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* Eric Scotson	02 Feb 09 Date
Infrastructure:	*Signed document on file* John Chirco	08 Feb 09 Date
Operations:	*Signed document on file* Paul Mosier	28 May 09 Date
Maintenance:	*Signed document on file* Paul Mosier	28 May 09 Date
Rolling Stock:	*Signed document on file* Frank Banko	17 Dec 08 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.

INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This technical memorandum identifies the basic elements of aerial, or elevated, structures and assesses the benefits of using a standard design for aerial structures carrying high-speed train. This document presents representative aerial structures for high-speed rail and introduces a basic design for high-speed train structure for the purpose of advancing the preliminary design and preparing capital cost estimates.

1.2 STATEMENT OF TECHNICAL ISSUE

This technical memorandum will serve as the basis for the CHST Design Manual, which will present standards and criteria specific to design of the high-speed train system. Preliminary structural design criteria for aerial structures are under development and contained within the Technical Memorandum 2.3.2 - Structure Design Loads.

Since multiple designers will be involved in the design and construction of the high-speed train system, alternate aerial structure designs are anticipated. A basic high-speed aerial structure design will be used to ensure that the structures considered in preliminary design achieve the CHSTP's design and performance requirements. Presentation of an aerial structure design concept is intended to provide designers with a basis for establishing structure footprints and proportioning materials and to promote development of uniform description of construction techniques and uniform cost estimates during preliminary design.

1.2.1 Definition of Terms

The following technical terms and acronyms used in this document have specific connotations with regard to California High-Speed Train system.

Alignment: The horizontal and vertical route of the high-speed rail guideway.

Ballasted Track: Rail lines installed over a specific type of crushed rock that is graded in such a manner that can support heavy loads of the rolling stock.

Ballast-less Track: Rail lines installed directly atop concrete slabs for support. Also referred to as slab track or direct fixation track.

Contact Wire: A suspended (overhead) wire system that supplies power from a central power source to an electric vehicle such as a train.

Footprint: Area of the ground surface covered by a facility, or affected by construction activities.

Guideway: A track or riding surface that supports and physically guides transit vehicles specially designed to travel exclusively on it.

High-Speed Train: A railroad system utilizing steel-wheel-on-steel-rail technology with a regular operating speed greater than 125 mph (200 kph).

Program-Level: Refers to a CEQA or NEPA environmental review that covers the broad spectrum of a large, complex, regionally extensive effort comprised of a number of smaller, regionally focused projects or phases.

Acronyms

CFR	Code of Federal Regulations
CIDH	Cast-in-Drilled-Hole
CISS	Cast-in-Steel-Shell
CHST	California High-Speed Train
CHSTP	California High-Speed Train Project
EIR/S	Environmental Impact Report / Statement
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
HST	High-Speed Train
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
OCS	Overhead Contact System
S/D	Span to Depth Ratio

1.2.2 Units

The California High-Speed Train Project is based on U.S. Customary Units consistent with guidelines prepared by the California Department of Transportation and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the United States, and are also known in the U.S. as "English" or "Imperial" units. In order to avoid confusion, all formal references to units of measure should be made in terms of U.S. Customary Units.

Guidance for units of measure terminology, values, and conversions can be found in the Caltrans Metric Program Transitional Plan, Appendix B U.S. Customary General Primer (http://www.dot.ca.gov/hq/oppd/metric/TransitionPlan/Appendice-B-US-Customary-General-Primer.pdf). Caltrans Metric Program Transitional Plan, Appendix B can also be found as an attachment to the CHSTP Mapping and Survey Technical Memorandum.

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 GENERAL

This technical memorandum considers the following design parameters and identifies a basic design for aerial structures suitable for dedicated high-speed train operations based upon the following design parameters:

1. Structural Performance: Achieve superstructure and substructure design requirements to ensure compliance with stringent project specific design criteria, including seismic resistance, fatigue resistance, strict train operation and passenger comfort issues. Ease of reparability after seismic events and collision damage protection to allow quick resumption of service.
2. Functionality: Provide rolling stock and trackbed support, meeting the electrification requirements for traction power supply and distribution, communications, train control, as well as providing space for walkways, duct banks, sound walls, and drainage.
3. Safety: At a minimum, no collapse structural criteria under extreme seismic events, ccontinuation of safe revenue high-speed train operations, after a seismic event, and the ability to perform required service, inspection and maintenance operations during routine and emergency conditions.
4. Serviceability: Provide for ease of routine inspections, maintenance and repairs.
5. Economy: Realize cost efficiencies based upon economy of scale, ease and speed of construction, use of prefabricated segments or rolling forms in standard superstructure cross sections.
6. Trackside Environment: Mitigate noise and vibrations, reducing visual and shadow impacts, maintaining required property access, and promoting aesthetics appropriate with surroundings.

This document has been developed concurrently with the structural loading and seismic design guidelines for use in advancing the preliminary design.

2.2 LAWS AND CODES

49 CFR Part 213, Appendix C - Statement of Agency Policy on the Safety of Railroad Bridges, is the current safety regulation of conventional railroad bridges in the United States. Federal Railroad Administration (FRA) requirements for containment of high-speed trains on aerial structures will be addressed in the design of the track structure.

Aerial structures located in proximity to airports or flight paths will be required to conform to applicable Federal Aviation Administration (FAA) codes and regulations.

Applicability of National Fire Protection Association (NFPA) requirements with regard to high-speed train aerial structures will be assessed during preliminary design.

Compliance and/or demonstration of equivalency with safety and regulatory requirements will be developed for the CHSTP Systems Requirements.

2.3 POLICY CONSIDERATIONS

Policy considerations may significantly influence the size, aesthetics and cost of the high-speed train aerial structures. In order to advance the design of aerial structures, assumptions regarding policy issues have been made which require confirmation. A summary of these issues and assumptions follow:

- Dedicated High-Speed Train Operations. Design of aerial structures for dedicated HST operation may restrict and potentially prohibit operation of conventional locomotives on these structures due to the higher axial loadings and forces for conventional trains. The potential operation of conventional rail vehicles on structures designed specifically to high-speed train standards may require speed or route restrictions.

- Intrusion Protection / Fencing. It is assumed that fencing around aerial structures will not be typically required since the structures will be grade separated throughout providing intrusion protection. A protective open rail or solid parapet approximately 4 feet high will be required along external walkways. Access control/detection will be required at maintenance access locations.
- Maintenance. It is assumed that, under normal conditions, regular maintenance activities will occur outside of the hours of revenue service. Speed restrictions will be imposed if emergency repair or maintenance is required on aerial structures during revenue service.
- Emergency Access. Walkways on aerial structures will be capable of safely exiting passengers during emergency conditions in accordance with requirements of NFPA-130.
- Lighting on Aerial Structures. Permanent maintenance lighting is not required to be installed on high-speed train aerial structures. Maintenance lighting will be provided as part of maintenance operations. Aerial structures will be required to have lighting facilities for emergency access and egress.
- Third Party Utilities. It is assumed that no leasing of cable space or duct banks is provided on the structure for third party utilities and therefore access to the guideway is not required by third parties.

3.0 ASSESSMENT / ANALYSIS

3.1 STANDARD DESIGN FOR HST AERIAL STRUCTURES

Potential advantages associated with a system wide standard design for an aerial high-speed train structure include:

- Economy. Design, construction and sourcing would take advantage of economies of scale leading to reduced cost.
- Constructability. Due to the large number of aerial structures anticipated, there would be opportunity for large-scale pre-fabricated assembly, potentially leading to simplified construction techniques and quick erection schedule.
- Risk Reduction. A thoroughly vetted design and consistent method of construction, inspection, and maintenance would reduce the risk of cost overruns and delays during design, construction and operation.
- Aesthetics. A common system-wide aesthetic would introduce consistency and promote a statewide identity to the high-speed train system.
- Quality Control. A standard design would simplify inspection and quality control.
- Ease of Maintenance. A standard design would allow for similar maintenance and inspection procedures to be developed throughout the high-speed train system. Additionally, with a standard design, an inventory of spare parts and segments can be maintained to facilitate rapid repair.
- System Integration. A standard aerial structure cross section would promote integration for structural and system interfaces.

Potential disadvantages associated with a standard design include:

- Reduced Flexibility. The high variability of conditions and environments that the high-speed train alignment would encounter may require non-standard structures.
- Discouraged Innovation. A standard design could potentially limit the structural designer's creativity and use of cost-effective alternative designs.
- Design Sequencing. A standard aerial structure design would need to be completed early in the design process in order to distribute to the project's design and construction teams.

3.2 DESIGN CONSIDERATIONS

The design parameters considered when developing a basic design for high-speed train aerial structures are summarized in the following sections:

3.2.1 Structural Performance

- Design Life. The design life of fixed facilities shall be 100 years. Elements that are normally replaced for maintenance, such as expansion joints, may be designed to a shorter term.
- Seismic Performance and Damage Resistance. The high-speed train alignment will pass through active seismic regions. Modern performance based methods shall be used in the aerial structure design. Resistance to damage due to multiple earthquake levels shall be considered, as shall resistance to potential collision of automobiles and trains with support columns and shared corridors.
- Reparability and Damage Protection. Design for pre-determined failure points and level of associated damage shall provide for fast repair and return to service.
- Passenger Comfort. Passenger comfort criteria dictate that the aerial structures shall be stiff and rigid structures.

- Load-Bearing Capacity. The aerial structure shall be designed to carry the dynamic live loads associated with the high-speed trains, maintenance trains, and potentially conventional trains in the shared-rail corridors.
- Fatigue. Excess vibration can cause structural fatigue due to wide structural stress variation, resulting in diminished structural capacity. The aerial structures shall be designed to prevent excessive reduction in load bearing and seismic response capacities due to fatigue.

3.2.2 Functionality

Aerial structure cross sections must accommodate all elements for high-speed operations, maintenance and emergency response. These elements include:

- Tracks
- Track Support
- Sound Walls
- Drainage
- Lighting
- Walkway Railing/Parapet
- Walkways/Stairs
- Maintenance Access
- Overhead Contact System
- Cable/Duct Banks
- Signal Heads
- Traction Power Supply System
- Communication System (Normal and Emergency Operations)

3.2.3 Safety

Emergency Egress and Access. Walkways provided on aerial structures shall allow safe egress and access as required during emergency conditions.

3.2.4 Serviceability

Service Inspections and Maintenance. Aerial structures shall provide for service and inspection of high-speed train track infrastructure.

3.2.5 Efficiencies and Economy of Scale

To take advantage of economy of scale and to facilitate rapid construction, aerial structures shall be designed with an easily fabricated cross-section.

- Materials. Readily available materials such as reinforced concrete (either poured in place or segmental precast pre-stressed) and steel sections shall be used.
- Poured-in-Place or Prefabrication. Poured-in-place concrete construction shall be the typical method for the foundation, columns, and column caps. Pre-fabricated concrete superstructures (i.e., box girders) would eliminate the need for erecting falsework and on-site curing time, and reduces temporary clearance requirements.
- Standard Cross Section. Use of a standard cross section would allow the use of standard reinforcement details, pre-stressing details, bearings, and shear keys for a wide range of conditions.
- Large Scale of Standard Elements. The expected total length of the aerial structures would allow for large scale production of pre-fabricated elements or the development of techniques for on-site implementation (i.e., poured-in-place with rolling forms).
- Manufacturing and Delivery. If a pre-fabricated cross sectional design is chosen, then the segments shall be designed to be suitable for transportation, storage, and erection on-site.

3.2.6 Trackside Environment

- Reduced Footprint. Elevated structures shall minimize potential impacts or disturbance to the existing ground surface.
- Noise and Vibration Mitigation. Sound walls and other measures shall be used to mitigate noise and vibration impacts where appropriate.
- Property Access. Aerial structures shall maintain transverse access beneath the high-speed train guideway.
- Color. Neutral colors that are consistently achievable and do not fade over time shall be considered along with the maintenance costs associated with color preferences.
- Texture. Texture along the support columns and the edges of the superstructure shall be used that would blend with the landscapes that the high-speed train guideway will traverse.
- Complementary/Contrasting Details. Sleek and modern design details shall not be mixed with traditional or historic design elements to avoid contrasting visuals. Consistent and complementary details shall be used throughout the alignment.
- Visual and Shadow Impacts. Cross sectional elements shall limit the impact of temporary and/or permanent visual impacts shadows where practical.

3.3 HIGH-SPEED TRAIN AERIAL STRUCTURE DESIGN ELEMENTS

The following elements shall be provided on high-speed train aerial structures:

3.3.1 Infrastructure

- Track/Track Support. The track support structure shall dampen vibration and noise from the tracks and reduce fatigue on aerial structures.
- Sound walls. Where noise and vibration mitigation is required, the aerial structures shall accommodate the space and weight of sound walls.
- Drainage. Drainage measures shall allow for removal of precipitation off the aerial structures.
- Lighting. Permanent lighting shall be required on the aerial structure to allow for emergency access and egress during all hours.
- Intrusion Detection. Intrusion detection and alarm systems shall alert the central control of intrusion into the aerial structure. CCTV cameras and support posts may be required.
- Walkways. Walkways shall be located on the outsides of each track, outbound of OCS poles.
- Guardrails/Parapets. Protective rail or parapet shall be provided along external walkways. Solid parapets may also serve to mitigate noise impacts.
- Emergency Access. Access to the high-speed train aerial structures shall be provided at regular intervals.
- Maintenance Access. Walkways, stairs and vehicle access facilities shall be provided for maintenance, service and inspection.

3.3.2 Systems

- Overhead Contact System. The proposed Overhead Contact System (OCS) shall consist of separately supported lines on either side of and over the tracks.
- Cable/Duct Banks. Aerial structure design shall provide adequate space for train control, communication, traction power supply and other utilities banks, including the capacity for a wireless network infrastructure for use by high-speed train passengers.
- Signal Heads. The design shall provide adequate space for required signal heads.
- Traction Power Supply System. Special design elements may be required for traction power facilities, such as substations, that are located near aerial structures.

3.4 HIGH-SPEED RAIL AERIAL STRUCTURES

Representative high-speed rail aerial were identified, compared and considered with regard to appropriateness for the California High-Speed Train Project based on the following. Summary information is presented in the following sections for the following structural parameters:

3.4.1 Existing High-Speed Rail Systems

3.4.1.1 TGV: Train à Grande Vitesse (France and Belgium)

The TGV system operates in Belgium and France. The TGV design typically consists of a combination of steel beams and pre-stressed concrete to create pre-cambered composite troughs as bridge decks for the high-speed trains as illustrated in Figures 3-1 and 3-2. The benefits of this design include its ease of construction and potential to use a ballasted track support system.

Advantages

- Noise and vibration is minimized due to use of ballast
- Prefabrication allows for quick assembly and implementation
- Independent structures may allow for rapid restoration of single track service following seismic events that damage a single guideway

Disadvantages

- Potentially new construction technique in the US
- Superstructure limited to short span lengths between columns
- Limited seismic performance of superstructure
- Designed for maximum speeds of 186 miles per hour
- Design needs to accommodate the added weight of ballast
- OCS poles located outside of walkway require stronger mast arms and supports

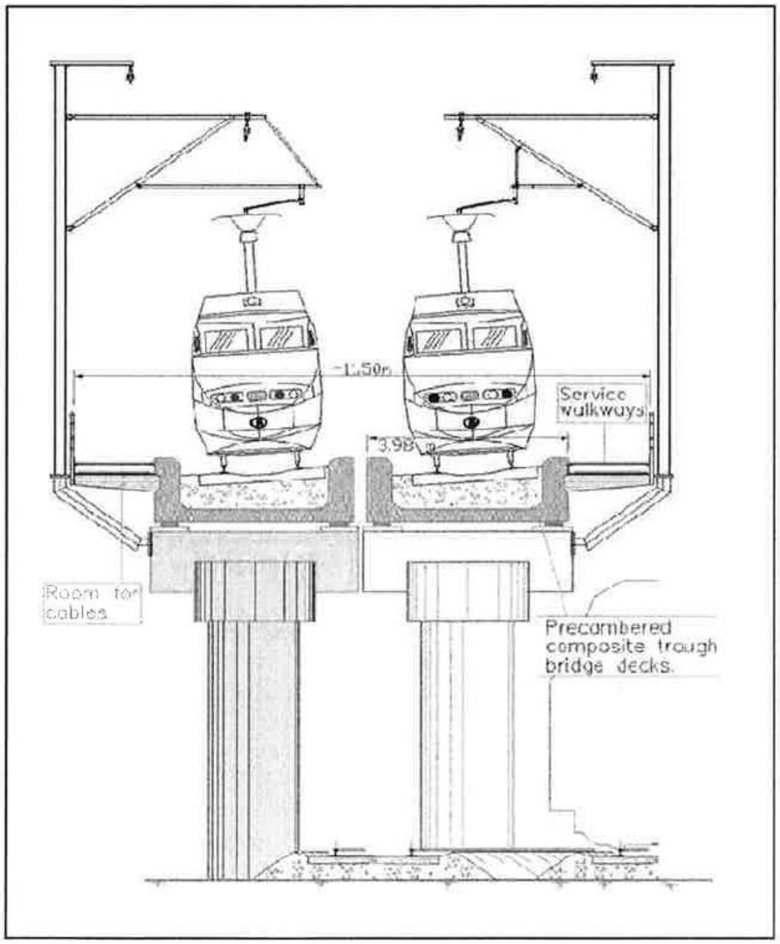

Figure 3-1: Deck Section for TGV in Belgium

Figure 3-2: TGV High-Speed Railway Viaduct in Belgium
Source: http://www.rail-be.net/Accessoires/Webs_Files/TUC_LGV.htm

Examples of TGV structures with concrete substructure and steel superstructures are presented in Figure 3-3 and Figure 3-4, illustrating an aerial structure over a flood plain and a river, respectively.

Figure 3-3: Cheval Blanc Viaduct, France

Figure 3-4: Mosel 3 Viaduct

3.4.1.2 AVE: Alta Velocidad Española (Spain)

As part of the inter-European high-speed train network connecting France to Spain and Portugal, the AVE high-speed rail is the most recently built and operated high-speed train that meets the high-speed train operating speed requirements. Resistance to high-speed dynamic train loading and fatigue are met by precast box girder design, as illustrated in Figure 3-5 and Figure 3-6.

Advantages

- Precast concrete box bridges allows for quick assembly and implementation
- Designed for speeds up to 220 mph
- Box girder is stiff meeting train and passenger performance criteria
- Open box girder allows access for maintenance and inspection
- Larger spans between piers - 80 to 200 feet (25 to 60 meters)

Disadvantages

- Two celled box girder restricts continuous maintenance access
- Train loads not located directly over webs, instead loads are first carried by top slab and transferred to webs
- Creating box girder to top of column moment continuity, if desired, is difficult requiring secondary closure pours and continuity tendons

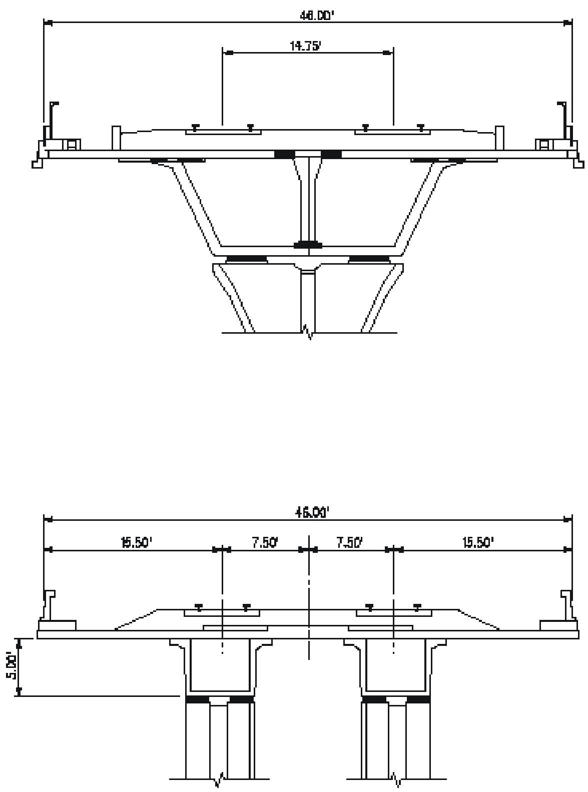

Figure 3-5: AVE Box Girder and Double Beam Cross Section
(Courtesy of PRAINSA)

Figure 3-6: AVE High Speed Rail Viaduct

3.4.1.3 THSR: Taiwan High Speed Rail

Portions of the Taiwan High Speed Rail alignment were designed and constructed as precast 30 meter-long, drop-in concrete box girder spans as illustrated in Figures 3-7 and 3-8. Spans are supported by vertical bearings and transverse shear keys.

Advantages

- Designed to withstand seismic events similar to those expected in California
- The shear key spring, foundation and bearing springs have been used effectively with stiff connections to withstand similar seismic events as those expected in California.
- Single box girder allows for ease of access
- Distances between columns allow for transverse access below the guideway

Disadvantages

- OCS poles located outside walkway require stronger masts and supports
- Open steel girders are difficult to maintain

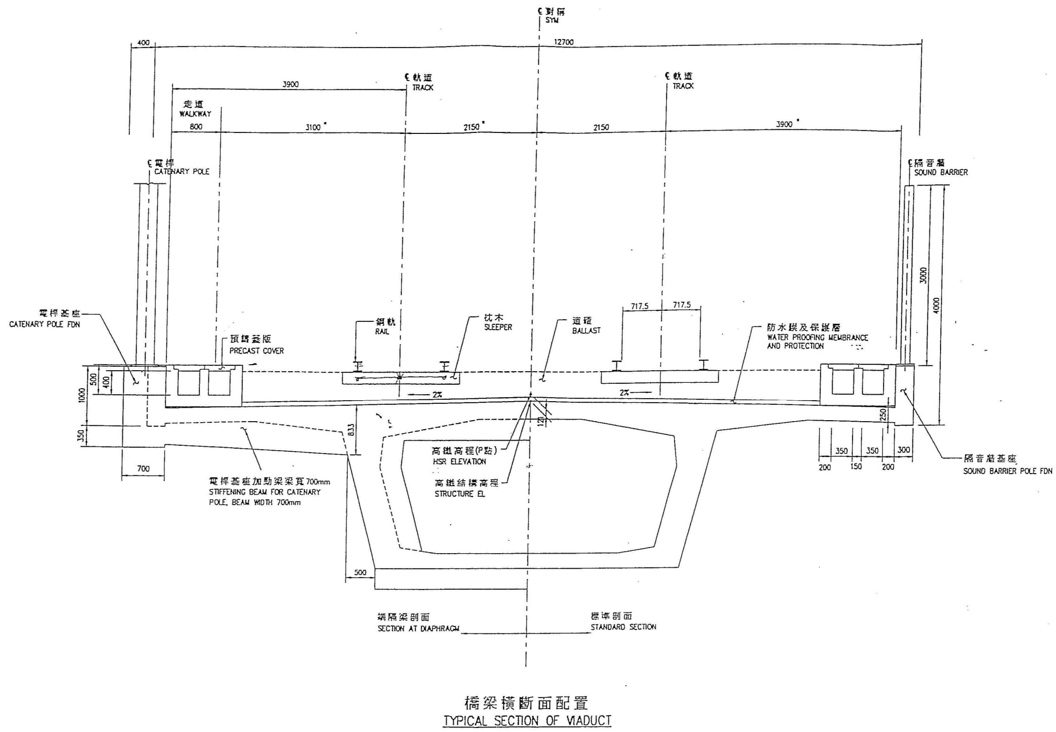

Figure 3-7: Section of Taiwan High-Speed Rail Viaduct

Figure 3-8: Taiwan High-Speed Rail Viaduct

Source: http://www.lusas.com/case/bridge/taiwan.html.

3.4.2 CHSTP Programmatic EIR/S

The typical aerial structure presented in the CHSTP Program Level EIR/EIS is shown in Figure 3-9. This structure is basically a hybrid Caltrans highway structure, which typically involves cast-in-place construction using temporary shoring and falsework. A single drilled concrete shaft supports a single circular column, which supports a multi-cellular concrete box girder. Directly fixed track is shown and the poles supporting the overhead contact system (OCS) are located outside of walkways.

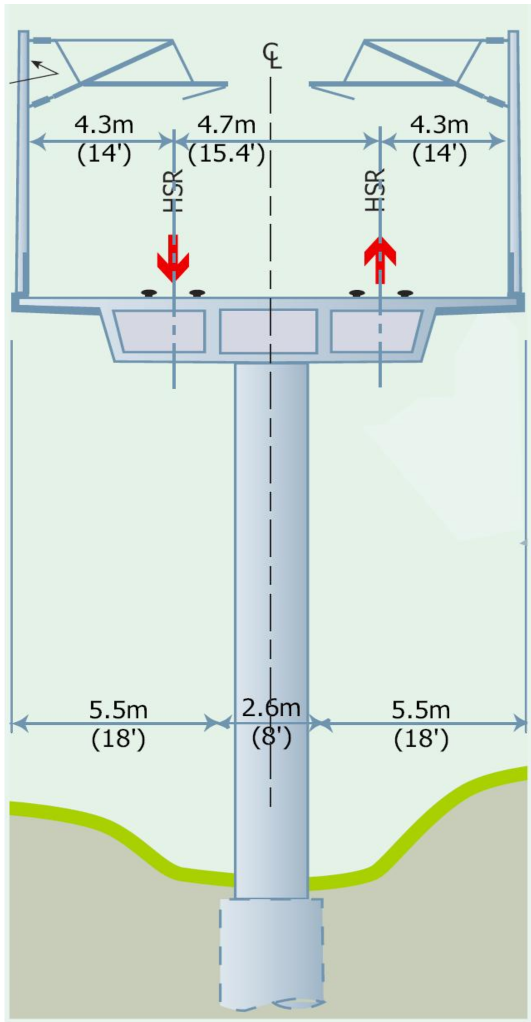

Figure 3-9: Viaduct Section from California High-Speed Train Program EIR/S

Source: Environmental Impact Report/Statement

3.5 BASIC HIGH-SPEED TRAIN AERIAL STRUCTURE

With the development of the project-specific seismic design criteria, the typical section of the CHSTP aerial structure has been refined. 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 3-10, and the cross section at the support is shown in Figure 3-11. 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.

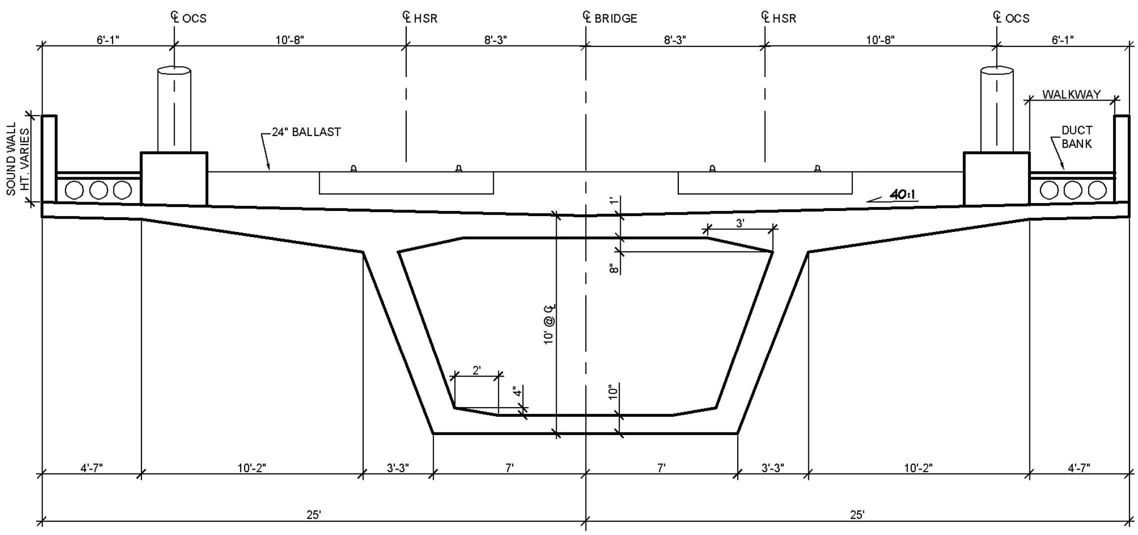

Figure 3-10: Basic High-Speed Train Aerial Structure Cross Section at Mid-span (100' span)

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.

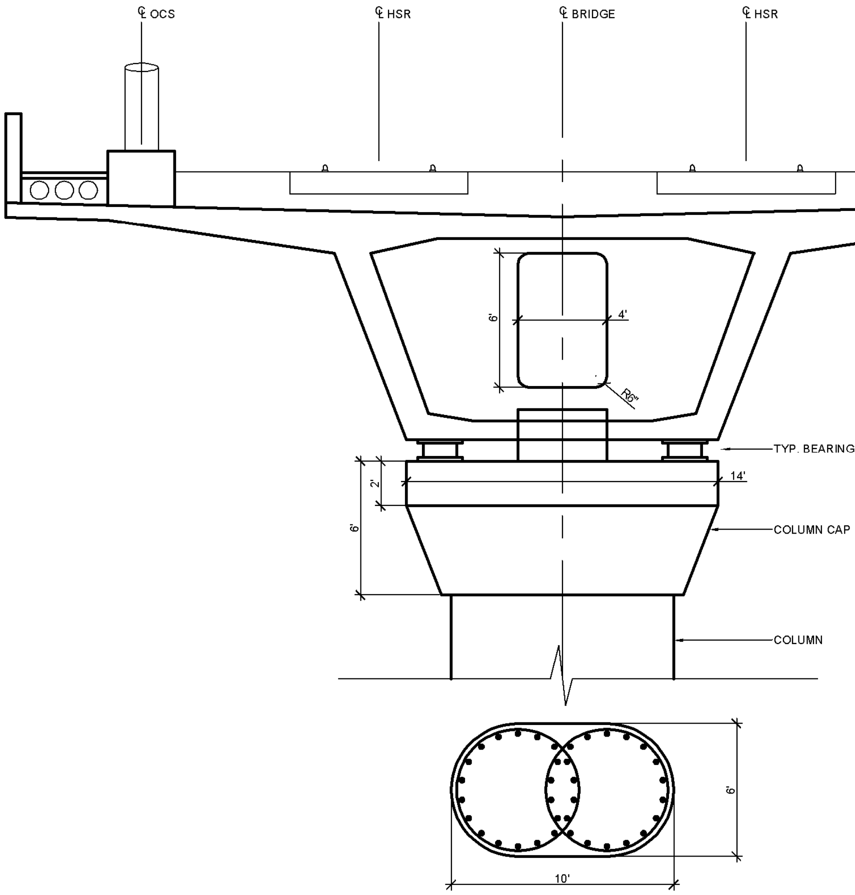

Figure 3-11: Basic High-Speed Train Aerial Structure @ Support

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 1.

Table 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.

3.5.1 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.

3.5.2 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.

<u>Cast-in-Place Construction</u>

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 3-12 illustrates such a shoring system used on the Taiwan High Speed Rail Project.

Figure 3-12: 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 3-13.

Figure 3-13: 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.

3.5.3 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 3-10. 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).

3.5.4 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:

1. Continuous span systems are stiff, particularly vertically, which may help meet the strict passenger comfort and operating criteria.
2. 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.
3. 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:

1. 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.

2. 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.

3.5.5 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.

4.0 SUMMARY AND RECOMMENDATIONS

Design guidance for the design of high-speed train aerial structures is presented in Section 6.0.

It is recommended that additional studies be conducted to determine efficient designs for the elements of aerial structures carrying high-speed train, based on various considerations including construction method, span lengths, superstructure depth, support conditions, pier design, passenger comfort, and seismic loads.

5.0 SOURCE INFORMATION AND REFERENCES

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7. "Innovative Composite Precast Prestressed Precambered U-Shaped Concrete Deck for Belgium's High-Speed Railway Trains" PCI Journal. S. Staquet et al.
8. Taiwan High-Speed Rail Project – Seismic Capacity and Performance Evaluation (SCPE). PBQ&D. January 28, 2004

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.

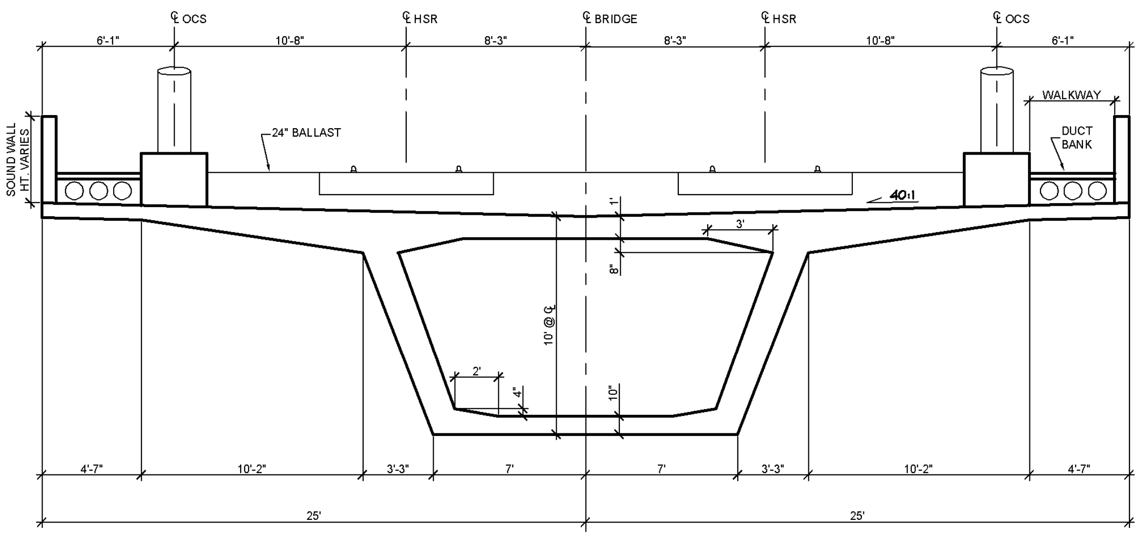

Figure 6-1: Basic High-Speed Train Aerial Structure Cross Section at Mid-span (100' span)

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.

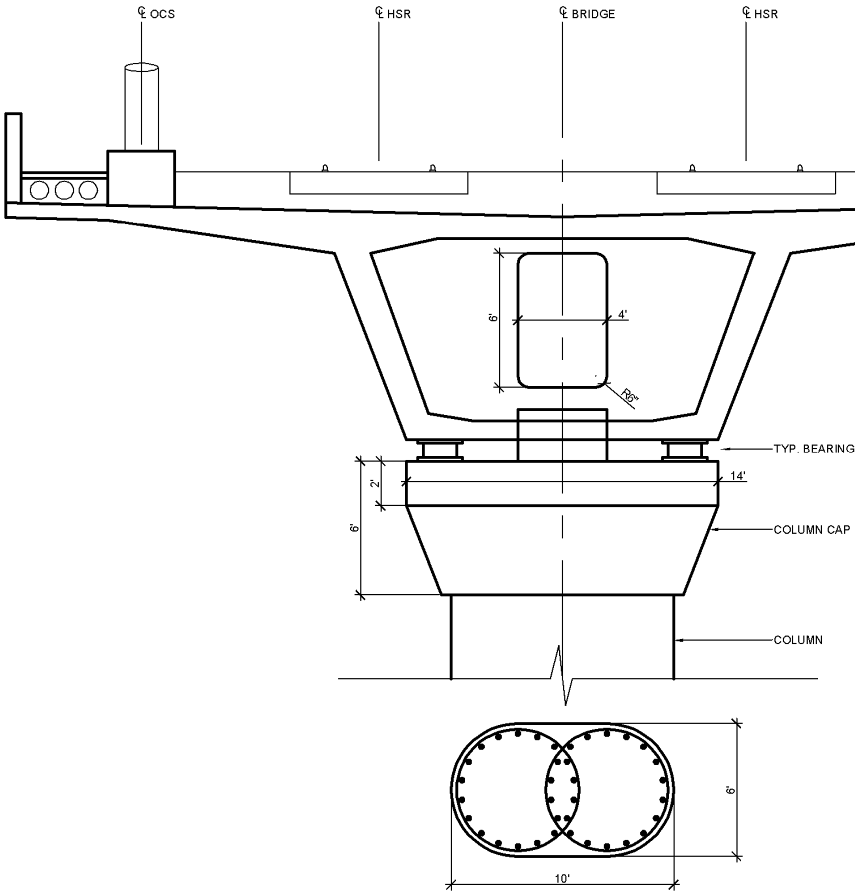

Figure 6-2: Basic High-Speed Train Aerial Structure @ Support

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.

<u>Cast-in-Place Construction</u>

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.

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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.

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