California High-Speed Train Project

TECHNICAL MEMORANDUM

Structure Design Loads
TM 2.3.2

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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 memorandums. 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* ______________ 27 May 09
Eric Scotson Date

Infrastructure: *Signed document on file* ______________ 2 Jun 09
John Chirco Date

Operations: *Signed document on file* ______________ 2 Jun 09
Paul Mosier Date

Maintenance: *Signed document on file* ______________ 2 Jun 09
Paul Mosier Date

Rolling Stock: *Signed document on file* ______________ 26 May 09
Frank Banko Date

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ABSTRACT

This technical memorandum assesses structural load effects including forces, deformations, strains, and related requirements to be used in the preliminary design of fixed facilities for the California High-Speed Train Project.

It establishes the load effects to be considered for the preliminary design of structures supporting high-speed trains as well as access to, and crossings above, the high-speed train facilities. These guidelines are necessary to ensure that the performance requirements of high-speed train structure are met and to provide a consistent basis for advancing the design of the alignment design, determining right-of way requirements, assessing constructability and scheduling considerations, and preparing cost estimates for the 15% design level.

The focus of this document is the design of bridges, aerial structures and cut-and- cover tunnels carrying dedicated high-speed train service. Future technical memoranda will be created for other high-speed train tunnel types.

Building and station design criteria references the California Building Code (CBC). CBC methodology will be used for all non-seismic related design. However, since the CBC primarily uses force-based seismic design, FEMA 356 is referenced for the performance (i.e.: strain and deflection) based seismic design methodology proposed for CHSTP.

As the project-specific, high-speed rolling stock has not yet been selected, a Cooper E-50 for the live loading plus impact as defined in the AREMA Specification was selected for the 15% design level. The E-50 loading was selected to approximate the dynamic loading effects of LM-71 and SW/0 load models. The preliminary criteria for load effects and simplified static design approach are intended to provide designers with a common design basis for establishing structure footprints and proportioning materials and to promote development of uniform description of construction techniques and uniform cost estimates. Dynamic analyses using representative high-speed trainsets will be required for advanced structural design.

The information included in this document is to be used in conjunction with seismic and geotechnical guidance developed for the high-speed rail project.

6.0 DESIGN MANUAL CRITERIA

6.1 General

This section provides design guidance for the load effects required under the Load and Resistance Factor Design (LRFD) design methodology for permanent and transient loadings that will affect the high-speed train structures. Additionally, this section establishes the load effects required for the preliminary design of structures supporting the high-speed train as well as access to, and crossings above, the high-speed train facilities. This section also provides guidance for structural classification and highlights the design parameters.

As the project-specific, high-speed rolling stock has not yet been selected, a Cooper E-50 for the live loading plus impact as defined in the AREMA Specification was selected for the 15% design level. The E-50 loading was selected to approximate the dynamic loading effects of LM-71 and SW/0 load models. The preliminary criteria for load effects and simplified static design approach are intended to provide designers with a common design basis for establishing structure footprints and proportioning materials and to promote development of uniform description of construction techniques and uniform cost estimates. Dynamic analyses using representative high-speed trainsets will be required for advanced structural design.

The focus of this document is the design of bridges, aerial structures and cut-and- cover tunnels carrying high-speed trains. Future technical memoranda will be created for other high-speed train tunnel types. Building and station design criteria references the CBC. CBC methodology will be used for all non-seismic related design. However, since the CBC primarily uses force-based seismic design, FEMA 356 is referenced for the performance (i.e.: strain and deflection) based seismic design methodology proposed for the CHSTP.

6.1.1 Structural Classifications

CHST facility structures provide a broad range of functions for the system. As such, consistent design standards with different design objectives need to be applied to various structures. Different facilities have varying design objectives and the design criteria should recognize that. Structural classification provides a method to differentiate between the various design objectives for the different structural types.

6.1.1.1 General Classifications

CHST facility structures are classified as:

- Bridges – high-speed train trackway structures crossing rivers, lakes or other bodies of water
- Aerial Structures – high-speed train trackway structures that are elevated
- Earth Retaining Structures – including U-walls and retaining walls
- Cut-and-Cover Underground structures – including cut-and-cover subway line structures
- Bored Tunnel Linings
- Mined Tunnels
- Buildings and All Other Above-ground Structures – including station buildings, station parking structures, secondary and ancillary buildings, sound walls, and miscellaneous structures
- Underground Ventilation Structures
- Underground Passenger Stations
- Equipment and Equipment Supports

This document assumes that CHST facilities, based on their importance to high-speed train service, are classified as Primary or Secondary Structures.

- **Primary Structures:** Primary Structures are those that directly support track and train loads and are structurally required for running trains. These include aerial trackways, stations, and earth retaining structures, cut-and-cover subways, and bored tunnels. Primary Structures also include other facilities and systems necessary for train services including, track, rail fasteners, earth embankments and fills, train control and communication facilities, traction power facilities, and Central Operations Centers.
- **Secondary Structures:** Secondary Structures are those that are not necessary for train service including, administrative buildings, shop buildings, storage facilities, cash handling buildings, parking structures and training facilities.

This document is related to design of Primary Structures.

6.1.2 Structural Design Parameters

1. All structures shall be designed for the appropriate loadings and shall comply with the structure gauge adopted for the high-speed train system.
2. Structure design load assumes dedicated high-speed rail operations. Freight rail vehicles will not operate on high-speed rail lines.
3. Structural design guidance shall apply to all structures adjacent to, above, or below the high-speed tracks.
4. 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.
5. The maximum design speed for the main tracks is 250 miles per hour; segments of the alignment will be designed to lesser speeds.
6. The bridges and aerial superstructures shall be designed as essentially rigid and stiff in order to meet serviceability and comfort requirements for high-speed train operation.
7. Design and construction of high-speed train facilities shall comply with the approved and permitted environmental documents.

6.1.3 Seismic Design Parameters

Seismic design will use a hybrid probabilistic-deterministic approach, with oversight by a Technical Advisory Panel (TAP)) and will implement industry best practices. A system-wide risk evaluation will be performed to assess and mitigate risks.

Continuing safe revenue operation of the high-speed train system during and after a strong seismic event is a priority of the Authority. Because of the high likelihood of major seismic activity during the life of the facility, preventive measures will be made to avoid an unnecessarily long shut-down of the system after a major earthquake and to avoid catastrophic failure during such an event. To this end, in the determination of the horizontal and vertical alignment, it is desirable to cross major fault zones at-grade without any structures at fault crossings where mitigating designs can be more cost-effectively employed. All faults should be crossed perpendicular to reduce the extent of damage. The system will also be designed to withstand smaller, more common earthquakes without impact to passenger safety or service interruption.

The goal of the structural performance during a seismic event is to safeguard against major failures, loss of life, and to prevent a prolonged interruption of high-speed train operations caused by structural damage. In order to achieve this, the following three seismic performance criteria have been established.

- **No Collapse Performance Level (NCL):** CHST facilities are able to undergo the effects of the Maximum Considered Earthquake (MCE) with no collapse. Significant damage may occur that requires extensive repair or complete replacement, yet passengers and personnel are able to evacuate safely. The MCE is the greater of the deterministic median or the probabilistic 2475 year return period event, with a 4% probability of exceedance for a design life of 100 years.

- **Safety Performance Level (SPL):** CHST facilities are able to undergo the effects of the Design Basis Earthquake (DBE) with repairable damage and temporary service suspension. However, normal service can resume within a reasonable time frame, and passengers and personnel can safely evacuate. Only short term repairs to structural and track components are expected. The DBE is the greater of the deterministic median plus one standard deviation or the probabilistic 950 year return period event, with a 10% probability of exceedance for a design life of 100 years.
- **Operability Performance Level (OPL):** CHST system will be able to operate at maximum design speed and safely brake to a stop during a Lower-level Design Basis Earthquake (LDBE). Normal service will resume when track alignments have been inspected and any necessary short term track repairs, such as minor realignment and grade-adjustment, are made. No structural damage is expected. The LDBE is the probabilistic 100 year return period event, with a 63% probability of exceedance for a design life of 100 years.

In general, an individual structure may need to comply with multiple performance criteria.

See Tech Memo 2.10.4 – Interim Seismic Design Criteria for the performance criteria requirements, based upon structure's Importance and Technical Classification.

6.2 Design Codes and Specifications

The structural design shall meet all applicable portions of the general laws and regulations of the State of California and of the respective local authorities.

Unless otherwise specified, the CHST facilities shall be designed in accordance with all applicable portions of the following standards and codes:

1. AASHTO LRFD: AASHTO LRFD Bridge Design Specifications 4th Edition, 2007 published by the American Association of State Highway and Transportation Officials
2. AREMA: American Railway Engineering and Maintenance-of-Way Association, Manual for Railway Engineering
3. ACI: American Concrete Institute, Building Code Requirements for Reinforced Concrete, ACI 318
4. AISC: American Institute of Steel Construction, Steel Construction Manual, Thirteenth Edition
5. AWS: Structural Welding Code, Steel, 1996 ANSI/AWS D1.1-96
6. AWS: Bridge welding Code ANSI/AASHTO/AWSD1.5-95
7. CBC: The California Building Code
8. California Department of Transportation (Caltrans) Bridge Design Manuals, latest edition
    - Bridge Design Specification (CBDS) - AASHTO LRFD Bridge Design Specification, 4th Edition, 2007, with California Amendments
    - Bridge Memo to Designers Manual (CMTD)
    - Bridge Design Practices Manual (CBPD)
    - Bridge Design Aids Manual (CBDA)
    - Bridge Design Details Manual (CBDD)
    - Bridge Memo to Designers Manual (CMTD)
    - Standard Specifications
    - Standard Plans
    - Seismic Design Memorandum
    - Caltrans Seismic Design Criteria ver. 1.4 (CSDC)
9. European Standard EN 1991-2:2003 Traffic Loads on Bridges

10. European Standard EN 1990 annexe A2: Application to Bridges
11. FEMA 356 - Prestandard and Commentary for the Seismic Rehabilitation of Buildings, November 2000

In addition, the design of structures to be built as part of the CHST project but owned by other agencies or private owners, shall meet the requirements of the agencies which normally have jurisdiction over such. In the event of conflicting requirements between the CHSTP Design Criteria and other standards and codes of practice, the CHSTP Design Criteria shall take precedence. For requirements which have not been included in the CHSTP Design Criteria, the order of code precedence shall be: 1) local codes; 2) U.S. National Standards; 3) others.

The design of the CHST structures shall be in compliance with these criteria, using the Load and Resistance Factor Design (LRFD) method. In specific situations such as structural steel, pre-stressed concrete, foundation stability and other serviceability requirements, allowable stress design is permitted. The structures shall be designed to resist temporary construction stages and loadings.

Where applicable, the structural analysis and design shall consider soil-structure interaction and non-linear behavior, as well as temporary construction loads during staged construction.

The following sections describe permanent and transient loading requirements to be considered for design of the structures.

6.3 Loads and Forces

The loads and forces defined in this Subsection shall apply to all structures or parts of structures specifically designed for high-speed train facilities.

For uniform (TU) and gradient (TG) temperature effects, creep and shrinkage effects on concrete (CSH), and other loads not specified herein, the requirements in CBDS shall be used.

6.3.1 Dead Load (DC, DW, EV)

The dead load shall include the weight of all components of the entire structure, appurtenances, utilities attached to the structure, earth cover, finishes, and all permanent installations such as trackwork, ballast, conduits, piping, safety walks, walls, sound walls, electrification and other utility services.

The dead loads used for the design of the high-speed train structures shall consist of the weight of the basic structure components, the weight of elements permanently supported by the structure (DC). The weight of earth cover above the tunnel roof (EV) is also considered as a dead load.

If applicable, dead load shall be applied in stages to represent the construction sequence required to construct the structure. Analysis shall include consideration of the maximum and minimum loading that may be imposed on the structure either during construction or that resulting from future placement or removal of the earth cover.

DC refers to the dead load of structural components and nonstructural attachments including trackwork, ballast, plinths, safety walkways, acoustical barriers, etc. DW refers to the dead load of wearing surfaces, utilities, cable trays, overhead contact system, and finishes and other items where the weight may be less certain over time.

Table 6.3-1 presents the unit weights to be used to calculate dead load:

Table 6.3-1 – Unit Weights of Common Materials

Item	Unit Weight
Ballast	120 pcf
Systems cable tray	180 pounds per foot of track
Normal weight concrete (plain or reinforced)	145 pcf
Electrification (overhead system and fastenings)	150 pounds per foot of track
Rails and fasteners (no ties)	200 pounds per foot of track
Steel	490 pcf
Timber (treated or untreated)	50 pcf
Soils	See Geotechnical recommendations
Fresh Water	62.4 pcf
Salt Water	64.0 pcf
Aluminum alloys	175 pcf
Cast iron	450 pcf
Asphaltic Concrete (A/C)	145 pcf

6.3.2 Hydrostatic Force (WA)

The effects of ground water hydrostatic force effect, including buoyancy (WA) shall be considered in the design of underground structures and the substructure of aerial structures and buildings, including foundations and piling.

Adequate resistance to flotation shall be provided at all sections for full uplift pressure on the structure foundation, based upon the maximum probable height of the water table defined in the Geotechnical Data Report. For the completed structure, such resistance shall consist of the dead weight of the completed structure and the weight of backfill overlying the structure (within vertical planes drawn through the outer edges of the structure roof and through all through all joints). Friction acting on rigid excavation support systems such as diaphragm walls in permanent structures may also be used to resist uplift.

Hydrostatic pressure shall normally be applied to all surfaces in contact with groundwater with a magnitude based on the depth of water and the applicable water density.

6.3.3 Hydrodynamic Force (WAD)

Hydrodynamic pressure effects acting on submerged portions of structures due to dynamic motion to be computed using the method of Goyal and Chopra [] or by equivalent means.

6.3.4 Earth Pressure (EV, EHAC, EHAR)

Substructure elements shall be proportioned to withstand earth pressure. Recommended soil parameters, earth pressures and loads due to surcharges shall be as provided for the particular structure in the Geotechnical Design Report.

Vertical Earth Pressure (EV): Depth of cover shall be measured from the ground surface or roadway crown, or from the street grade, whichever is higher, to the top of the underground structure. Saturated densities of soils shall be used to determine the vertical earth pressure. Recommended values shall be presented in the Geotechnical Data Report.

Unless otherwise specified, when roadway traffic can come within a distance of one-half the wall height from the face of the wall, a live load surcharge equal to two (2) feet of equivalent weight of earth shall be added to the earth load. When determining the maximum load on the heel of wall footing, the live load surcharge shall be excluded.

Lateral Earth Pressure – Static: For structures retaining draining cohesionless (granular) soil, lateral earth pressure shall be determined in accordance with the following paragraphs of these criteria. For structures retaining other soil types, the definitions shall be provided for those soil types shall be in the Geotechnical Data Report.

Yielding Walls (EHAC): For the purpose of these criteria, yielding walls are defined as walls which, at the top, are unrestrained and free to move a distance of at least 0.004H, where H is defined as the height of the wall from the base of the heel or the top of wall foundation to the finished grade directly above the heel. One such example is a cantilever retaining wall.

For yielding walls, the static lateral soil pressure shall be determined using the active lateral pressures expressed as equivalent fluid soil pressures. Recommended values shall be provided in the Geotechnical Data Report.

Rigid Walls (EHAR): For the purpose of these criteria, rigid walls are defined as walls which are restrained at the top so that the amount of deflection required to develop active pressure conditions is not possible. All permanent excavation support walls as well as tunnel portal transitions or U-sections are considered rigid walls.

For rigid walls, the static lateral soil pressure shall be determined using the at-rest lateral pressures expressed as equivalent fluid soil pressures. Recommended values shall be provided in the Geotechnical Data Report.

6.3.5 Surcharge Load (EHS)

Surcharge loads (EHS) are those lateral loads resulting from vertical loads applied at or below the adjacent ground surface. The procedures for determining the surcharge load shall be provided in the Geotechnical Data Report.

Underground structures shall be designed for loading from existing adjacent buildings or structures. Consideration shall be given to the maximum and minimum loads that can be transferred to the design structure, and design loads shall be assumed to be the same as those for which the adjacent structure was designed. In the absence of this information, loads based on provisions in the CBC, or the actual and heaviest occupancy for which the building is suitable, shall be used. Design loads on underground structures and underpinning loads from existing buildings or structures shall be based upon the actual weight and the heaviest occupancy for which the building is suitable in accordance with the CBC.

Structures that may support developments above the stations or station facilities in the future shall be designed to reflect that future load. Surcharge loads modeling future developments shall not be applied concurrently with traffic or future traffic surcharges in the same locations. If a future development extends to the surface land adjacent to an underground station then a surcharge shall be applied to the station for design of the station support system. The surcharge shall model the loading due to the maximum development currently allowed by zoning.

6.3.6 Earth Settlement Loads (ESET)

Earth settlement loads (ESET) are forces or displacements imposed on a structure due to both uniform or differential settlement under sustained loading. Guidance to determine expected settlement effects shall be provided in the Geotechnical Data Report.

6.3.7 Live Loads (LLP, LLV, LLRR, LLHR, LLH, LLHL, LLHT)

As the project specific rolling stock has not yet been selected, the trainset used for the 15% design is Cooper E-50 loading plus impact as defined in the AREMA Specification. Once the rolling stock is determined, the live load criteria will be expanded to consider the design trains.

The loads defined in this section shall apply to all structures or parts of structures designed to provide for, and access to, trains. For preliminary design, loads are assumed to be due to Cooper E-50 maintenance trains, street loads, construction equipment, passengers, and pedestrians, movement of equipment, equipment and potential surcharge from adjacent rail roads.

Live load is moving load excluding wind load, stream flow, hydraulic pressure, earth pressure and seismic actions.

6.3.7.1 Floor and Roof Live Loads (LLP)

Where appropriate at stations, buildings, and walkways, floor and roof live loads (LLP) shall be in accordance with CBC with the following exceptions:

- Station platforms and concourse areas shall be 100 pounds per square foot.
- Emergency and maintenance walkway shall be 100 pounds per square foot.
- Live loads on service walkways and sidewalks shall be 100 pounds per square foot, or for a concentrated live load of 1,000 pounds applied anywhere on the walkway and distributed over a 2 feet by 2 feet area
- Safety railings shall be designed to withstand a horizontal force of 50 pounds per linear foot applied at right angles to the top of the railing. The mounting of handrails and framing of members for railings shall be such that the completed handrail and supporting structure shall be capable of withstanding a load of at least 200 pounds applied in any direction at any point on the top rail. These loads shall not be combined with the 50 pounds per linear foot. For the design of structure components which support train loads and a walkway, the walkway live loads shall not be applied simultaneously with the train loads.
- Stationary and hinged cover assemblies internal to high-speed train facilities shall be designed for a minimum uniform live load of 100 pounds per square foot or a concentrated live load of 1,000 pounds over a 2 feet by 2 feet area. Deflection at center of span under 100 pounds per square foot uniform live load shall not be more than 1/8 inch. If equipment installation uses a cover under part of the travel path then the cover shall be designed to support that live load.. Covers at street level shall be designed for LLH loads described in Section 6.3.7.4.

No impact factors apply to LLP.

6.3.7.2 High-Speed Train Loading (LLV)

The project specific rolling stock has not yet been determined.

Once the rolling stock has been determined, then impact factors shall be determined by use of a dynamic model considering the structural configuration, supports, foundation flexibility, rolling stock loads, and design train speed.

Where a structure supports multiple tracks, the loading shall be applied for those number of tracks either simultaneously or individually, whichever governs design..

A fatigue damage assessment shall be performed for all structural elements which are subjected to fluctuations of stress. For structures supporting multiple tracks the loading shall be applied to a minimum of two (2) tracks in the most unfavorable positions. The fatigue damage shall be assessed over the required structural life of 100 years.

6.3.7.3 Maintenance and Construction Train Loading (LLRR, LLHR)

In addition to the high-speed train loading, the structures shall be designed to support maintenance and construction trains. For the 15% design level, train loads are based on the Cooper loading E-50 plus impact as defined in the AREMA Specification. Impact values shall assume either direct fixation or ballasted track support, whichever governs.

Where a structure supports multiple tracks, the loading shall be applied for those number of tracks either simultaneously or individually, whichever governs design.

To account for adjacent railing servicing maintenance and construction trains, LLHR refers to the lateral surcharge due to such trains. No impact factors apply to LLHR.

6.3.7.4 Highway Loads (LLH, LLHL)

Facilities designed that support highway loads shall be designed for a minimum of HL-93 Truck Loading based on the CBDS Specification. Highway bridges spanning over high-speed train trackways shall be designed for the provisions in the CHSTP Design Criteria in addition to CBDS.

The design vehicular live loading HL-93 (ref. CBDS 3.6.1.2.1) includes the design truck load in addition to the design lane load. LLH refers to the application of the vertical vehicular live loading.

LLHL refers to the lateral surcharge due to vehicular live loading. No impact factors apply to LLHL.

For underground structures beneath city streets or planned roadways including culverts, spread footings and pile caps, the applied vehicular live load shall be based on the HL-93 loading. The distribution of this live load shall be in accordance with the following:

- Fill height less than two feet: Live load shall be applied as concentrated wheel loads directly to the top of the slab in addition to the uniform load specified in HL-93 loading.
- Fill height greater than two feet: Concentrated wheel loads shall be distributed over a square area, the sides of which shall equal 1.15 times the depth of the fill and added to the HL-93 uniform load.
- When distribution areas overlap, the total load shall be uniformly distributed over an area defined by the outside limits of the individual areas.
- The design lane load shall be distributed over that portion of a lane width as described in CBDS.

For design or evaluation of highway bridges that could support permit loads, Caltrans guidelines shall be consulted for routing and sizes of the permit vehicles.

6.3.7.5 Future Live Loads on Buried Structures (LLHT)

An area surcharge shall be applied at the ground surface both over and adjacent to underground structures to simulate possible roadway and sidewalk live loads. This surcharge (LLHT) is also intended to account for loads from future construction activities over and adjacent to the underground structures. Such construction may result in permanent loads or in temporary loads from construction equipment and drayage or from stockpiling of construction materials, or excavated earth. It is possible that loads such as those from hauling trucks, may be applied inadvertently to the underground structures. The surcharge shall be applied to all underground structures, unless: 1) positive and recognizable means are provided at the ground surface to ensure that the above types of loadings cannot occur; and, 2) the Authority specifically permits in writing, the application of a surcharge of lesser magnitude.

The vertical surcharge shall be considered as a static uniform load applied at the station roof as follows:

600 psf for $x < 5$

600-40 (x-5) psf for $5 < x < 20$

0 for x > 20

x = Vertical distance from the top of structure roof to ground surface, in feet.

No impact factors apply to LLHT.

LLHT surcharge shall not be applied, when:

- Vehicular Loading specified in Section 6.3.7.3 or 6.3.7.4 is applied, or when
- Specific, applicable building surcharge as described in Section 6.3.5 is applied.

Recommended coefficients for horizontal surcharge loading shall be presented in the Geotechnical Data Report.

6.3.8 Vertical Impact Factors (I)

Moving trains and vehicles impart dynamic load to bridges, which are considered in design codes through a dynamic coefficient. In the specific operation of high-speed trains, the phenomena of "resonance" due to the repetitive application of axle loads at high frequencies must be considered.

For determining vertical impact factors (I) associated with high-speed train rolling stock (LLV), a dynamic model considering the structural configuration, supports, foundation flexibility, rolling stock loads, and design train speed must be used.

Note that Dynamic Impact Factors are based on Eurocode 6.4.4-6, which were originally derived for speeds of 218 mph or less. Impact Factors require validation for higher speeds.

For determining impact factors (I) associated with maintenance and construction train loading (LLRR), AREMA Specifications shall be used as follows:

Spans less than 80 feet, I = 40 – 3 L ^2 / 1600

Spans greater than 80 feet, I = 16 + 600 / (L – 30)

The calculated value from AREMA shall be applied at top of rail as a percentage of live load. In addition, for local design of track railing and fasteners, an additional 20% of live load is to be applied to each rail as a vertical force to model the couple caused by potential rocking of the train.

For determining impact factors (I) associated with highway loading (LLH), CBDS shall be used.

Impact applies to the following:

- Superstructure, including steel or concrete supporting columns, steel towers, legs of rigid frames, and generally those portions of the structure which extend down to the main foundation.
- The portion above the ground line of concrete or steel piles that support the superstructure directly.
- Underground structures and culverts having a cover of less than three feet.

Impact does not apply to the following:

- Retaining walls, wall-type piers, and piles except those described above.
- Foundations, footings, and base slabs which are in direct contact with earth.
- Floor and roof live loads (LLP) as per Section 6.3.7.1.
- Culverts and underground structures having a cover of three (3) feet or more.

6.3.9 Nosing and Hunting Effects (NE)

For slab track with direct fixation, the nosing and hunting effects (NE) of the wheels contacting the rails shall be accounted by a 22,000 pound force applied to the top of the low rail, perpendicular to the track centerline at the most unfavorable position.

NE is not applicable for the design of bridge decks with ballasted track.

6.3.10 Slipstream Effects (SS)

Guidance for slipstream effects (SS) from passing trains will be developed at a later date.

6.3.11 Acceleration and Braking Forces (LF)

Acceleration and braking forces (LF) act at the top of the rails in the longitudinal direction of the track.

For acceleration and braking forces from maintenance and construction trains (LLRR) use AREMA. For acceleration forces from truck loading (LLH) refer to CBDS.

For acceleration and braking forces from high-speed trains (LLV):

Acceleration force = 25% of LLV < 225 kips (1001 kN)

Braking force = 25% of LLV < 1350 kips (6000 kN)

These loads are to be distributed equally to all axles over the length of the train. Note that acceleration and braking forces will require review and revision when project-specific rolling stock is selected.

6.3.12 Centrifugal Force (CF)

For tracks on a curve, centrifugal force (CF) shall be considered as a horizontal load applied toward the outside of the curve at 6.0 ft. above top of rail.

The centrifugal force (CF) is a function of the train live load (LLV or LLRR), impact (I), and horizontal radius of curvature:

For U.S. customary units:

$CF = (LLV \text{ or } LLRR)\ [V^2 * f / 15R]$

V = train speed (mph)

R = horizontal radius of curvature (ft)

f = reduction factor:

$f = 1$ (for V< 75 mph)

$f = 1 - [(V - 75)/1000] \times [509/V + 1.75] \times [1 - (9.45/ L_f)^{1/2}]$ (for V > 75 mph)

L_f = length (ft) of the loaded portion of curved track on the bridge.

6.3.13 Wind Loads (WS)

Bridges and aerial structures shall be designed to withstand a wind load (WS) of:

80 psf transversely, and 30 psf longitudinally when there is no train on the structure. The wind shielding area shall include the exposed area of all bridge elements. Wind loads to act simultaneously.

30 psf transversely and longitudinally when there are trains on the structure. The wind shielding area shall include the exposed area of all bridge elements including OCS poles and catenary. A train shall be considered as a box 14.1 ft. high with its lower boundary 1.0 ft. above top of rail and its length such as to produce the most critical loading condition for the structure. Wind loads to act simultaneously.

25 psf vertically for both cases of train occupancy on the structure. This load shall be applied upward at the windward quarterpoint of the transverse width of the superstructure.

Wind loads (WS) on building and station structures shall be as per CBC.

Wind loads (WS) on highway structures shall be per CBDS.

6.3.14 Derailment Load (DR)

HST aerial structures shall be constructed such that in the event of a derailment, the damage to the structure shall be minimal. Overturning or collapse of the structure shall not be allowed.

Two design situations shall be considered:

- Derailment with the vehicle remaining in the track area. Collapse of any major part of the structure shall not be allowed but local damage can be tolerated. The components of the structure shall be designed to an Extreme Limit State with two vertical line loads each of 3.5 kips per foot over a length of 21 feet and 4.5 feet apart. These loads shall be parallel to the track in the most unfavorable position inside an area 1.5 times the track gauge on either side of the track centerline or as limited by any derailment containment feature. For ballasted track, the loads may be assumed to be distributed over a width of 16 inches at the underside of the ballast.
- Derailment with the vehicle remaining balanced on the edge of the bridge. Overturning or collapse of the structure shall not be allowed. For the determination of overall stability a vertical line of 4.2 kips per foot over a length of 65 feet shall be applied to the edge of the deck.

Structures alongside or above the high-speed tracks supported by columns, piers or walls located near the tracks are classified as being within two zones:

- Zone 1: Minimum distance from the support to the center line of the adjacent track less than 9.8 ft (3.0 m)
- Zone 2: Minimum distance from the support to the centerline of the adjacent track between 9.8 ft (3.0 m) and 16.4 ft (5.0 m).

Beyond 16.4 ft (5.0 m) from the centerline of the track, no provision for impact by the high-speed train need be made.

The collision loads HL and HT that have to be taken into account in the design of supports within the two zones are given in Table 6.3-2. The two loads are applied equally in the load combination:

$$DR = H_L + H_T$$

Table 6.3-2 Impact Collision By High-Speed Train With Structures

Zone	Train Speed V (mph)	Impact Load (kips)	
		H_L	H_T
Zone 1 d < 10.0 ft.	V > 30	900	350
	V ≤ 30		
	Secondary track		
Zone 2 10.0 ft ≤ d ≤ 16.5 f)	V > 30	900	350
	V ≤ 30	500	200
	Secondary track		

where:

H_L = horizontal longitudinal point load parallel to the track and applied at the support 6.0 ft. above the level of the lower rail

H_T = horizontal transverse point load perpendicular to the track and applied at the support 6.0 ft. above the level of the lower rail

6.3.15 Seismic Loads (EQM, EQD, EQL)

Seismic loads will apply to all structures in the CHSTP. These structures vary from bridges and aerial structures, to retaining walls, filled embankments, cut embankments, tunnel portal transitions, cut and cover tunnels, bored tunnels both soft ground and rock, access shafts, as well as buildings and stations of all types.

Detailed, project specific seismic design criteria are presented in Tech Memo 2.10.4 – Interim Seismic Design Criteria. This memo defines the seismic design philosophies, seismic analysis/demand methodologies, and structural capacity evaluation procedures for the three levels of design earthquakes. These three levels are:

- Maximum Considered Earthquake (MCE) or (EQM): 2475 year return period, 4% probability of exceedance for the design life of 100 years.
- Design Basis Earthquake (DBE) or (EQD): 950 year return period, 10% probability of exceedance for the design life of 100 years.
- Lower-level Design (LDBE) or (EQL): 100 year return period, 63% probability of exceedance for the design life of 100 years.

Note that in general, an individual structure may need to comply with multiple performance levels, depending upon its Importance and Technical Classification.

6.4 Load Factors and Load Modifiers

For building and station structures, the design shall be in accordance with the concepts and general methodology of the CBC. Where stations and ancillary buildings are to support train loads, then the criteria for bridge and aerial structures below shall also apply.

For bridge and aerial structures, the design shall be in accordance with the concepts and general methodology of CBDS Section 1.3.2. The governing formula for LRFD design is:

$$\Sigma \eta_i \gamma_i Q_i \leq \Phi R_n = R_r$$

Where:

γ_i = load factor applied to force effects. (see Table 3.4-1)

Φ = resistance factor applied to minimal resistance (see Table 3.4-3)

η_i = load modifier relating to ductility, redundance and importance (>1.05)

Q_i = force effect

R_n = nominal resistance

R_r = factored resistance, ΦR_n

For loads for which a maximum value of “η_i” is appropriate, the value of “η_i” shall be greater than 1.05 to account for the 100 year design life of the facility. Load factor values “γ_i “are provided in Table 6.4-1.

Variation of load factors for permanent loads, γ_p, are presented in Table 6.4-2.

Some selected resistance factors “Φ” are presented in Table 6.4-3.

6.4.1 Design Load Combinations

The load combinations to be used for design for bridge and aerial structures are presented in Table 6.4.1. The description of the load combinations follows:

- “Service 1” is for design toward operational use of the facilities, allowable stress design (ASD) design of steel elements, service level prestress concrete design, and the design of temporary struts and permanent struts that will be instrumented.
- “Buoyancy at Dewatering Shutoff” is for evaluation of uplift with a minimum weight structure.
- ”Strength 1” is for strength design of concrete and steel structures.

- "Strength 2" is for strength design of concrete and steel structures to meet the Lower Level Design Basis Earthquake (LDBE) requirements.
- "Extreme 1" is for design to meet Design Basis Earthquake (DBE) performance requirements.
- "Extreme 2" is to design for a derailment of the high-speed train to meet performance requirements.
- "Extreme 3" is for design to meet Maximum Considered Earthquake (MCE) performance requirements.

Note that for each load combination shown below, the designer shall consider physically achievable subsets (i.e.: omitting load factors by setting $\gamma_i = 0$) which may govern design.

Table 6.4-1 - Load Combinations and Load Factors, γ_i

Load Combination/ Limit State	DC DW WA	EV	EHS	EHAC EHAR ESET	LLP (LLV + I) (LLH + I) (LLRR + I) LLHR LLHL LLHT	NE SS CF LF	TU TG	CSH	WS	EQL WAD	EQD WAD	EQM WAD	DR
Service 1	1.0	1.0	1.0	1.0	1.0	1.0	0.5/1.2	0.5/1.2	0.3				
Buoyancy @ Dewatering Shutoff	1.0	.8		1.0					0.3				
Strength 1	γ_p	γ_p	γ_p	γ_p	1.75	1.75	0.5/1.2	0.5/1.2					
Strength 2	γ_p	γ_p	γ_p	γ_p	0.50	0.5	0.5/1.2	0.5/1.2		1.0			
Extreme 1	1.0	1.0	1.0	1.0							1.0		
Extreme 2	1.0	1.0	1.0	1.0									1.0
Extreme 3	1.0	1.0	1.0	1.0								1.0	

Table 6.4-2 - Load Factors for Permanent Loads, γ_p

Type of Load	γ_p Load Factor	
	Maximum	Minimum
DC: Dead Load of Tunnel Structure Excluding Interior Finishes & Non-Structural Elements WA: Hydrostatic water pressure	1.25	0.9
DW: Dead Load of Interior Finishes & Non-Structural Elements	1.50	0.9
EHAC, EHAR: Horizontal Earth Pressure	1.50	0.9
ESET: Earth Settlement Effects	1.50	0.9
EV: Vertical Earth Pressure	1.50	0.8
EHS: Earth Surcharge	1.50	0.75

Permanent Loads:

DC:	dead load of structural components and nonstructural attachments
DW:	dead load of architectural finishes, wearing surfaces and utilities
WA:	hydrostatic force effect
EV:	vertical earth pressure from dead load of fill
EHS:	earth surcharge load/building surcharge
EHAC:	horizontal earth pressure load for active earth pressure
EHAR:	horizontal earth pressure load for at rest earth pressure
ESET:	earth settlement effects

Transient Loads:

LLV:	weight of high-speed vehicle
LLP:	roof and floor live loads
LLH:	weight of HL-93 truck loading
LLRR	weight of maintenance and construction train (Cooper E-50)
LLHL:	earth pressure loads from surcharge due to highway traffic loads
LLHR:	earth pressure loads from surcharge due to railroad loads
LLHT:	earth pressure loads from future live loads
I:	vertical impact effect
NE:	nosing and hunting effect from trains
SS:	slipstream effect from passing trains
CF:	centrifugal force effect in curved track
LF:	acceleration or breaking force applied to structures
TU:	uniform temperature effects
TG:	gradient temperature effects
CSH:	effects from creep and shrinkage of concrete
WS:	wind load on structure
EQL:	forces, deformations, and strains generated by Lower-Level Design Basis Earthquake (LDBE) effects
EQD:	forces, deformations, and strains generated by Design Basic Earthquake (DBE) effects
EQM:	forces, deformations, and strains generated by Maximum Considered Earthquake (MCE) effects
WAD:	hydrodynamic force effect
DR:	derailment load from high-speed trains

6.4.2 Resistance Factors

Selected resistance factors Φ, with CBDS reference, are listed in Table 6.4-3.

Table 6.4-3 Selected Resistance Factors, Φ

Description	Factor	CBDS Reference
Tension controlled reinforced concrete	0.90	5.5.4.2
Tension controlled prestressed concrete	1.00	5.5.4.2
Shear and torsion, normal weight concrete	0.90	5.5.4.2
Compression controlled sections with spirals or ties	0.75	5.5.4.2
Bearing on concrete	0.70	5.5.4.2
Flexure or shear on structural steel	1.00	6.5.4.2
Axial compression in structural steel	0.90	6.5.4.2
Axial tension, yielding of gross section in structural steel	0.95	6.5.4.2
A325 and A490 bolts in shear or tension	0.80	6.5.4.2
Aluminum in tension, ultimate	0.90	7.5.4
Aluminum in tension, yield	0.75	7.5.4
Aluminum in compression	0.80	7.5.4
Drilled shaft tip resistance in clay	0.40	10.5.5
Drilled shaft side resistance in clay	0.45	10.5.5
Drilled shaft tip resistance in sand	0.50	10.5.5
Drilled shaft side resistance in sand	0.55	10.5.5
Driven piles in axial compression in clay (value depends on design method)	0.25 -0.40	10.5.5
Driven piles in axial compression in sand (value depends on design method)	0.30 – 0.45	10.5.5
Tensile resistance or soil anchor tendon, A615 bars	0.90	11.5.6
Tensile resistance or soil anchor tendon, A722 bars	0.80	11.5.6

For design of elements not listed refer to CBDS.