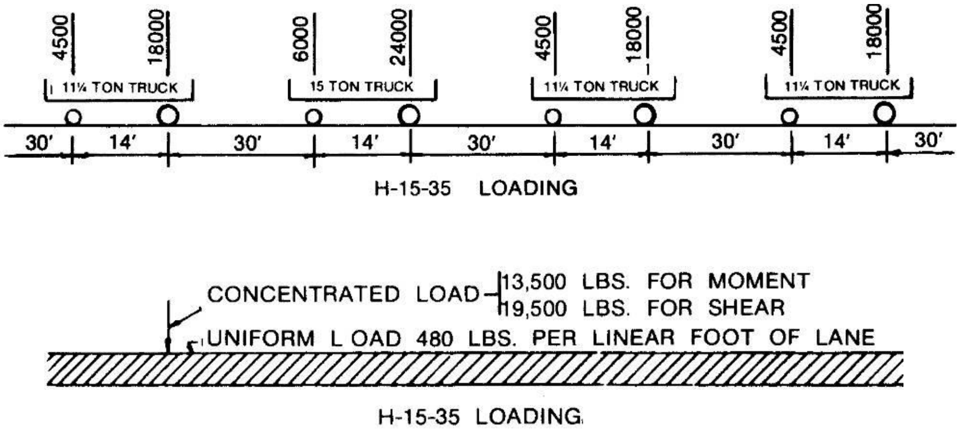

Figure 6 - Truck loading used for design of Tower Bridge.

Current Design Loads — Streetcar Loading

Three different electric traction vehicles are being considered for the new streetcar system: a replica Birney Trolley (Birney), a modern streetcar such as the Inekon TRIO (modern streetcar), and a Sacramento Regional Transit light rail vehicle (LRV).

The Birney trolley consists of a single car with two two-axle trucks as shown in **Figure 7**. Fully loaded, the Birney weighs approximately 30 tons, with the load assumed to be equally distributed between the four axles. The Birney trolleys are between 44 and 50 feet long, with a distance of approximately 21 feet between centerlines of trucks.

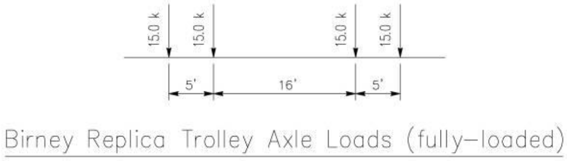

Figure 7 - Birney replica trolley loading.

The modern streetcar consists of a single articulated vehicle with two two-axle trucks as shown in **Figure 8**. Fully loaded, the modern streetcar weighs approximately 52 tons, with the load assumed to be equally distributed between the four axles. The modern streetcars are approximately 66 feet long, with a distance of approximately 39 feet between centerlines of trucks.

Figure 8 - Inekon TRIO “modern” streetcar loading.

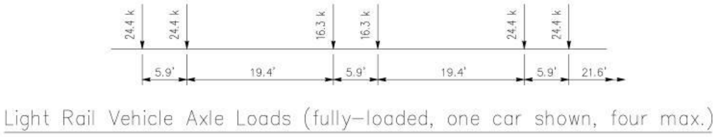

Figure 9 - Sacramento Regional Transit Light Rail Vehicle loading.

The LRV consists of up to four articulated vehicles with three two-axle trucks as shown in **Figure 9.** . Fully loaded, the LRV weighs approximately 65 tons per vehicle (260 tons for a four-car train), with the load distributed more heavily to the outer trucks (see **Figure 9**). The LRVs are approximately 78 feet long, with a four-car train being a total of 312.5 feet long. The distance between centerlines of trucks varies between 25 feet and 29 feet.

The LRV is clearly the heaviest of the potential streetcar vehicles, especially in the four-car train configuration. However, the modern streetcar has higher individual axle loads. Consequently, for members with short spans, the modern streetcar will be the controlling loading, while for those with longer spans, the LRV will control.

Current Design Loads — Highway Loading

Current design vehicles designated HS 20-44 (HS 20) weigh 72,000 pounds (36 tons). These trucks are 2.4 times as heavy as those for which the bridge was originally designed. However, for longer spans, such as the overall truss spans, the HS 20 lane loading controls over the individual truck loading. In contrast to the factor of 2.4 between the H 15 and HS 20 trucks, the difference between the H 15 and HS 20 lane loadings is only a factor of 1.33. Consequently, for highway loading, the affect of applying current loads is greatest for members with shorter spans such as the stringers and floor beams, and smallest for those with longer spans, such as the main trusses.

Streetcar Dead Loads

Other loads that must be considered with the reintroduction of streetcars to the bridge are dead loads associated with track, train control equipment and an Overhead Catenary System (OCS). These are typically on the order of 350 pounds per linear foot of track. So, for a single track the additional load to the lift span would be approximately 35 tons. For two tracks, the added dead load would be approximately 70 tons. Strengthening of the floor system for double tracking would further add to the dead load.

The lift span is extremely sensitive to the addition of dead load and to the distribution of dead load both longitudinally and laterally. The lift span weighs approximately 1,000 tons, while the total out-of-balance between the dead load of the span and the counterweights is less than 12 tons (i.e., the two counterweights combined weigh over 988 tons). Caltrans' goal is to avoid adding additional lifting weight to the span. The repainting project added approximately 7.5 tons to the total dead load of the lift span. The re-decking project, on the other hand, reduced the total dead load slightly (between 10 and 15 tons), and the sidewalk widening project, by using fiber reinforced polymer (FRP) decking in place of concrete, is expected to again reduce the total dead load of the lift span slightly, even thought the new FRP sidewalks will be more than twice as wide as the existing lightweight concrete ones.

Seismic Loading

Although the Tower Bridge is on the seismic retrofit list, according to Caltrans, it has never been thoroughly evaluated for seismic loads. Recently revised design ground motions are greater than those used in the past. Caltrans policy on previous projects has been not to require seismic evaluation as long as the dead load was not increased.

Existing and Required Capacity

The capacity assessment of the existing bridge was performed according to the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Condition Evaluation of Bridges*, Caltrans *Bridge Design Specifications* and the American Railway Engineering and Maintenance of Way Association (AREMA) *Manual for Railway Engineering*.

Because the lane configuration in Alternative 1 was considered unacceptable to Caltrans, no structural analysis related to this alternative was performed.

Trusses

Detailed analysis of the main trusses was beyond the scope of this investigation. Instead, the capacity of the trusses to carry the proposed streetcar loads was evaluated by comparing the proposed loads to the original design loads and to the current rated capacity of the bridge.

As noted previously, for a 200-ft span, highway lane loading governs over truck loading. Consequently, the difference in loading between the design H 15 loading and current HS loading is only a factor of 1.33. Conversely, the heaviest of the proposed streetcar loadings, the LRV loading produces a load affect (assuming a four-car train) only about 20 percent of that produced by the Cooper's E 50 loading. When the worst case proposed loading (two streetcar tracks with LRVs and two lanes of HS 20 lane loading) is compared to the original design live load of four lanes of H 15 and one track of Cooper's E 50, the proposed total live load affect is less than 75 percent of that for the original design loads. Similarly, the combination of two lanes of modern streetcar loading and two lanes of HS 20 result in a load affect less than half of the original design load, and a combination of two lanes of Birney loading with two lanes of HS 20 results in an even smaller total load affect.

The load factor rating of the bridge performed by Caltrans shows an inventory rating of 32.0 tons, or approximately 80 percent of the full HS 20 loading. This can be considered a lower bound capacity for all of the members considered because the rating is based on the controlling member in the structure; all other members must have at least the capacity of the controlling member. Because the trusses were designed for the heavier Cooper's E 50 train loading, along with four lanes of H 15 lane loading, it is reasonable to conclude that the trusses were probably not the controlling members for the rating. A detailed review of Caltrans rating calculations in the next phase would be expected to confirm this assumption. That said, a comparison of the total live load associated with two lanes each of LRVs and HS 20 lane loading shows that this combination would significantly exceed the total rated capacity if the trusses were the controlling members, whereas a single track of modern streetcar along with two lanes of HS 20 would exceed the rated capacity by only about 20 percent. On the other hand, two lanes of either the modern streetcar or the Birney along with two lanes of HS 20 would be less than the total rated live load.

We can therefore conclude that the trusses are adequate for lane configuration Alternatives 2 and 3 for either the modern streetcar or the Birney trolley. Further study would be required to determine definitively if the trusses are adequate for the alternatives with the LRV.

Floor Beams

Floor beams were evaluated in a manner similar to that for the trusses: approximate load affects on the floor beams associated with the proposed loadings were compared to the load affects for the original design loading. As with the trusses, and as would be expected, the loads on the floor beams associated with the proposed streetcar loadings are small in comparison to the original design loads, regardless of which streetcar vehicle is applied (well under 50 percent of the original design loading). However, for the floor beams, because of the relatively short live load span (25 feet 2 inches), the LRV and modern street car load affects are not significantly different. Furthermore, again looking at the rating as a lower bound capacity for the floor beams, a comparison of the proposed four-lane configuration with the rated capacity shows that the proposed streetcar lane configurations all create less load affect on the floor beams than the rated capacity.

Therefore, as with the trusses, we can conclude that the floor beams are adequate for lane configuration Alternatives 2 and 3 for any of the proposed streetcar vehicles, including also, in this case, the LRV loading.

Stringers

Stringers were evaluated in a manner similar to that for the trusses: approximate load affects on the stringers associated with the proposed loadings were compared to the load affects for the original design loading. There are two main types of stringers to be evaluated: the two “railroad stringers” under the original tracks, and the “roadway stringers” supporting the remainder of the deck (exclusive of the sidewalks).

For the railroad stringers, the load affects associated with the original Cooper’s E 50 loading are more than double those of any of the proposed streetcar loads or HS 20 loading. Therefore, it is clear that the railroad stringers are adequate for any of the proposed loading configurations or vehicles. Because the railroad stringers are so much larger and more closely spaced than the roadway stringers, it is clear that they could not be the controlling members for the load rating, as they both have greater capacity and are subjected to a smaller magnitude of loading than the roadway stringers.

On the other hand, for the roadway stringers, none of the proposed load arrangements or vehicles results in load affects less than those associated with the design H 15 loading. However, the load rating for the roadway stringers indicates a higher capacity than the original design load. Even so, only the Birney trolley results in load affects less than the rated capacity of the stringers. Therefore, for lane configuration Alternative 3, use of either the modern streetcar or the LRV would result in the need to strengthen the eight roadway stringers. Even with the Birney trolley, in order to run it with traffic, support for the rails would have to be provided independent of the deck slab or the existing roadway stringers, as the deck is not thick enough to support an embedded rail and the stringer spacing does not match the rail gauge. Consequently, only lane configuration Alternative 2 is viable without strengthening of either the deck, four of the roadway stringers, or both.

Structural Modifications

Addition of streetcars to the existing bridge is expected to require significant strengthening only of the roadway stringers, and only for lane configuration Alternative 3. For this alternative, two strengthening options are the concrete bridge deck could be removed, higher capacity steel stringers installed to replace the smaller deficient stringers, and the bridge deck reconstructed. The higher capacity steel stringers would be placed as close as possible to the underside location of each rail of the track. For lane configuration Alternative 2, either embedded track (similar to the original design) or direct fixation track (placed on top of the bridge deck) could be feasible, as this alternative would require a dedicated ROW for the streetcar. Alternatively, the existing stringers could be strengthened with cover plates and transverse beams added between the stringers below the deck to directly support the rails.

If existing stringers were removed and replaced, rather than adding stringers or strengthening the existing ones, the use of high performance steel would offer some weight savings that could offset the additional weight of the track, train control equipment and OCS. Strengthening the existing stringers would necessarily add significant weight to the lift span. Either solution would potentially adversely affect the historic character of the bridge. However, because of their location near the center of and below the deck, the new or strengthened stringers would not be apparent to any but the most determined viewers of the bridge.

The existing hoist system has very little spare capacity, so any addition of dead load to the lift span may significantly affect the operation of the lift span. Added dead load associated with strengthening the stringers and adding track, train controls and an OCS must either be limited or offset by weight savings elsewhere in the span. As noted earlier, the sidewalk widening may reduce the total dead load somewhat, as could replacing, rather than strengthening stringers. Given that the deck is already constructed of lightweight concrete and polyester concrete, and that the existing lightweight concrete deck is one of the character-defining historic features of the bridge, replacement of the deck with a lighter deck system is not likely to be an option.

There are a couple of other concerns regarding a two-track system on the bridge. Lateral balancing of the lift span, especially with the strengthening or replacement of stringers, would be more difficult than for a single track solution. Also, because the single track alternative would closely match the original electric railway configuration on the bridge, it would have less affect on the historic character, although return of streetcars to the bridge would be, in itself, a restoration of sorts of one of the long-missing original features of the bridge. It should also be noted that the concrete pylons were originally span wire supports, and could again serve their historic purpose.

Finally, any re-introduction of electric transit to the bridge will require consideration of electrical stray current. Stray current provisions will need to be added to the bridge to prevent stray current corrosion.

Clearances

Adequate vertical clearances exist on the Tower Bridge truss spans for streetcars and their OCS. However, if tracks were placed near in the outer lanes, the vertical clearance may be less than desirable.

Two lanes of LRVs on the Tower Bridge would not be feasible without narrowing the shoulders to 3 feet. Two lanes of Birney or modern streetcars would be feasible with the existing 11-foot lane configuration.

Operational Issues

Integral to the decision of which lane configuration alternative to pursue are traffic operations such as streetcar and automobile/truck traffic flow and the potential congestion associated with reducing the bridge from four to two traffic lanes (Alternative 2). The double track alternative requires that the track be embedded flush with the deck, while the single track alternative allows for the possibility of deck-mounting the track.

Additionally, the schedule and operation of the streetcar will have to be coordinated with the opening/closing of the lift span for boat traffic. Similarly, consideration will have to be given to operations during construction. Strengthening or replacement of the deck stringers will require closure of at least two lanes on the bridge, and possible complete closure to traffic. Additionally, it may or may not be feasible to open the bridge during the strengthening operation. Some work may be done with the bridge in the open position to avoid blocking river traffic.

Caltrans is planning a project to overhaul the electrical and mechanical systems on the lift span. There may be value ion coordinating that project with any modifications proposed to accommodate streetcars on the bridge.

Capitol Mall Separation (Capitol Mall over Interstate Route-5)

Bridge Description

The Capitol Mall Separation (Br. No. 24 0236) was constructed in 1966 and is a three-span prestressed concrete box girder structure that carries Capitol Mall/State Route 275 (SR 275) over Interstate Route 5 (I-5). This structure actually consists of two independent structures carrying the eastbound and westbound lanes of Capitol Mall and separated by a 1-inch joint centered on the raised median. The structure is approximately 225 feet long with spans, from west to east, respectively, of 48 feet, 87 feet, and 90 feet. The total width of the deck is approximately 108 feet, including barriers, sidewalks, raised median, and a 90-foot roadway. The structure is supported by concrete abutments at each end and two intermediate concrete bents. Each concrete bent consists of two flared concrete columns founded upon concrete pile footings and piles.

In contrast to the Tower Bridge, the Capitol Mall Separation was not designed for interurban trains or any other rail vehicles. However, being designed in the 1960s, it was designed for HS 20 loading and overload vehicles.

Existing and Proposed Lane Configurations

Currently, the structure, as shown in **Figure 10**, accommodates one eastbound auxiliary lane between 1st Street and an off ramp to 3rd Street, two eastbound through traffic lanes, a 10-foot raised median, two westbound through traffic lanes, one westbound auxiliary lane extending from the on ramp from 3rd Street to a right turn only lane at 1st Street, and four 2-foot shoulders. There is also a westbound left turn lane to 1st Street that starts just before the west end of the separation structure. The separation structure has sufficient width within its 90-foot roadway to accommodate streetcars either in existing traffic lanes or in the median, except at the westbound left turn lane.

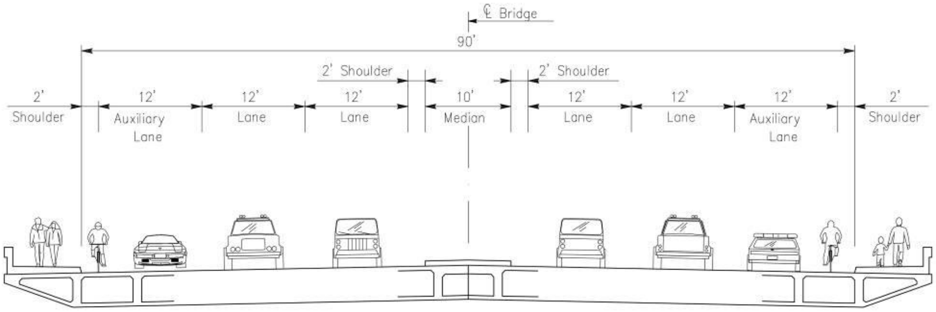

Figure 10 - Typical Section of Capitol Mall Separation showing existing lane configuration -two through and one auxiliary traffic lane in each direction with median and narrow shoulders.

According to Caltrans, there is a plan to remove the two ramps to and from 3rd Street. If this is done, then the two outer (auxiliary) lanes on the structure may no longer be needed, especially if the Tower Bridge is reduced to two lanes. For purposes of this discussion, the two auxiliary lanes will hereafter be referred to as the outer traffic lanes. Following are three potential lane configuration alternatives that were investigated:

Alternative 1: Six Traffic Lanes and One Dedicated Streetcar Track

This alternative would consist of placing a single dedicated streetcar track in the existing 10-foot median while maintaining the existing six lanes on the bridge. **(Figure 11)**. This lane configuration could be accommodated with either flush-mounted rail or rail on the raised median. This configuration is incompatible with the westbound left turn lane unless the turn lane is shortened so it is not on the structure and the track splits between the separation structure and 1st Street.

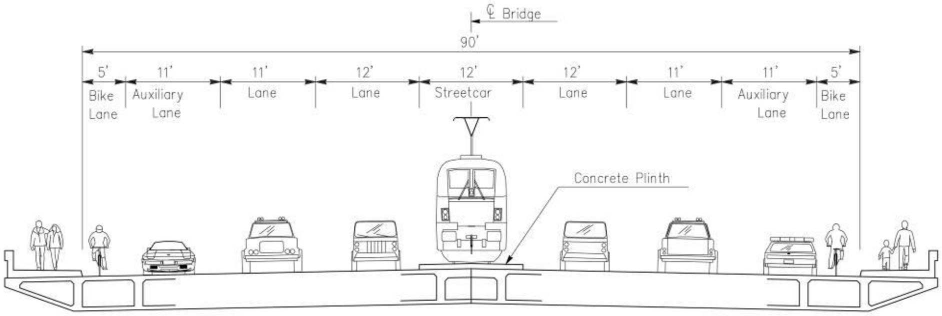

Figure 11 – Typical Section of Capitol Mall Separation showing lane configuration Alternative 1 – two through and one auxiliary traffic lane in each direction and one dedicated streetcar track, with shoulders/bike lanes.

Alternative 2: Four Traffic Lanes and Two Mixed Flow Lanes

This alternative would consist of adding double track to either the two inner or two outer lanes to create two mixed flow lanes as shown in **Figure 12**. This configuration would not require change to the existing raised median and lane configuration, except that the one eastbound and one westbound lane would be converted into a mixed flow lane where automobiles, trucks, and streetcars would all share the same lane. This alternative would require either flush-mounting the track in the existing bridge deck or overlaying the bridge deck with up to 7 inches of concrete or asphalt to raise the entire deck surface to the track elevation.

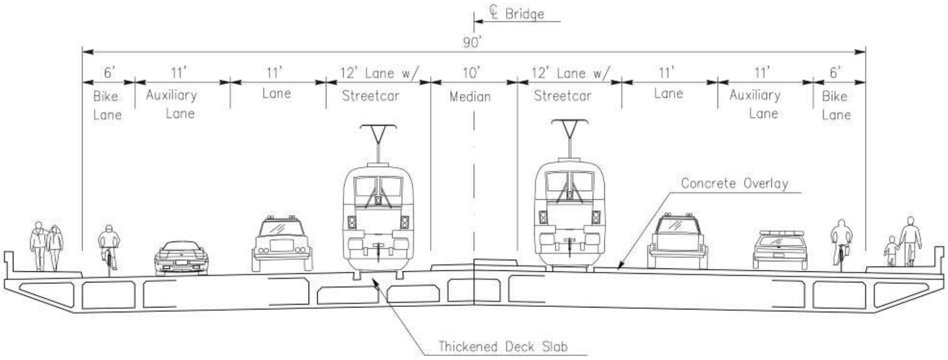

Figure 12 – Typical Section of Capitol Mall Separation showing lane configuration Alternative 2 – one through, one auxiliary and one mixed-flow traffic lane in each direction, with median and shoulders/bike lanes.

Alternative 3: Four Traffic Lanes and Two Dedicated Streetcar Tracks

This alternative would consist of adding double track in dedicated ROW replacing either the two inner or two outer lanes, as shown in **Figure 13**.

Original Design and Proposed Loads

The Capitol Mall Separation, in contrast to the Tower Bridge, was not designed for rail vehicle loading of any kind, but was designed for six lanes of HS 20 trucks as specified on the as-built

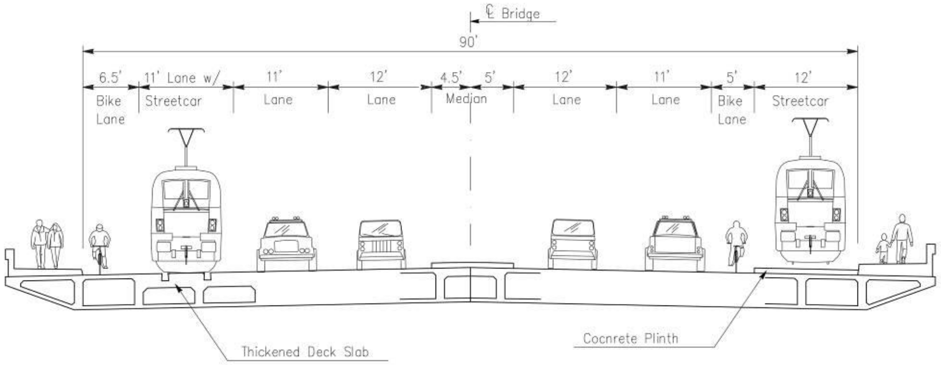

Figure 13 – Typical Section of Capitol Mall Separation showing two variations of lane configuration Alternative 2 – two through and one mixed-flow (on left) or dedicated streetcar (on right) traffic lane in each direction, with median and shoulders/bike lanes.

plans. In further contrast to the Tower Bridge, with the addition of the proposed streetcar, the total combined truck and streetcar load will be higher than the live loading for which the structure was originally designed. To evaluate this structure, the computer program Bridge Design System (BDS) was run for the as-built structure as well as each of the proposed load configurations, including all three of the proposed streetcar vehicles (Birney, modern streetcar and LRV) and all three possible track structural configurations (embedded flush with the existing deck, on a raised plinth, and embedded in a full-width deck overlay). While thickening all or part of the deck slab is considered feasible to accommodate the track, adding prestressing to increase the overall dead load or live load capacity would most likely be prohibitively expensive, if feasible at all. The capacity assessment of the structure followed the same AASHTO and AREMA requirements as noted for the Tower Bridge.

Because the existing separation structure is actually two independent, parallel, symmetric structures, and BDS is a two-dimensional frame analysis and design program, only half of the structure was analyzed for this investigation. In the as-built analysis, in addition to the structure dead load, loads associated with water and sewer pipes, an existing 2-inch asphalt wearing surface, and a 35 pounds per square foot (psf) future wearing surface were included. As with the Tower Bridge analysis, other loads considered with the reintroduction of streetcars included dead loads associated with track, train control equipment and an Overhead Catenary System (OCS) assumed to be 350 pounds per linear foot of track.

Existing and Required Capacity

Alternative 1 Discussion of Analysis

For Alternative 1, because of concerns about differential deflections between the two structures, the embedded track option (flush with the existing deck) was not considered desirable as it would result in one rail on each structure barely 2 feet from the edge of deck. Consequently, for this alternative, the analysis assumed the track to be placed on an 8-foot wide slab 7 inches thick attached to one side of the longitudinal joint and "floating" on the adjacent structure. In this scenario, the rail live load was assumed to be carried equally on the two adjacent structures, but the concrete pad would ensure that the two rails would move as a unit. This raised pad was assumed to replace the existing concrete median, thus minimizing the additional dead load associated with the raised track.

Alternative 2 Discussion of Analysis

For Alternative 2, two track structural options were considered: 1) embedded into a reinforced top slab thickened to a depth of 20 inches over a width of two box girder cells (approximately 14 feet) for each track and 2) embedded in a full-width, 7-inch thick, lightweight concrete overlay of the existing deck. For the former alternative, it was assumed that the dead load associated with the 2-inch asphalt wearing surface would remain, as would the 35-psf future wearing surface. For the latter option, the existing asphalt wearing surface was assumed to be removed as was the provision for a future wearing surface. Consequently, the deck overlay option resulted in additional dead load only the equivalent of roughly 2 inches of lightweight concrete.

Alternative 3 Discussion of Analysis

Structurally, Alternative 3 is similar to Alternative 1, except that instead of having only half of the dead and live loads associated with one track applied to the structure, loads associated with a full track were applied to each structure, including a raised concrete pad.

Structural Modifications

The BDS analyses for all of the proposed lane configurations and all three streetcar vehicles indicate that the overall capacity of the existing structure is adequate for these alternatives. Local thickening and strengthening of the deck slab would be required for flush-mounted embedded rail.

Consideration will also have to be given for the Capitol Mall Separation, as for the Tower Bridge, for electrical stray current. Stray current provisions will be added to the bridge to mitigate stray current corrosion.

Operational Issues

Traffic operations such as streetcar flow and automobile/truck traffic flow will have to be evaluated. Traffic flow study and consideration will have to be given to direct fixation track mounted on the top of the bridge deck; and how quickly the top of the track can drop to existing street grade when off of the bridge to allow automobile and truck traffic to cross over the streetcar track. Crossing over the track will be required at left turn lanes and intersections for track in the center and at intersection for right turns for double track in the outer lanes.

Conclusions

Following is a summary of conclusions reached based on our data collection and analyses of the two structures:

- The addition of streetcars to both the Tower Bridge and the Capitol Mall Separation is feasible using either Birney replica trolleys or modern streetcars such as the Inekon TRIO.
- The Capitol Mall Separation also has adequate capacity for Sacramento Regional Transit LRVs.
- The Tower Bridge appears to have adequate capacity for LRVs on a single, central track, but more detailed analysis would be required to confirm this.
- Both single and double track alternatives are structurally viable for the Capitol Mall Separation.
- Double tracking on the Tower Bridge may be structurally feasible, but would require strengthening or replacement of at least four stringers and a portion of the deck, as well as the addition of support beams for the rails if the existing stringers are to remain and be strengthened.
- Stray current provisions would be required for both structures.
- Tracks on the Capitol Mall Separation could be recessed into a thickened and strengthened deck slab, placed in a full-width overlay, or set on a raised concrete pad.
- Vertical clearances through the trusses on the Tower Bridge are adequate for any lane configuration.

Assumptions and Limitations

The evaluations performed of the Tower Bridge and Capitol Mall Separation for this investigation were, by design, limited by the assumptions and conditions listed below. It is anticipated that, if this project is to move forward, an in-depth evaluation of both structures and detailed design of track, train control and OCS, as well as details of structural modifications would need to be performed.

Assumptions — General

- The Birney and modern streetcars can run in 11-foot lanes.
- The Sacramento Regional Transit LRVs require a 12-foot lane.
- The minimum vertical clearance (measured from top of rail to top of pantograph) is 12 feet 7 inches for the Birney and modern streetcars in dedicated ROW or 14 feet 0 inches in mixed flow lanes (preferably 16 feet 0 inches), and 14 feet 8 inches minimum (19 feet 6 inches desirable) from LRVs.

Assumptions — Tower Bridge

- Only the lift span was analyzed. It was assumed that the other spans would have similar results.
- Major structural members have not lost significant capacity due to structural deterioration.
- Foundation capacity is adequate.
- The structure rating documented in Caltrans' inspection report is correct and is based on the roadway stringers.

Assumptions — Capitol Mall Separation

- The design loads included a 35 psf future wearing surface.
- Existing prestressing strand has an ultimate tensile strength of 250 ksi and is composed of stress-relieved strand.

Limitations

- Based on conversations with Caltrans and the riveted, simple-span construction of the Tower Bridge, fatigue loading was not considered in this analysis and is not expected to be a significant consideration.
- No seismic analysis was performed on either structure.
- No analyses were performed on the substructure elements of either structure.

References

American Association of State Highway and Transportation Officials (AASHTO), *Bridge Design Specifications*, 17th Edition, Washington, D.C., 2002.

American Association of State Highway and Transportation Officials (AASHTO), *Manual for Condition Evaluation of Bridges*, 2nd Edition and interims, Washington, D.C., 2003.

American Railway Engineering and Maintenance of Way Association (AREMA), *Manual for Railway Engineering*, Washington, D.C., 2002.

California Department of Transportation, *Bridge Design Specifications*, Sacramento, CA, 2005.

Sacramento Regional Transit District, *Light Rail Design Criteria*, Sacramento, CA, 1993.