California High-Speed Train Project

TECHNICAL MEMORANDUM

Design Guidelines for High-Speed Train Aerial Structures TM 2.3.3

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Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to ensure:

- Technical consistency and appropriateness
- Check for integration issues and conflicts

System level reviews are required for all technical memoranda. Technical Leads for each subsystem are responsible for completing the reviews in a timely manner and identifying appropriate senior staff to perform the review. Exemption to the System Level technical and integration review by any Subsystem must be approved by the Engineering Manager.

System Level Technical Reviews by Subsystem:

Systems: *Signed document on file*_________ 02 Feb 09 _
Eric Scotson Date

Infrastructure: *Signed document on file*_________ 08 Feb 09 _
John Chirco Date

Operations: *Signed document on file*_________ 28 May 09 _
Paul Mosier Date

Maintenance: *Signed document on file*_________ _28 May 09 _
Paul Mosier Date

Rolling Stock: *Signed document on file*_________ _17 Dec 08 _
Frank Banko Date

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ABSTRACT

Aerial structures will carry the high-speed train alignments at grade separations over water and steep terrain, in congested urban areas, and will allow transverse access below the guideway. Due to the potentially large amount of aerial structures, development of design guidance is warranted to ensure that these structures will achieve the design and performance requirements, promote an efficient design, and allow for the preparation of capital cost estimates.

This technical memorandum outlines the important performance and functional needs of a basic aerial structure carrying dedicated high-speed train operation. Design elements considered include:

- Structural Performance
- Functionality
- Safety
- Serviceability
- Construction Efficiency
- Trackside Environment

In this document, high-speed rail aerial structures currently in use are presented for illustrative and comparative purposes. Design elements that are required for high-speed rail operation are identified along with basic structural design parameters to be considered including material type selection, construction options, approximate span length and span to depth ratio, and alternate span articulation. Based on a qualitative assessment, a basic conceptual aerial structure cross section, span length, span-to-depth ration, and span articulation is proposed for advancing the preliminary design. Development of substructure design concepts are specific to geologic and geographic considerations and are not included in this design guidelines document.

Refined design is not included in the scope of this memorandum. Approximate dimensions are given to initiate discussion and to establish the basic structural parameters for the basic design.

6.0 DESIGN MANUAL CRITERIA

6.1 BASIC HIGH-SPEED TRAIN AERIAL STRUCTURE

A basic high-speed train aerial structure is presented to illustrate the necessary structural performance, functionality, safety, serviceability, economical, and aesthetic considerations for the CHSTP. The cross section at mid-span is shown in Figure 6-1, and the cross section at the support is shown in Figure 6-2. The cross section shown is for a nominal 100-foot-long typical span with a span to depth (S/D) ratio of 10. The typical span could be longer (up to 130-foot-long) with a proportionally deeper cross section and thicker top deck, bottom soffit and web sections. Note that although a ballasted track is shown, the cross section is also applicable to a direct fixation track structure.

Approximate dimensions are given to initiate discussion and to establish the basic structural parameters for the basic design.

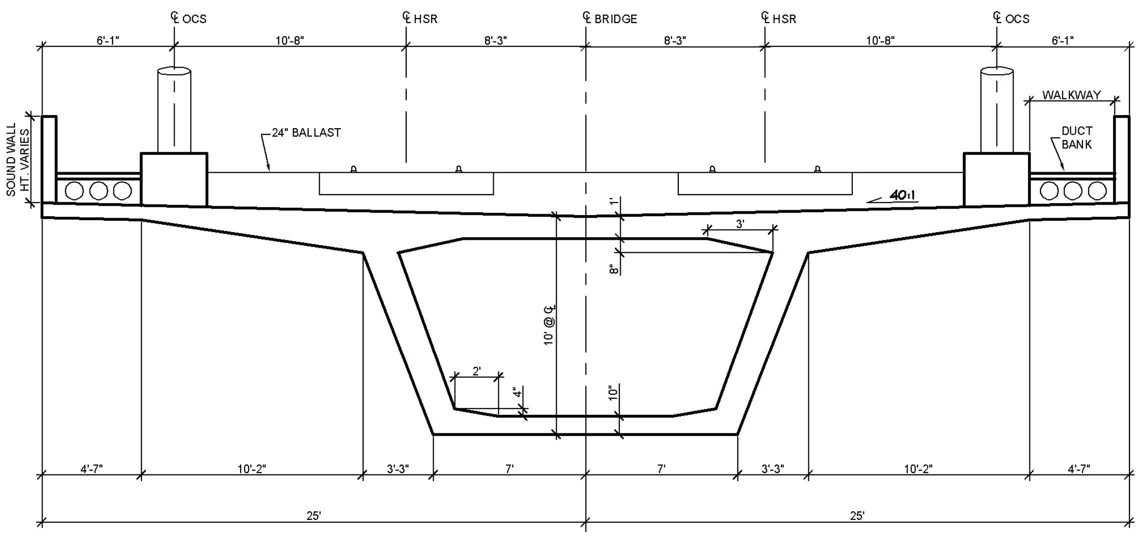

Figure 6-1: Basic High-Speed Train Aerial Structure Cross Section at Mid-span (100' span)

The proposed basic aerial structure is a prestressed concrete single cell box girder, spanning approximately 100 to 130 feet and supporting two parallel train tracks. The single cell box girder has been proven to be an economical and structurally efficient cross section, with the single cell facilitating maintenance inspection.

For preliminary design purposes, the box girder is assumed to be simply supported vertically by a pair of bearings and transversely by a shear key at the column cap.

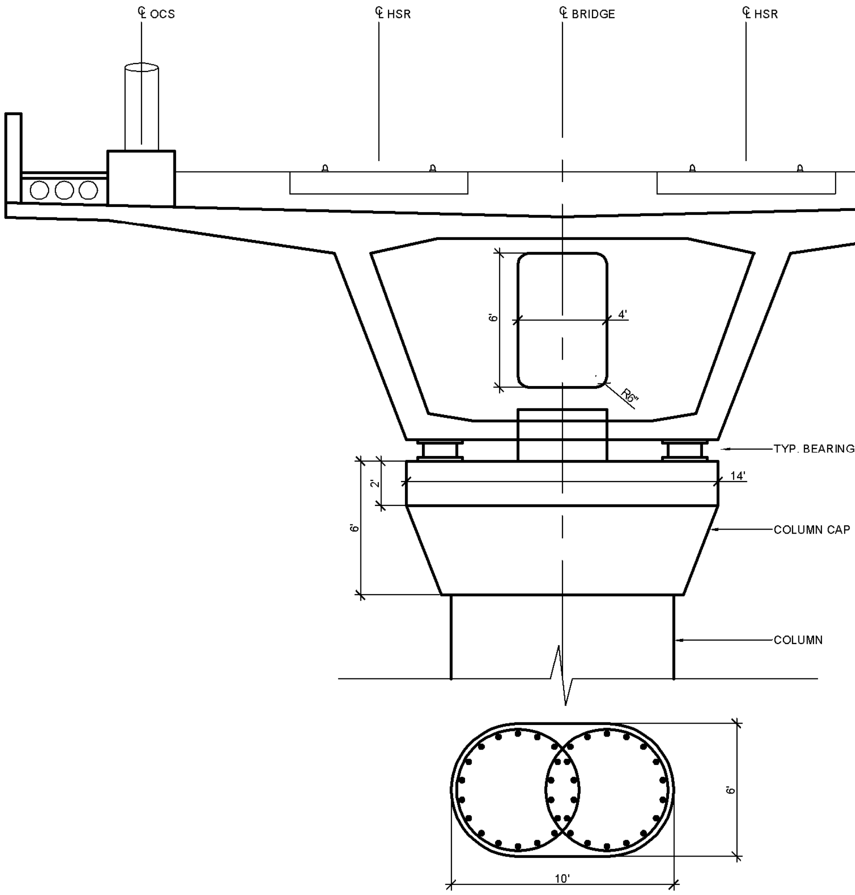

Figure 6-2: Basic High-Speed Train Aerial Structure @ Support

A basic foundation design has not been developed due to the variance of ground conditions along the high-speed train alignment. Foundation types are anticipated to be either spread footing or pile supported based upon local geotechnical and seismic conditions.

The typical cross section has been developed to address CHSTP design parameters. These are summarized in Table 6-1.

Table 6-1: Design Parameters for Basic High-Speed Train Aerial Structure

Structural Performance	
Design Life	100 years as defined in TM 1.1.2: Design Life
Design Criteria Compliance	Rigid and stiff structure needs to comply with stringent project specific design parameters, including seismic resistance, passenger comfort, and train performance criteria
Load-Bearing Capacity	Carries self weight, ballast, dynamic live loads of high-speed trains
Damage Resistance	Ductile seismic design philosophy based upon project seismic design criteria
Fatigue Resistance	Structural design and routine maintenance will address and monitor fatigue

Reparability	Inelastic action directed to base of columns during severe seismic event, where observable and readily repairable. Standard bearings and ancillary parts allow for inventory to facilitate quick replacement
Functionality	
Tracks	Allow for double main tracks to be carried on a single structure
Track Support	Allow for both direct fixation and ballasted track
Sound Walls	Accommodate low sound walls, where required, to mitigate sound from wheel on rail connection while not obstructing passenger views
Drainage	Drainage is collected away from the tracks and the duct banks through the girder and directed to discharge location at columns
Overhead Contact System (OCS)	Provided based on electrical current requirements
Traction Power Supply System	Mount multiple, large diameter conduits on columns and route onto the guideway
Lighting	Permanent maintenance lighting is not required to on aerial structures. Maintenance lighting will be provided as part of maintenance operations. Aerial structures are required to have lighting facilities for emergency access and egress
Walkways	Walkways are located outward of the OCS masts.
Railing/Parapet	Continuous railing or solid parapet is provided along outside of viaduct. May be solid parapet or open railing
Intermittent Access Stairs or ramps	Structurally independent; located to meet maintenance and operational requirements. Access control/detection is required at stair and ramp access locations.
Maintenance Access	Structurally independent of high-speed train guideway. Access control/detection is required at maintenance access locations
Cable/Duct Banks	Provided on both sides, under walkways
Signal Heads	Space provided in the cross-section to accommodate panels
Safety	
Passenger Evacuation	Walkways located outward of OCS poles with provision for emergency access and egress
Intrusion Protection / Detection	Continuous intrusion protection not required due to vertical separation. Fencing and detection systems to be installed where required
Serviceability	
Allowance for Regular Inspections, Maintenance and Repairs	Access stairways, walkways, and, single cell concrete girder provided for inspection.
Economy	
Materials & Structure Type	Pre-stressed concrete box girders

Economy of Scale	Schedule efficiency and cost economy are based upon precast segmental production or cast in place production with reusable traveling shoring
Manufacturing and Delivery	Precasting segments, transporting and erecting the segments to be further investigated
On-Site Storage	Storage sites for segments to be determined
Trackside Environment	
Ground Plane	Elevated structure minimizes permanent disturbances to existing ground surface
Noise Mitigation	Low sound walls mitigate sound from wheel on rail connection
Vibration Mitigation	Ballast (or ballastless tracks with lining) mitigates vibration
Property Access	Elevated structure maintains transverse access beneath the guideway
Color	Natural concrete color or pigmented concrete
Texture	Smooth or textured surfaces
Complementary/Contrasting Details	Architectural treatments as appropriate
Visual and Shadow Impacts	Standard structure promotes system identity, dimensions of box girder to minimize permanent shadows

Discussions relevant to the selection of the basic high-speed train aerial structure are presented in the following sections.

6.1.1 Material Type

Historically, concrete has proven to be the most cost effective material type for use in elevated transit structures in California. This is evident in the predominant use of concrete by Caltrans for highway over-crossings, as well as the typical standard concrete structures for BART in the Bay Area and the Metrolink system in the Los Angeles Basin. Adding to concrete's appeal is its reduced maintenance needs, especially when compared to steel.

Reinforced and prestressed concrete design and construction technology has advanced significantly over the last few decades, partially due to its extensive use in earthquake prone California.

As the typical aerial structure design progresses, the use of high-strength concrete, with a breaking strength, $f'_{c,}$ in excess of 8000 psi should be considered. High-strength concrete merits discussion since concrete's stiffness increases with strength, which bodes well for aerial structures subject to severe deflection and vibration limitations. During advanced design, the cross section may be optimized to reduce the weight of superstructure and structure foundations.

Steel remains a viable option, although more so for special case aerial structures. For standard mass produced aerial structures, steel's material and fabrication costs would prove costly. Additionally, historically steel has been shown to be maintenance intensive.

6.1.2 Constructability

Recognizing that the HST preferred alignment may consist of long lengths of elevated structures, a fast, repetitive and versatile construction method must be used to meet the project goals.

Cast-in-Place Construction

Traditionally in California, concrete box girders are constructed by cast-in-place methods, which require temporary shoring, falsework, as well as additional clearance provisions to take into account space occupied by falsework. Such superstructure erection is typically slow, requiring large labor efforts for the falsework, shoring placement and removal.

Recent advances in travelling, self launching shoring techniques may prove viable for mass production for the high-speed train project. Figure 6-3 illustrates such a shoring system used on the Taiwan High Speed Rail Project.

Figure 6-3: Example of Travelling Shoring System

Source: http://www.ibtengineers.com/Taiwan-High-Speed-Rail.html

The construction of the substructure (including the piles, pile caps, spread footings, columns and column caps) occurs separately and before the cast-in-place superstructure is built. The substructure will be constructed by traditional poured-in-place concrete methods.

Advantages

- The superstructure can be cast monolithically with the columns, which can result in superior structural performance for train operation, passenger comfort, and seismic response.
- Monolithic connections eliminate the need for maintenance intensive bearings.

Disadvantages

- The schedule impacts for this method are greater compared to precast construction due to required closure pours coupled with the falsework set up and removal operations.

Precast Construction

Another method to provide speedy, reliable mass production of aerial structures is precast segmental construction. Precast segmental construction was first introduced to California with the Pine Valley Bridge (San Diego County, 1974) and has continued with the recently completed Otay River Bridge in San Diego.

The construction of the substructure (including the piles, pile caps, spread footings, columns and column caps) occurs separately and before the erection of the precast segmental superstructure. The substructure will be constructed by traditional poured in place concrete methods.

Each precast segment could extend over the entire 100 to 130 foot span. The segment construction may be performed remotely in a construction yard and transported to the site.

Note that the use of high strength concrete, with its correspondingly higher rate of strength gain, enables the segments to be handled at an earlier date, thus potentially accelerating the production schedule.

One viable erection scheme for the precast segments is a deck supported, self launching overhead gantry, which involves the use of travelling construction girders situated above the bridge deck as illustrated in Figure 6-4.

Figure 6-4: Example of Overhead Gantry

Source: http://www.launching-gantry-operator.com

The overhead erection scheme allows span by span erection without the need for construction shoring or falsework, and with minimal temporary supports and bracing. The crane and launching system will be a cost effective solution for a multi-spanned structure since the costs for such a system will be offset by a shorter construction schedule.

Structurally, this type of full span segment construction is geared towards a series of adjacent simply supported spans. Should the span articulation need to include continuous spans passing over or monolithic with the columns, then extra provisions for closure pours and continuity post-tensioning between the spans would be needed for the complicated assembly.

Advantages

- Fast method of construction for multi-span structures.
- This construction method may be the most cost effective.

Disadvantages

- For an optimized design, segment lengths are limited to approximately 100 to 130 foot spans. This relatively short span length requires more foundations and has a significant increase to the structure costs.
- Support bearings require routine maintenance and increase the life cycle costs for this alternative.
- It may be more challenging to meet the performance requirements (seismic, passenger comfort, etc) when designing for this type of construction.

6.1.3 Span Length and Span to Depth Ratio

A 100 foot-long span was used as the typical span length for the single cell box girder shown in Figure 6-1. This span is based upon the typical span used in the Taiwan High-Speed Rail system, which is 30 meters in length. Taiwan's system was designed to withstand seismic events similar to those expected in California.

For the precast option, transportation and erection constraints limit the length of the segment. The 100 foot-long segment as proposed will weigh approximately 750 tons. Segments of longer length will be proportionally heavier and considerably more difficult to transport, especially in urban areas with obstructions.

Note that in general, shorter segment spans are lighter, easier to transport, but require more foundations. Longer spans are heavier, more difficult to transport, and require fewer but significantly stouter foundations.

Note that for some situations, a longer typical span length may be feasible and may prove to be cost-effective if the project site is easily accessible and transportation distance is short.

At this time, for preliminary sizing and dimensioning of the segmental box girder, a span to depth ratio of 10 was used. Thus for a 100 foot span, the depth of the box girder is 100/10 = 10 feet. This span to depth ratio is stout and justified given the heavy design loads used for the 15% Design level.

In comparison, a typical highway bridge would have a span to depth ratio ranging from 15 to 25 (i.e., for a span of 100 feet, the structure depth may range from approximately 4 to 7 feet).

6.1.4 Span Articulation

Full span precast segmental construction by overhead gantry is applicable to a series of spans, where each box girder is simply supported vertically at each end by pairs of bearings and transversely supported at each end by internal shear keys. If continuity between the spans or with the column is needed for structural reasons, then additional provisions for closure pours and continuity post-tensioning must be made.

Should cast-in-place construction using a travelling shoring system be used, the superstructure can be made continuous over the columns or cast monolithically with the columns with relative ease, although continuity post-tensioning would be likely.

Continuous span systems have structural advantages, for example:

4. Continuous span systems are stiff, particularly vertically, which may help meet the strict passenger comfort and operating criteria.
5. Continuous spans provide moment continuity with the column top. Thus, for longitudinal forces or motions, the system can take advantage of the inherent frame-action so the column responds in double curvature. This should reduce the demands on the foundations and has the potential for construction savings.
6. Since the superstructure is monolithic with the top of the columns, there are no bearings and no potential for the spans to become unseated during strong motion seismic events. The maintenance associated with the bearings would also be eliminated.

Disadvantages of using continuous spans include:

3. Using a precast construction method and providing span to column top continuity complicates the construction process, lengthens the construction cycle, and is potentially more costly, since closure pours/curing time and secondary continuity post-tensioning between spans are needed.

4. The analysis and methodology to determine the expected stress state in continuous spans is more complicated, due to secondary moment effects and creep/shrinkage.

Note that span articulation is a subject worth debate. In the recently completed Taiwan High Speed Rail system, both simple and continuous span articulation was used.

6.1.5 Substructures

The substructure, including piles, pile caps, spread footings, columns and column caps, will be constructed by traditional cast-in-place concrete means.

A wide variety of soil and seismic conditions will be encountered along the high-speed train alignment. Typical foundations are anticipated to be conventional spread footings, if soil conditions are acceptable, or pile cap with either cast-in-drilled-hole (CIDH) or cast-in-steel-shell (CISS) piles extending down into competent material, in regions of more marginal soils.

The columns shall either have constant cross section, or cross section increasing in area from bottom to top (i.e., smaller cross section at the bottom). Architectural concrete flares and treatments may be added as unconfined sacrificial concrete.

The column will have a reinforced structural core, with vertical, shear, and confinement reinforcement. As part of the seismic design philosophy, any inelastic action ("plastic hinge") will occur at the column base, where it is both observable and more readily repairable.