California High-Speed Train Project

TECHNICAL MEMORANDUM

OCS Requirements

TM 3.2.1

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Released by:	*Signed document on file*_______ Anthony Daniels, Program Director	_13 July 09_ Date

Revision	Date	Description
0	13 July 09	Initial Release

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:	Not Required	Date
Infrastructure:	*Signed document on file* John Chirco	26 Apr 09 Date
Operations:	Not Required	Date
Maintenance:	Not Required	Date
Rolling Stock:	*Signed document on file* Frank Banko	08 May 09 Date

TABLE OF CONTENTS

ABSTRACT

The California High Speed Train Project (CHSTP) will provide high-speed train service in the state of California with proposed terminal stations (end-of-line or end-of route) in Sacramento, San Francisco, Fresno, Bakersfield, Los Angeles, Anaheim and San Diego. Intermediate stations will serve locations along the alignment. For much of the alignment, high speed trains will operate along a dedicated track with stations that exclusively serve high speed train operations. There are also two locations (the Lossan and Caltrain corridors) where the proposed California High-Speed Rail (CHSR) line will operate within a shared right-of-way with conventional passenger railroad lines.

The purpose of this technical memorandum is to review standards and best practices to provide criteria for the overhead contact system requirements of the California High Speed Train Project to:

- Provide a general system description and define the general performance requirements of the overhead contact system
- Define the overhead contact system performance requirements for high speed
- Provide a general detailed description of the overhead contact system
- Define the environmental requirements and climatic conditions applicable to the CHSTP overhead contact system
- Define the electrical requirements including the electrical clearances applicable to the overhead contact system
- Define the overhead contact system mechanical requirements
- Define the overhead contact system structural requirements
- Define the grounding and bonding requirements applicable to overhead contact system
- Define the overhead contact system interface requirements in order to ensure that they will be adequately taken into account in the design, procurement, construction and testing processes
- Define the requirements applicable for the execution of the design, construction, testing and commissioning of the overhead contact system.

Development of the design criteria for the Overhead Contact System will include review and assessment of, but not be limited to, the following:

- Existing FRA, State of California General Orders, NESC, IEEE and NFPA guidelines where applicable
- Existing international standards, codes, best practices and guidelines used for existing High Speed Line Systems and applicable for the Overhead Contact System for applicability to the CHSTP.
- Other existing international standards, codes, best practices and guidelines applicable for the Overhead Contact System

The current design practices for high-speed overhead contact system presently in operation throughout the world are considered in the development of the Overhead Contact System for the CHST project.

1.0 INTRODUCTION

1.1 Purpose of Technical Memorandum

The purpose of the technical memorandum is to review standards and best practices to provide criteria for the overhead contact system requirements of the California High Speed Train Project to:

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It will thus promote safe and efficient operations for high-speed rail train service on both segments of the California High Speed Train Project (CHSTP) alignment that are dedicated to very high speed and for those in shared use operation.

This memorandum presents data relating to the design, construction and testing of the overhead contact system that must be satisfied for high-speed train operation. Where available, it is based on best worldwide present practices and on present U.S. Federal and State Orders, guidelines and practices. Document searches were conducted to identify definitive criteria to be used for the CHST project application and, in some cases, data was not available. Present practices for high speed railways were reviewed and used to define criteria for the CHST project that is incorporated in this memorandum.

It is anticipated that the design will be advanced consistent with applicable codes of practice, design guidelines and other information that defines the CHSTP programmatic, operational, and performance requirements. Additional guidance on the vehicle clearances, pantograph clearance envelopes, electrical clearances and electrical requirements, grounding and bonding requirements, mechanical requirements, and structural requirements to be used for high speed train operations will be transmitted in separate documents.

Following review, specific guidance in this technical memorandum will be excerpted for inclusion in the CHSTP Design Manual.

1.2 STATEMENT OF TECHNICAL ISSUE

High speed current collection and the pantograph – overhead contact system interface are extremely important, i.e. one of the most important technical issues when planning high speed train operation. Ensuring minimum or no interruption of contact continuity between the rolling stock pantographs and the overhead contact system cannot be realized without having carefully defined performance requirements of the overhead contact system, and of its interface with the pantographs.

In addition to the traction power collection, other technical items related to the overhead contact system performance must be defined for the design, construction and testing to ensure that the overhead contact system will satisfactorily ensure safe operation, and maximum reliability, availability, maintainability and safety.

They include electrical requirements, environmental requirements applicable to the CHSTP overhead contact system, mechanical and structural requirements, requirements applicable to the grounding and bonding of the system, interface requirements and construction and testing requirements.

1.3 GENERAL INFORMATION

1.3.1 Definition of Terms

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

Arcing - The flow of current through an air gap between a contact strip and a contact wire usually indicated by the emission of intense light.

Aerodynamic force - Additional vertical force applied to the pantograph as a result of air flow around the pantograph assembly.

Contact force - The vertical force applied by the pantograph to the overhead contact line. The contact force is the sum of forces for all contact points of one pantograph.

Contact point - Point of mechanical contact between a contact strip and a contact wire.

Contact Wire - A solid overhead electrical conductor of an Overhead Contact System with which the pantograph of electric trains makes contact to collect the electrical current.

Contact Wire Height - Height of the underside of the contact wire above top or rail level when not uplifted by the pantograph of an electric train.

Catenary - An assembly of overhead wires consisting of, at a minimum, a messenger wire, also called catenary wire, supporting vertical droppers (hangers) that support a solid contact wire which is the contact interface with operating electric train pantographs.

Dedicated Corridor - Segment along the CHSTP alignment where high speed trains operate exclusive of other passenger railroads.

Dynamic Envelope of Pantograph - A clearance envelope around the pantograph static profile that takes into account under dynamic situation the pantograph sway and pantograph uplift.

Electrical clearance - Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure or a vehicle.

Electrical clearance – dynamic (passing) - Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure or a vehicle during the passage of an electrically powered vehicle equipped with a pantograph

Electrical clearance - static - Minimum clearance between live parts of either the OCS or a vehicle pantograph and grounded (earthed) parts of a fixed structure when not subjected to the passage of an electrically powered vehicle equipped with a pantograph

Insulated Overlap (or electrical overlap) - A sectionalizing length of the overhead contact system formed by cutting insulation into the out-of-running sections of the two adjoining and overlapping catenaries having between them a minimum electrical clearance realized by an air gap. The contact and messenger wires of these two overlapping tension sections that terminate at opposite ends thus allow, in this arrangement, creation of a sectionalizing point in the OCS as required for operational and maintenance reasons, and the passage of pantographs under power from one energized electrical sub-section to the next, both supplied by the same Utility source.

Interoperability - In the context of the European High Speed Lines, the aptitude of the European High Speed lines railway network to allow high speed trains to run safely and continuously with the specified performances. It is based on the whole of the legal, technical and operational conditions that must be fulfilled to satisfy to the necessary requirements. Thus, for example, a German high-speed train satisfying the requirements of the Rolling Stock Technical Specification for Interoperability (TSI) is able to run safely and continuously on a French High Speed Line of which the infrastructure satisfies the different requirements of the different infrastructure Technical Specifications for Interoperability. These TSI design standards were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.

Live - An electrically energized circuit or component.

Live Part - A part or component connected to an energized circuit and therefore live as not insulated from the energized circuit.

Maximum force - The maximum value of the contact force.

Mean force - The statistical mean value of the contact force.

Minimum force - The minimum value of the contact force.

Overhead Contact System (OCS) - Also called Overhead Catenary system or Overhead Contact Line. A system, part of the traction power electrification system, comprising overhead wires including the contact wire and messenger (or catenary) wire placed above the upper limit of the rail vehicle gauge, but also auxiliary wires (aerial feeder and aerial ground wires), supports, foundations, balance weight arrangements, electrical switches and isolators, and other equipment and assemblies. It supplies to non self-powered rail vehicles operating beneath the overhead wires, through roof mounted current collection equipment, electric energy coming from a traction power substation.

Overlap - See Uninsulated Overlap and Insulated Overlap.

Pantograph - Device consisting of spring-loaded hinged arms fitted to the roof of a train that collects current from the contact wire of an overhead contact system.

Pantograph current - Current that flows through the pantograph

Pantograph Clearance (or Pantograph Clearance Envelope) - A clearance envelope around the pantograph static profile.

Pantograph head - Pantograph equipment comprising the contact strips and their mountings.

Pantograph sway- Lateral displacement of the pantograph induced, under the dynamic passage of the electrical vehicle, by vehicle and pantograph lateral displacements that include gauge deviation, roll and lateral vehicle shock loads, and cross-track tolerance.

Phase Break - An electrical break separation separating two electrical sections of the Overhead Contact System supplied by two different Utility sources that may be out-of-phase.

Quasistatic force - Sum of pantograph static force and aerodynamic force at the particular train speed.

Section Insulator - A sectionalizing device installed in the overhead catenary permitting isolation of two adjacent catenary sub-sections while permitting the passage of pantographs under power from one energized electrical sub-section to the next one, both supplied by the same Utility source.

Shared Use Corridor - Segment along the CHSTP alignment where high speed trains share ROW with other passenger railroads, i.e. Caltrain, MetroLink, and Amtrak

Shared Use Track - Segment along the CHSTP alignment where high speed trains operate with other passenger railroads, i.e. Caltrain, MetroLink, and Amtrak, on the same tracks.

Span Length - The distance between two consecutive OCS supporting structures.

Stagger - The normally alternated offset of the contact wire from the tangent or superelevated track centerline by registration at each support that causes the contact wire to sweep side to side over the pantograph head during vehicle operation.

Static contact force - The mean vertical force exerted upward by the collector head on the overhead contact line, and caused by the pantograph-raising device, while the pantograph is raised and the vehicle is at standstill.

Steady arm - A lightly loaded registration arm that serves to steady the contact wire from lateral displacement.

Superelevation (or cant) - The difference in elevation between the outside rail of the curve and the inside rail of the curve measured between the highest point on each rail head.

System Height (or System Depth) - The vertical distance between the messenger and contact wires, at the support structure.

Trolley Wire - Alternative term for contact wire used for single wire OCS. See Contact wire and Overhead Contact System.

Tension Length (or Tension section) - Length of a catenary section between its two termination points.

Tensioning device - A device, typically placed at each end of a tension length and used in balance weight arrangement to maintain a constant mechanical tension of a conductor of an auto-tensioned catenary.

Uninsulated Overlap (or mechanical overlap) - A length of the overhead contact system where the contact and messenger wires of two adjoining tension sections overlap before terminating at opposite ends, thus allowing pantographs under power to transition from one tension section to the next.

Uplift - Lift of the contact wire and/or messenger wire due to the upward pressure of passing pantograph(s).

Yoke Plate - An OCS component which permits termination of two (or more) auto-tensioned wires on the same anchoring OCS structure using only one balance weight arrangement.

Acronyms

AAR	Association of American Railroads
AREMA	American Railway Engineering and Maintenance of Way Association
Caltrans	California Department of Transportation
CHST	California High-Speed Train
CHSTP	California High-Speed Train Project
CFR	Code of Federal Regulations
FRA	Federal Railroad Administration
GO	General Order
PUC	Public Utilities Commission of the State of California
SCRRA	Southern California Railroad Authority
SNCF	Société Nationale des Chemins de fer Français (French National Railway Company)
TSI	Technical Specification for Interoperability of European High-Speed Lines
UIC	International Union of Railways (Union Internationale des Chemins de Fer)

1.3.2 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 any 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, Appendice 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, Appendice B can also be found as an attachment to the CHSTP Mapping and Survey Technical Memorandum.

2.0 DEFINITION OF TECHNICAL TOPICS

2.1 General

Design criteria and other specific requirements related to the Overhead Contact System must be defined for the design, procurement, construction design and construction and testing of the CHSTP to ensure that the overhead contact system will satisfactorily ensure safe operation, and maximum reliability, availability, maintainability and safety at maximum envisaged operating high speeds.

It is anticipated that the type of rolling stock for the CHSTP together with the pantograph type and the Overhead Contact System will not be selected prior to the completion of the 30% Design Level (Preliminary Engineering). Accordingly, the design guidelines included in this document are intended to accommodate the CHSTP preliminary engineering needs without precluding any potential high speed system technology. The design is conducted with the assumption that the high speed train sets technologies together with the high speed pantographs and the high speed overhead contact system that can most likely meet the CHSTP performance requirements will be those of the French (Alstom – AGV), German (Siemens - ICE 3 - Velaro E, Japanese (Hitachi- Shinkansen N700), and Bombardier (AVE S-102). Refinements in the design and associated design elements may therefore be required following vehicle, pantograph, and overhead contact system supplier selection.

The traction power supply system of the California High Speed Train Project will be a 2x25 kV – 60 Hz system (i.e. 25kV-0-25kV) utilizing a 25kV catenary and a negative (-25kV) longitudinal feeder together with autotransformers spaced approximately every five (5) miles along the CHSTP right of way.

The CHSTP Overhead Contact System shall permit a maximum operational speed of 125 mph in existing corridors where high-speed passenger trains and American passenger trains may both operate on the same main line shared tracks. In addition, it is envisaged that time separated freight traffic may also operate on a few miles of these shared use corridors' electrified tracks.

Elsewhere, on dedicated high-speed sections, the CHSTP Overhead Contact System shall permit a maximum operational speed of 220 mph with consideration that faster operation will not be unnecessarily precluded in the future.

2.2 LAWS, CODES AND STANDARDS

2.2.1 NORTH AMERICAN RECOMMENDED PRACTICE AND LEGAL REQUIREMENTS IN CALIFORNIA

AREMA Manual

The primary orientation of the American Railway Engineering and Maintenance of Way Association (AREMA Manual) is to provide guidance in the engineering of railroads moving freight at speeds up to 70mph and passenger trains at speeds up to 90mph with the exception of the still incomplete Chapter 17, High-Speed Rail Systems.

The material presented in the AREMA Manual varies considerably in level of detail and applicability to the CHSTP. Therefore, a reference to the AREMA Manual without a more specific designation of applicable chapter and section is not sufficient to describe any requirement.

When using the AREMA Manual, the statement at the beginning of each chapter will assist in understanding the scope, intent, and limitations of this document.

> "*The material in this and other chapters in the AREMA Manual for Railway Engineering is published as recommended practice to railroads and others concerned with the engineering, design and construction of railroad fixed properties (except signals and communications), and allied services and facilities. For the purpose of this Manual, RECOMMENDED PRACTICE is defined as a material, device, design, plan, specification, principle or practice recommended to the railways for use as required, either exactly as presented or with such modifications as may be necessary or desirable to meet the needs of individual railways, but in either event, with a view to promoting efficiency and economy in the location, construction operation or maintenance of railways. It is not intended to imply that other practices may not be equally acceptable.*"

Legal requirements in California

The requirements of CPUC General Orders shall govern regardless of lesser dimensions in other standards or guidelines. Legal minimum clearances around railroad tracks in California are defined in PUC GO 26-D and legal rules for Overhead Electric Line Construction are defined in PUC GO 95. However, the latest, i.e. PUC GO 95, is not applicable for 25kV electrified overhead contact systems and is in the process of being amended to allow the construction and operation of 25kV electrification systems.

2.2.2 CHSTP DESIGN CRITERIA FOR THE OVERHEAD CONTACT SYSTEM

Design criteria for the CHSTP are under development. When completed, a CHSTP Design Manual will present design standards specifically for the construction and operation of high-speed railways based on international best practices. Initial high-speed rail design criteria will be issued in technical memoranda that provide guidance and procedures to advance the design of project specific elements. Criteria for design elements not specific to HSR operations will be governed by existing applicable standards, laws and codes.

The development of the CHSTP design criteria applicable for the Overhead Contact System is based on a review and assessment of available information, including the following:

- AREMA Manual
- California Public Utilities Commission General Orders 95 and 26-D
- Amtrak guidelines and present practices
- Federal and State Orders guidelines and present practices
- Caltrain Design Criteria (April 15, 2007)
- Existing ASCE, IEEE and NFPA standards and guidelines where applicable
- Technical Specifications for Interoperability of European High-Speed lines
- Other existing international standards, codes, best practices and guidelines used for existing High-Speed Line Systems and applicable for the Overhead Contact System for applicability to the CHSTP.

It is to be noted that Sections 1 to 8 and 12 of Chapter 33 ‘’Electrical Energy Utilization’’ and Section 1.8 of Chapter 28 “Clearances” of the AREMA Manual can be referenced for guidance for overhead electrification. However, these sections of the AREMA Manual do not address high-speed or very high speeds which are only succinctly addressed in Chapter 17 of the same manual. This is why guidelines provided by the Technical Specifications for Interoperability of European High Speed lines (TSI) are referenced since these design specifications were developed specifically for the design, construction and operation of interoperable high-speed railways in Europe and are based on European and international best practices.

Initial high-speed rail design criteria will be issued in technical memoranda that provide guidance and procedures to advance the preliminary engineering (15% and 30% design) of the project. When completed, a Design Manual will present design standards and criteria specifically for the design, construction and operation of the CHSTP high-speed railway based on international best practices.

The CHSTP design standards and guidelines may differ from local jurisdictions’ codes and standards. In the case of differing values, conflicts in the various requirements for design, or discrepancies in application of the design guidelines, the standard followed shall be that which results in the highest level of satisfaction for all requirements or that is deemed as the most appropriate by the California High-Speed Rail Authority. The standard shall be followed as required for securing regulatory approval.

3.0 ASSESSMENT / ANALYSIS

3.1 GENERAL

Data applicable to overhead contact systems used overseas for existing high-speed railways, as well as specific data and American and International standards or guidelines applicable to the CHSTP overhead Contact System were collected along with the CHSTP characteristics design criteria that are applicable for sections of the CHSTP dedicated to very high speed operation only and for sections of the CHSTP that are shared use corridors for both high-speed trains and conventional passenger trains. Additionally, it is envisaged that time separated freight traffic may also operate on a few miles of the shared use corridors' electrified tracks.

From those data, the following OCS requirements are considered as guiding criteria for the overhead contact system of the CHSTP.

3.2 GENERAL OVERHEAD CONTACT SYSTEM REQUIREMENTS

3.2.1 OVERHEAD CONTACT SYSTEM GENERAL DESCRIPTION AND REQUIREMENTS

3.2.1.1 System Description and General Performance Requirements

In order to minimize the number of substations and EMC problems along the CHSTP alignment, the line will be fed in 2 x 25 kV, 60 Hz configuration, in accordance with the Technical Memorandum 3.1.1.1 "Traction Power 2x25kV Autotransformer Electrification System & Supply Voltages" utilizing Traction Power Supply Stations, Switching Stations and Paralleling Stations (with autotransformers).

The Traction Power Supply Stations (SST) are connected to the HV Utility Supply and spaced approximately every 30 miles, while the Switching Stations (SWS) are spaced approximately at mid distance between SST's, i.e. at about 15 miles from a SST, and the Paralleling Stations (PS) are spaced approximately at 5 miles intervals. At these locations, the transformer parallels the track 1 and track 2 power supplies and balances the two 25 kV supplies (longitudinal feeder and catenary) with respect to each other.

At the Traction Power Supply Stations and Paralleling stations, the center tap of the respective supply transformers and auto-transformers is connected to and referenced to the running rails.

The Overhead Contact System which provides electric traction power to the pantographs of the electric trains using the CHSTP route is therefore configured as a 25kV-0-25kV arrangement with a catenary at a nominal voltage of 25kV to ground and a negative (so called -25kV) longitudinal feeder in phase opposition with the catenary. The OCS shall transfer electric power from the Traction Power Supply Stations to train(s) under all operating conditions and provide reliable operation under all environmental conditions detailed in section 3.2.1.2.1.

The OCS shall provide uninterrupted (except at Phase Break separations) traction power collection at the maximum operating speed of 220 mph (with consideration that faster operation in the future will not be unnecessarily precluded) along the CHSTP sections dedicated to high-speed and at a maximum operating speed of up to 125mph on shared used corridors.

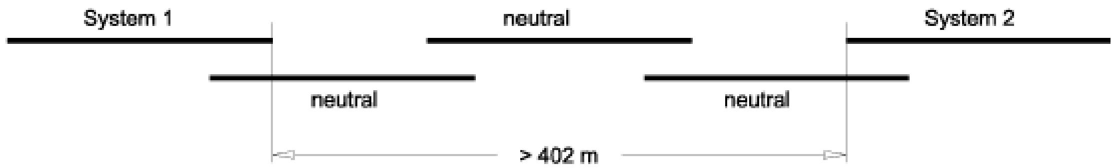
To allow unrestricted bi-directional working enabling train services to continue operation under emergency conditions and to facilitate routine OCS maintenance, the CHSTP OCS will be electrically divided into electrical sections and sub-sections. On the main line, Phase Break separations and Insulated Overlaps shall only be used for power supply sectionalizing purpose.

For the CHSTP, the OCS phase break arrangements are located in front of SWSs (and if required in front of SSTs) to electrically separate two successive catenary electrical sections fed by different 25kV AC sources; i.e. not to the same phase. The electric trains shall therefore be able to go through the phase break arrangement without establishing an electrical continuity between the successive electrical sections which are fed from different phases. This shall be realized at the maximum operating speed and with the train pantographs raised and in contact with overhead catenary, but with the pantograph breaker off.

Two types of designs of phase separation sections may be adopted on the CHSTP sections dedicated to very high speed, either:

- a phase break design where all the pantographs of the longest trains are within the neutral section with the length of this neutral section being at least 1319 feet (402 m),

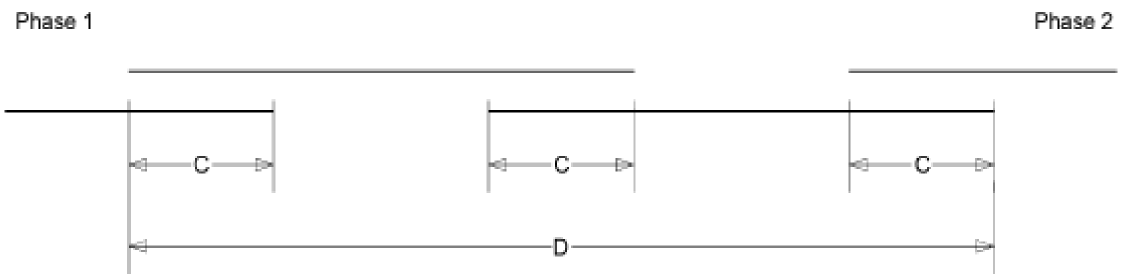
Arrangement of system separation section with long neutral section



or:

- a shorter phase break separation with an overall length of this separation being less than 466 feet (142 m) including clearances and tolerances constituted by three insulated overlaps as shown below.

Arrangement of phase separation with short neutral section



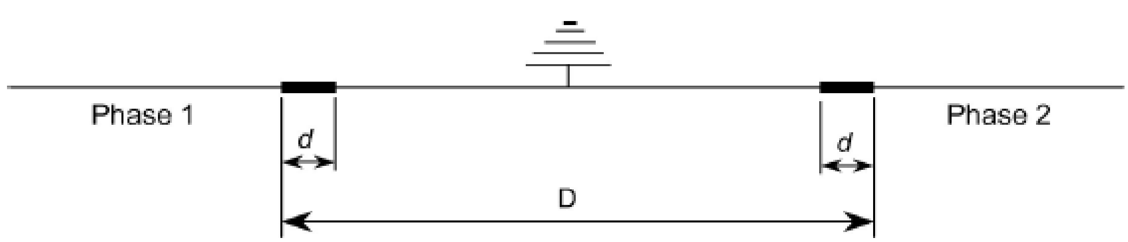
Length D < 142 m

Overlapping sections C: pantograph in contact with two contact wires.

Adequate means shall be provided to allow a train that is stopped within the above phase break arrangements to be restarted; i.e. the neutral section shall be connectable to the adjacent sections by remotely controlled switches/isolators.

On shared use corridors where the maximum operation speed is 125 mph, the designs of phase break separation sections as specified above can be adopted. In addition, a third phase break design arrangement using insulators and having its centre section connected to the current return path / ground may also be adopted. This neutral section is generally formed by insulating rods or double section insulators with D ≤ 27 feet (8 m) and shall be of a proven and reliable phase break design for 125 mph operational speed.

Separation Section with Insulators



The design of the OCS phase break arrangement shall therefore be interfaced with the rolling stock (for the number and for the spacing of pantographs that shall be 656 feet) and the signaling (for the exact mileage locations and lengths of the OCS phase break arrangements). Please refer to section 3.2.2 for these interfaces.

Insulated overlaps which shall be used on the main line, for operational and maintenance reasons, to separate successive electrical sub-sections are described in section 3.2.1.3.1 of this Technical Memorandum.

Elsewhere, on diverted tracks and stabling tracks, Section Insulators performing at speeds up to 125 mph would be acceptable in lieu of insulated overlaps for sectionalizing purpose.

Several CHSTP technical memoranda supplement this “OCS requirements” Technical Memorandum:

- The pantograph static, dynamic and electrical envelopes together with vertical space required for the OCS between supports are presented in the “Pantograph Clearance Envelopes” Technical Memorandum.
- The 2x25kV grounding and bonding network for the CHSTP is described in the ‘‘CHSTP Grounding and Bonding’’ Technical Memorandum.
- The electrical requirements applicable for the CHSTP OCS are described in the ‘‘OCS Electrical Requirements’’ Technical Memorandum.
- The mechanical requirements applicable for the CHSTP OCS are described in the ‘‘OCS Mechanical Requirements’’ Technical Memorandum.
- The structural requirements applicable for the CHSTP OCS are described in the ‘‘OCS Structural Requirements’’ Technical Memorandum.

3.2.1.2 Overhead Contact System Performance Requirements for High-speed

3.2.1.2.1 OCS Dynamic Performance

At the high speeds envisaged for the CHST, the high speed current collection and the interaction between the overhead contact system and the pantograph represent very important aspects in establishing a reliable power transmission without undue disturbances. Indeed, ensuring minimum or no interruption of contact continuity between the rolling stock pantographs and the overhead contact system cannot be realized without having carefully defined performance requirements of the overhead contact system, and of its interface with the pantographs.

This interaction is mainly determined by:

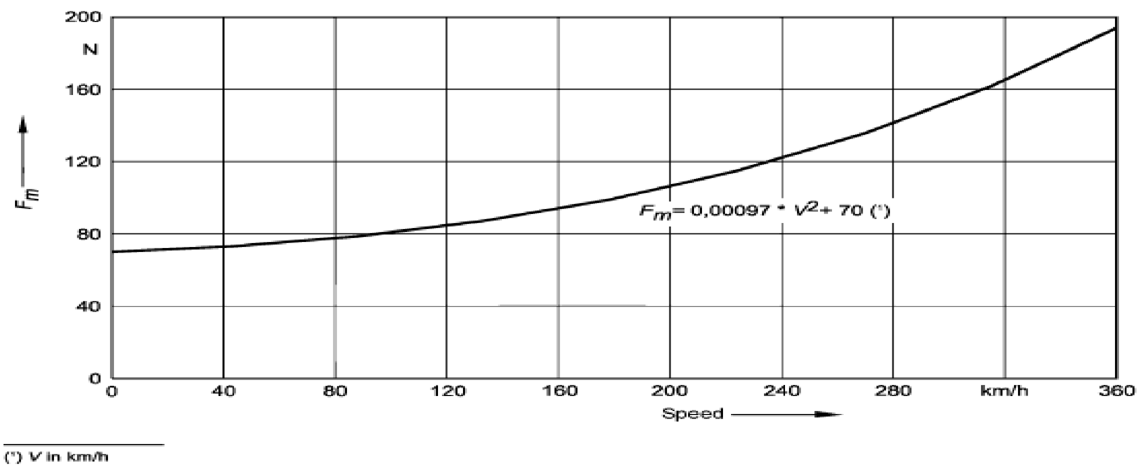
- The static and aerodynamic efforts which depend on the design of the pantograph and the nature of the contact strip of the pantograph. For 25kV AC overhead contact systems, the static force shall be adjustable between 9 and 27 pound force (40 and 120 N) and the nominal static force is to be 15.75 (+4.5,-2.25) pound force (70 N + 20 N/-10 N). Only pantographs designed and proven for very high speed performance shall be considered for the CHST.
- The number of pantographs in service per train and the pantographs spacing (which is necessary to confirm the OCS phase break design arrangement for which a 656 feet (200m) spacing is required) that have a fundamental impact on the collection quality since each pantograph can interfere with others on the OCS.
- The compatibility of the contact strip material with the contact wire regarding limitation of wear on those components. On high-speed lines, there should be only one type of current collector head used for all trains and carbon strip material is recommended to minimize wear.
- The protection of the pantograph and overhead contact line equipment in case of a broken pantograph collector strip. Pantographs shall be equipped with a fail safe device that will detect any failures of the contact strips and will trigger the lowering of the pantograph in case of a failure.

- The dynamic behavior and its impacts on the current collection quality aiming to a continuous and uninterrupted power supply without disturbances.

Concerning the dynamic behavior requirements, the collection quality shall be assessed by the following measurable parameters:

1) Either by counting of arcing that can be only carried out by on site testing, or by determining at the design stage, the mean value (Fm) and the standard deviation (σ) of measured or simulated contact forces. The mean contact force is the mean value of the forces due to static and aerodynamic actions. It is equal to the sum of static contact force and the aerodynamic force caused by the airflow on the pantograph elements at the considered speed. The mean uplift force is a characteristic of the given rolling stock pantograph.

In this context, Fm represents a target value which should be achieved to ensure on one hand a current collection without undue arcing and which should not be exceeded on the other hand to limit wear and hazards to current collection strips. The target for mean contact force Fm for AC systems is shown in the following graph as a function of the running speed:



Graph of the Fm Target value

In case of trains with multiple pantographs simultaneously in operation, the mean contact force Fm for any pantograph shall be not higher than the value given the above graph since for each individual pantograph the current collection criteria shall be met.

The maximum contact force (Fmax) is usually within the range of Fm plus three standard deviations σ for at grade sections while higher values may occur elsewhere.
In addition to the minimum and maximum contact forces, the statistical value $F_m - 3\sigma$ (which represents the value for which appears a loss of contact between the pantograph and the contact wire) permits to assess the regularity of the contact between the pantograph and the overhead contact system. The value $F_m - 3\sigma$ shall be positive to avoid contact losses.

2) The contact loss percentage. For a quality current collection, the loss of contact of the pantograph strip on the contact wire shall be quite low as a loss of contact may generate an electric arc which will cause rapid wear, and even the breaker switching off in case of an important arc due to high contact loss. For sections dedicated to very high speed, the on site measuring arc percentage NQ shall be ≤ 0.2 % at maximum line speed, and NQ shall be ≤ 0.1 % at the maximum speed of 125mph in shared use corridors. For a given speed of the vehicle, this arcing percentage characteristic NQ is given in % by the following formula: $NQ = \frac{\sum t_{arc}}{t_{total}} .100$, and the minimum arc duration taken into account is 5ms.

3) The vertical movement of the contact point (which is the point of the mechanical contact between a contact strip and a contact wire) at the maximum operational speed. This criteria permits to assess whether or not the OCS and pantograph behave in good working conditions as the vertical height of the contact point above the track shall be as uniform as possible along the

span length; this is essential for high-quality current collection. This shall be verified by measurements or by simulations for the maximum speed by using the mean contact force Fm for the longest span length, and need not to be verified for uninsulated or insulated overlap spans. It is presented as a graph of the contact point vertical position along a certain distance to evaluate the extent of its vertical movement The maximum difference between the highest and the lowest dynamic contact point height within one span shall be less than 3.15 in. (80mm) at the maximum operational speed on the sections dedicated to very high speed, and less than 3.94 in. (100mm) at the maximum speed of 125mph in shared use corridors.

4) The propagation speed of the waves created on the contact wire by the pantograph forces. Indeed, the speed of wave propagation on the contact wire is another characteristic parameter for assessing the suitability of a contact line for high-speed operation. This parameter depends on the specific mass and the stress of the contact wire. As the maximum operation speed shall not be more than 70% of the wave propagation speed, it means that for a 220 mph maximum operational speed, the wave propagation speed shall be above 314 mph.

The above criteria conformance will have to be confirmed by the Overhead Catenary System supplier by a dynamic OCS-pantograph dynamic interaction simulation or equivalent records of on site testing results for speeds above 220mph. Notwithstanding the above, the Overhead Catenary System of the CHSTP shall therefore be a proven system capable of current collection 220 mph in the sections of the CHSTP dedicated to very high speed and for operation at 125 mph in the shared use corridors.

For uniformity and maintainability purposes, the designs of the OCS for 125 mph and 220 mph shall generally be similar using the same conductors and equipment. However, shared operation of high speed trains with other trains having a higher gauge will require a higher contact wire height in shared use corridors and consequently larger and heavier OCS steady arm arrangements, while still acceptable for 125 mph. Also, the existing corridors' track alignment includes heavy curves and thus the maximum operating speed of 125 mph in these corridors will authorize a few adaptations such as permitting to reduce the mechanical tensions in the messenger and contact wires.

3.2.1.2.2 OCS RAMS Requirements

In terms of RAMS requirements, the design performance of the high speed overhead contact system for the CHST shall permit to guarantee and to demonstrate, through data gathered during previous operations of this high speed OCS system, a very high level of Reliability, Availability, Maintainability and Safety through a RAMS analysis.

3.2.1.3 Overhead Contact System Detailed Requirements

3.2.1.3.1 OCS Detailed Description

The catenary consists of a bronze or other copper alloy bare messenger wire supporting, by means of copper alloy droppers (also called hangers), a solid copper (or copper alloy) contact wire (OCS Standard Drawings ref. OCS 001 for very high speed and OCS 011 for speeds up to 125 mph). Both the contact and messenger wires shall be auto-tensioned such that the mechanical tension of each conductor remains constant whatever its temperature is.

The catenary is supported from cantilever frames designed to provide the required system height (encumbrance) and to register the correct stagger of the wires relative to the track center line. Please refer to the CHSTP OCS Standard Drawings ref. OCS 002 to OCS 007 for very high speed and OCS 012 to OCS 017 for speeds up to 125 mph.

An aerial ground wire, connected at regular intervals to the track via impedance bonds, is run alongside the catenary to connect each OCS supporting structure, such that all OCS non live metallic supports are at the same ground (and track) reference potential (OCS Standard Drawings ref. OCS 001 for very high speed and OCS 011 for speeds up to 125 mph).

The negative longitudinal feeder is run at the top of the OCS masts, preferably field side (OCS Standard Drawings ref. OCS 002 for very high speed and OCS 012 for speeds up to 125 mph), but sometimes track side above the catenary when the right-of-way configuration dictates (OCS Standard Drawings ref. OCS 003 for very high speed and OCS 013 for speeds up to 125 mph); i.e. above viaducts or in sections where the width of the right-of-way would not permit the feeder conductor to be installed field side.

In the sections dedicated to very high speed, tunnels should be of sufficient area so as to permit installation of bare feeder wires (OCS Standard Drawing ref. OCS 005 for very high speed). However, in the shared use corridors, tunnels of smaller sections (OCS Standard Drawing ref. OCS 015 for speeds up to 125 mph) may necessitate installation of pull off only reduced system height equipment and may not permit installation of bare longitudinal feeder. In such case, insulated feeder cables would have to be used in lieu of bare feeder conductors.

The overhead contact system shall be free running under overhead bridges. New bridges shall therefore be designed to accommodate a free height clearance. On dedicated shared use corridors, existing bridge height clearances shall be reviewed so as to accommodate free running OCS as well.

For constructability and maintenance purposes, the catenary conductors are installed in tension lengths. Mechanical or uninsulated overlaps that represent the lengths of the overhead contact system where the contact and messenger wires of two adjoining tension sections overlap before terminating at opposite ends, shall allow pantographs to transition smoothly from one tension section to the next under power. Please refer to the CHSTP OCS Standard Drawings ref. OCS 006 for very high speed and OCS 016 for speeds up to 125 mph.

For sectionalizing purposes as mentioned before in 3.2.1.1, some overlaps shall be insulated overlaps. In this arrangement, the contact and messenger wires of the two overlapping tension sections represent a sectionalizing length of the overhead contact system formed by cutting insulation into the out-of-running sections of the two adjoining and overlapping catenaries having between them a minimum electrical clearance realized by an air gap. The insulated overlap thus represents a sectionalizing point in the OCS as required for operational and maintenance reasons, and allowing for pantographs to transition from one energized electrical sub-section to the next one under power. Please refer to the CHSTP OCS Standard Drawings ref. OCS 007 for very high speed and OCS 017 for speeds up to 125 mph.

3.2.1.3.2 Catenary conductors, droppering, contact wire height and stagger, auto-tensioning and tension lengths requirements

In order to ensure that the CHSTP catenary system will have a known and proven dynamic behavior that will make it suitable for an operational speed up to 220 mph on sections dedicated to very high speed and up to 125 mph on shared use corridors, the catenary characteristics including those of the contact and messenger wires and of their mechanical tensions, together with the droppering system shall be those of an existing proven high-speed overhead contact system.

The messenger wire shall be kept vertically in line (“plumb”) with the contact wire and droppers shall support the contact wire from the messenger wire at regular intervals. The dropper design shall be a current carrying dropper eliminating the need for in-span jumpers and shall ensure that there is no “hard spot” on the contact wire. The length and position of the droppers shall be such that they provide the correct contact wire profile for high-speed current collection.

The contact wire shall be pre-sagged in each span. For CHSTP sections dedicated to very high speed, the amount of sag required shall preferably be calculated as 1/2000 of the span length, measured at mid span. However, on shared use corridors, the amount of sag required for speeds up to 125 mph shall be calculated as 1/1000 only of the span length, measured at mid span. Please refer to the CHSTP OCS Standard Drawings ref. OCS 001 for very high speed and OCS 011 for speeds up to 125 mph.

The contact wire shall be installed and maintained at a nominal constant and minimum 17'-4.7"(5300mm) height at support all along the sections dedicated to very high speed where the maximum vehicle static gauge height will be 14 ft 9 ¼ in accordance with the ''Structure Gauge'' Technical Memorandum. Also, the height difference at each adjacent structure is to be less than 1/2 in so as to ensure a constant contact wire height as required for satisfactory pantograph current collection at high speed.
On shared use corridors where the maximum operating speed is 125 mph, and where high speed vehicles will share the track with other American passenger cars of a maximum vehicle static gauge height of 17 ft. in accordance with the ''Structure Gauge'' Technical Memorandum, the contact wire height shall generally be set up at a height 18'-8.4"(5700 mm) at support. Where time separated freight traffic may also operate on a few miles of the shared use corridors' electrified tracks, the contact wire will have to be set up at a nominal height of 22 ft. (6.705 m) at support to allow for the passage of Plate H freight vehicles of a maximum static gauge of 20 ft 2 in. in accordance with the ''Structure Gauge'' Technical Memorandum.

The pantograph static, dynamic and electrical envelopes together with vertical space required for the OCS between supports are presented in the "Pantograph Clearance Envelopes" Technical Memorandum.

The contact wire height transition between sections dedicated to very high speed and shared use corridors shall be realized in areas where the speed does not exceed 125 mph. The maximum contact wire gradients and the corresponding maximum gradient changes shall not exceed, according to the maximum speed, the following values:

Maximum speed	Maximum contact wire gradient	Maximum contact wire gradient change
> 125 mph	0	0
125 mph	2/1000	1/1000
100 mph	3.3/1000	1.7/1000
75 mph	4/1000	2/1000
60 mph	6/1000	3/1000
45 mph	8/1000	4/1000
30 mph	13/1000	6.5/1000

On tangent track (straight track) the contact wire shall be staggered at each location to alternate sides of the pantograph centre line. The stagger shall normally be set at ±8 in. On curved track, the staggers shall be calculated on a case by case basis taking into account the track cant, radius track curvature, and wind speed.

The method of auto-tensioning these conductors shall be by balance weight arrangements using tensioning devices. For very high speed, the tensions are to be applied to the contact and messenger wires individually by using separate balance weights, tensioning devices and anchoring positions as shown on the CHSTP OCS Standard Drawing ref. OCS 008. For speeds up to 125 mph in the shared use corridors, the messenger and contact wires will be auto-tensioned using one common balance weight arrangement and a yoke plate as shown on the CHSTP OCS Standard Drawing ref. OCS 018.

The mechanical tension in each of the contact and messenger wires shall be automatically maintained over a 25^{o}F to 170^{o}F temperature range in above grade sections, while after the first 1300 ft. in tunnels, the temperature range for auto-tensioning the conductors shall be 35^{o}F to 155^{o}F.

Maximum tension lengths from anchor to anchor shall not exceed 4000 ft. in tunnels and in front of power supply stations and 4600 ft. in open route. Exceptions up to 5000 ft. may be allowed on a case-by-case basis. At approximately mid-distance between auto-tension termination anchors, mid-point arrangements shall be installed such that maximum half tension lengths do not exceed 2000 ft. in tunnels and 2300 ft. in open route. Please refer to the CHSTP OCS Standard Drawings ref. OCS 009 for very high speed and OCS 019 for speeds up to 125 mph.

3.2.1.3.3 Environmental and climatic requirements

The CHSTP Overhead Contact System shall ensure reliable operation under the conditions given below.

Humidity: The OCS equipment for above grade sections of the alignment shall resist heavy fog and high humidity up to 100% humidity. The OCS shall be designed to operate without failure or deterioration in all humidity conditions found in California. This includes 100% humidity conditions including rain and fog in the open route, and 100% humidity in tunnels.

Ice: In accordance with Figure 7.1 ''Ground snow loads'' of the ASCE Standard “Minimum Design Loads for Building Structures”, snow and ice along the CHSTP alignment are quite rare. In accordance with Table 250-1 and Figure 250-3(a) of the NESC, the OCS design should not take into account any ice thickness for loading design purpose.

Wind: The ASCE Standard “Minimum Design Loads for Building Structures” defines the basic wind speed corresponding to the wind load for wind force resisting structure as a three (3) second gust speed at 33 feet above ground for open terrain, exposure C and associated with an annual probability of 0.02 (50 year mean recurrence interval) of being equaled or exceeded. This basic wind speed is, in accordance with Figure 6-1 of the ASCE Standard, Vbws = 85 mph for the State of California. This maximum three (3) second gust speed corresponds, in accordance with Figure C6-1 of the ASCE Standard, to a mean maximum hourly wind speed of (Vbws/1.52 =) 56 mph approximately.

For OCS design, in accordance with Section 4.2.2 of Chapter 33 of the Area Manual, two different wind speeds, the operational wind speed and the design wind speed shall be used:

- the operational wind speed shall be used to compute catenary support, catenary wire displacement for pantograph security and maximum span length calculations and will be taken as Vop = 60 mph.
- the design wind speed shall be used to determine the ultimate strength requirements of the OCS and will be taken as Vbws = 85 mph corresponding to the ASCE and NESC basic wind speed for the CHSTP route.

The wind velocity pressure qz shall be calculated by the NESC formula:

$q_z = 0.00256\ V^2\ K_z\ G_{RF}\ I\ C_f\ A$ in lb/sq ft (equivalent to $q_z = 0.613\ V^2\ K_z\ G_{RF}\ I\ C_f\ A$ (in N/m^2) where:

- 0.00256 (0.613 in the metric system) is the velocity pressure numerical coefficient reflecting the mass density of air for the standard atmosphere,
- K_z is the velocity pressure exposure coefficient,
- V is the basic wind speed (3 s gust wind speed at 33 feet above ground for open terrain, exposure C; i.e. Vbws),
- G_{RF} is gust respond factor,
- I is the importance factor (I being equal to 1.00 for OCS), and
- C_f is the force coefficient shape factor,
- A is the projected wind area.

Note: K_z, V and G_{RF} are based on open terrain with scattered obstructions (exposure category C as defined by ASCE, and used as the basis for the NESC extreme wind criteria) and the wind velocity pressure shall be increased for very exposed areas by the ASCE factor K_{zt} to take into account these very exposed area cases.

Loads due to wind for OCS structural calculations shall be multiplied by the load factors given by table 253-1 of the NESC.

Please refer to the Technical Memoranda ''OCS Structural Requirements'' and ''OCS Mechanical Requirements''.

Temperature: For the purpose of the CHSTP, based on typical and extreme ambient temperatures recorded along the CHSTP route, ambient temperatures considered for the design, range from 25°F to 120°F.

Note: In long tunnels, only the first 1300 ft. of catenary from each portal is subject to external ambient temperature variations. Nevertheless, after the first 1300 ft, the ambient temperature in tunnels shall be considered as ranging from 35°F to 105°F and the messenger and contact wires in tunnels are to be regulated with automatic tensioning.

Atmospheric Pollution: The OCS equipment above grade sections of the alignment shall resist polluted atmosphere that may occur in high industrial areas together with fog and marine atmosphere coming from the ocean. In tunnels and cut & cover boxes of the shared use corridors where high speed trains and other passenger trains traffic could be combined with diesel freight trains, OCS tunnel equipment shall resist such tunnel corrosive atmosphere.

3.2.1.3.4 Electrical requirements

The electrical requirements applicable for the CHSTP OCS are described in a separate document, namely the ''OCS Electrical Requirements'' Technical Memorandum.

This ''OCS Electrical Requirements'' Technical Memorandum provides electrical characteristics of the overhead catenary system, including those of insulators, electrical switches and isolators, as well as insulated conductors. They also include safe distances to be used between live parts or conductors to a place where a person may stand, such as on a station passenger platform, and minimum distances that will be used for the CHSTP between live conductors, and between live conductors and grounded structures, parts or conductors.

This includes the OCS static and dynamic electrical clearances that are recommended values to be used for the CHSTP, based on UIC clearances and clearances used on very high-speed lines in Europe that are listed in the following table:

Clearances	For CHSTP sections dedicated to very high speed		For share used corridor for speeds up to 125 mph	
	Static (in.)	Dynamic (in.)	Static (in.)	Dynamic (in.)
Normal	1'-0.6" (320mm)	8.7" (220mm)	1'-0.6" (320mm)	8.7" (220mm)
Minimum	1'-0.6" (320mm) .	8.7" (220mm)	10.6" (270mm)	6.7" (170mm)

3.2.1.3.5 Mechanical requirements

The mechanical requirements applicable for the CHSTP OCS are described in a separate document, namely the ‘’OCS Mechanical Requirements’’ Technical Memorandum.

This ‘’OCS Mechanical Requirements’’ Technical Memorandum provides the maximum span lengths that can be allocated in tangent track and in curved tracks for the CHSTP sections dedicated to very high-speed as well as the maximum span lengths that can be allocated in tangent track and in curved tracks on shared use corridors where both high speed vehicles and American passenger trains will operate on the same tracks.

For pantograph security purposes, the permissible lateral deflection of the contact wire in relation to the track centreline under the action of crosswind shall be ≤ 15 ¾ in.

For planning purposes and for a contact wire height of 18’-8.4”(5700 mm) or less, a 210 ft. maximum along track spacing of OCS supporting structures should be considered in tangent track. Such a maximum along track OCS mast spacing should however be reduced in curves and basically range from say, 190 ft. for a 25000 ft radius to 90 ft for a 1000 ft radius.

At the maximum operational speed, the uplift of the contact wire that can reach up to 6.9”(175mm) at mid span is expected to be up to five 4.9”(125 mm) at the steady arm point on very high speed dedicated sections. In order to ensure safety in all conditions (including under strong wind conditions and slight misadjustments of pantographs), the dynamic pantograph envelope shall consider twice the value of the estimated or simulated uplift S_0 at the support point, i.e. 9.8” (250 mm) minimum. The design of the OCS cantilever and registration shall consequently allow for a steady arm uplift clearing at least the dynamic pantograph envelope, and thus allow for a minimum uplift of 9.8” (250 mm).
For the 18’-8.4”(5700 mm) contact wire height, on tracks of shared used corridors that will be shared by both high speed trains and American passenger trains a maximum uplift of 3.9”(100mm) is expected for a speed of 125mph, and thus the dynamic pantograph envelope for 18’-8.4”(5700 mm) contact wire height considers 7.9”(200mm) uplift at the support point. The design of the OCS cantilever and registration shall consequently allow for a steady arm uplift clearing at least the dynamic pantograph envelope, and thus allow for a minimum uplift of 7.9”(200mm) for the 18’-8.4”(5700 mm) contact wire height. For reduced speeds to a maximum of 125mph and with traffic of conventional passenger cars not having UIC rolling stock characteristics, the design considers the recommendation of Part 2 of Chapter 33 of the AREMA Manual for the determination of the pantograph sway. Please refer to ‘’Pantograph Clearance Envelopes’’ Technical Memorandum that provides the static, dynamic and electrical envelopes of the pantograph and the vertical space required for OCS for very high speed dedicated sections and for shared use corridors.

This ‘’OCS Mechanical Requirements’’ Technical Memorandum also provides minimum factors of safety that shall be used for the OCS design, as well as requirements for positioning OCS independent mast versus portal structures or headspans.

3.2.1.3.6 Structural requirements

The in above grade sections, OCS structures are to be galvanized Universal Column (U.C.)/H-beams and are to be designed and manufactured to the relevant steel standards.

Where the OCS is closely supported, such as at overlaps and turnouts, multiple cantilevers will be attached to a single structure. As the applied loads shall not cause twisting of the structure by more than five (5) degrees, a heavier section shall be used.

The OCS supporting structures shall be calculated in accordance with relevant American standards (NSCE, ASCE, ANSI) and, in addition, the maximum mast deflection across track, including wind loading, is not to exceed two (2) inches at contact wire level.

For multi track areas when independent masts cannot be installed between tracks, portal structures using drop tubes that will permit maintaining mechanical independence of the equipment related to individual tracks are to be designed with respect to overall aesthetics of the complete OCS. Such portal structures will, for example, have to be used at crossovers and intermediate passenger stations where single masts cannot be installed. Please refer to the CHSTP OCS Standard Drawings ref. OCS 004 for very high speed and OCS 014 for speeds up to 125 mph. However, to equip maintenance yard multi track areas or in shared use corridors such as at passenger stations approach, headspans arrangement (OCS Standard Drawing ref. OCS 020) may be used if considerations dictate.

In tunnels and cut and covers, or for wall fixings, supports shall be fixed using either C-channels or anchor expansion bolts of the undercut type. Should structures need to be attached to the wall of tunnels, bridges, or to open cut walls, this is to be achieved by bolted connections suitable for the loading conditions and material it is attaching to. In order to reduce the risk of drilling into rebars, specialized equipment would have to be used to locate reinforcing bars before drilling and the minimum distance from a reinforcing bar to the drilled hole shall be two (2) inches.

Each and every OCS support location shall be individually numbered for ease of identification on site. Structure number plates shall be fitted to the structure at a height of 6ft-6in approximately above rail level. For supports located in tunnels, the number plate shall be attached to the wall using suitable fixings.

3.2.1.3.7 Grounding and bonding requirements

The 2x25kV grounding and bonding network for the CHSTP is described in a separate document, namely the ‘‘CHSTP Grounding and Bonding’’ Technical Memorandum. It shall ensure via the track rails, the continuity of the return traction system to the grounding bars of the SSTs, SWSs and PSs sites.

The overall grounding and bonding protection network consists of OCS aerial ground conductors, connections from these aerial ground conductors to the general buried ground conductor/grounding pillars/impedance bonds connected to the track, and connections between all the later and the SSTs, SWSs and PSs grounding bars.
In addition, the OCS grounding and bonding system shall safely connect all OCS metallic non live parts and also safely bond overhead bridges.

The bonding and grounding of the OCS and of other lineside equipment shall ensure, in accordance with IEC 479-1 that the touch potentials are not exceeding:

- 60 V where accessible to the public under all power supply feeding conditions
- 650 V for less than 200 ms under short circuit conditions.

Additionally, under isolation conditions of a section of OCS, grounding measures shall be put in place such that both the catenary and the feeder wire are safely grounded to ensure that maintenance can be carried out safely. The system used for grounding under isolation conditions is to protect maintenance personnel from hazards such as induction caused by adjacent OCS and high voltage power line crossings. Furthermore it is to be able to support full, short circuit loads in the event of the section becoming energized by incorrect closure of a switch(es) and or circuit breakers or by a pantograph “bridging” an insulated overlap or section insulator.

3.2.2 INTERFACE REQUIREMENTS

The main CHSTP technical interfaces which the Overhead Contact System shall satisfy are listed hereafter:

3.2.2.1 Traction Power Supply Interfaces

The main interfaces between the Overhead Contact System and the Traction Power Supply for the CHSTP are:

- Physical interface locations will be at the Traction Power Supply Stations (SST) that are connected to the HV Utility Supply and spaced approximately every 30 miles, at the

Switching Stations (SWS) that are spaced approximately at mid distance between SSTs, i.e. at about 15 miles from a SST, and at Paralleling Stations (PS) that are spaced approximately at 5 miles intervals. At these Traction Power Supply Stations (TPSS) locations, aerial bare feeder conductors of adequate equivalent copper cross-sections together with feeding jumpers will connect the 25 KV traction busbars located within the TPSS site to the 25KV Catenary and its associated longitudinal negative feeder. If the locations of the TPSS are not close enough to permit direct electrical connections to the catenary and its associated longitudinal negative feeder via aerial bare feeder conductors, insulated feeder cables will have to be dimensioned and run from the TPSS busbars, in dedicated troughs and/or ducts along the track and up to the OCS masts where the electrical connections are to be made.

- Electrically, these interface points at SSTs, SWSs and PSs must be in accordance with the CHSTP Feeding and Sectionalizing Diagram that provides the locations of the TPSS Station sites, as well as the OCS sectionalizing information.
- In addition, the design and locations of voltage transformers that shall be installed on the Overhead Catenary System to monitor the voltage presence of each electrical section and sub-section shall be interfaced with the Power Supply and SCADA (or equivalent data transmission system) and Signaling to permit a satisfactory information monitoring management system.
- Based on the selected train characteristics and operating train traffic timetables (including ultimate scenario), traction power simulations shall be carried out in order to demonstrate the adequacy of the traction power supply system configuration with final locations of SSTs, SWSs and PSs together with the voltage along the line, and to verify the design choice of transformer ratings and selected OCS. This design simulation exercise requires not only train traffic timetables and trains data, but also power supply and OCS and return systems data to be as exact as possible to permit precise analysis and best assessment of potential margins of the traction power supply system.
- The OCS voltage drop shall be in accordance with IEC 60850 “Supply voltages of traction systems”, whose main voltage criteria are as follow:
  - Operating nominal system voltage: 25.0 kV
  - Highest permanent voltage U_{max1}: 27.5 kV
  - Highest non-permanent voltage U_{max2}: 29.0 kV
  - Lowest permanent voltage U_{min1}: 19.0 kV
  - Lowest non-permanent voltage U_{min2}: 17.5 kV
- Short-circuits and other fault conditions occur and the power supply and electrification systems need to be designed so that the power supply controls detect these faults immediately and trigger measures to remove the short-circuit current and isolate the affected part of the circuit. After such events, the system has to be able to restore supply to all installations as soon as possible to resume operations. It is also to be noted that the electrical protection interfaces with the trains, and thus circuit breaker tripping in traction power substations and on trains has to be coordinated. The maximum short circuit current shall be 12kA for protection measurement purpose and accordingly for specification of the electrical equipment.

3.2.2.2 Signaling Interfaces

The main interfaces between the Overhead Contact System and the Signaling System for the CHSTP are:

- The OCS phase break arrangement, exact mileage locations and lengths, together with the locations of the associated signals (additional to the automatic track magnets) for opening and closing the train pantograph circuit breakers during the passage through a phase break separation (generally located in front of the Switching Stations (SWS), and as required for operational and maintenance purpose in front of Traction Power Supply Stations (SST). Also, the Signaling System interfaces the power control at phase break locations with the Rolling Stock System.

- The signaling visibility in order that trackside signals not be obstructed to train driver visibility by OCS masts and associated OCS equipment.
- The signaling speed diagram providing the start and finish mileages of the maximum speed trains can operate on the CHSTP alignment, both on sections dedicated to very high speed and shared use corridors.
- The traction return current and the grounding and bonding system which includes the design principles, as well as the track connection (via impedance bonds) and buried ground conductor connections (with associated grounding plates), including details and locations.
- The signaling schemes, as well as signaling grounding and bonding diagrams to permit interfacing correctly the above mentioned interfaces.

3.2.2.3 Civil Works and Track Interfaces

The main interfaces between the Overhead Contact System and the Track and Civil Works for the CHSTP are:

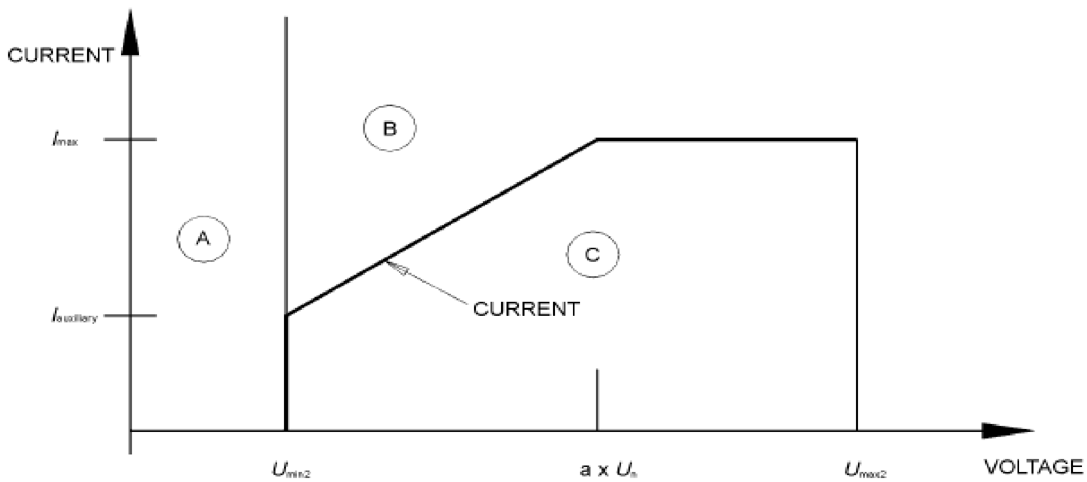
- The design, construction tolerances and as-built information of the track platforms and associated cross-sections including details and as-built information of track drainage, retaining walls, wind and sound walls, fencing, etc necessary to design and install the OCS in open route.
- The design, construction tolerances and as-built information of tunnels, cut and covers and trenches together with cross-section details, niches, tunnel lining and segments details and cut and cover soffit and walls details to which OCS equipment will be fixed, preferably using either OCS anchor bolts or civil pre-installed C-channels necessary to design and install the OCS in tunnels..
- The track alignment at OCS phase break locations so as to ensure no (or reduced) track gradient and tangent track alignment as far as possible at these specific interface locations.
- The track alignment providing all information related to track curves, spirals and superelevation necessary for the OCS basic and installation designs.
- The track construction and maintenance tolerances, as well as the as-built track information necessary to design and install the OCS all along the CHSTP alignment.
- The track turnout and crossover designs and as-built information necessary to design and install the specific OCS arrangements to the different type of points and crossings that would be used for the CHSTP.
- The design, construction tolerances and as-built information of the overhead bridges and associated elevation and cross-section information including details necessary to design and install the OCS (free running in sections of the CHSTP dedicated to very high speed) under overhead bridges.
- The design and as-built information of underbridges and viaducts together with cross-section details, OCS masts fixing arrangement details (preferably using civil manufactured bases with anchor bolts) and as-built information necessary to design and install the OCS on viaducts and underbridges.
- The dimensions and locations of the turnout and crossover construction and maintenance areas in order to design accordingly the OCS supporting arrangement (i.e. single OCS masts replaced by overhead portal structures in these areas).
- The geotechnical information providing ground pressure values related to the platform ground and permitting to precisely size, calculate and further allocate the different types of OCS mast foundations (basically located between 10 ft and 14 ft from the closest track centerline).
- The platform and track alignment surveys.

- The grounding and bonding continuity of alongside fences, wind and sound walls, gates, barriers and any other civil structures installed within the right-of-way fenced limits necessary to design and install the grounding and bonding associated with the OCS.

3.2.2.4 Rolling Stock Interfaces

The main interfaces between the Overhead Contact System and the Rolling Stock for the CHSTP are:

- The manufacturer rolling stock static and dynamic gauges of the trains that will be operated on the electrified tracks of the CHSTP and which are required for the OCS design and particularly for setting up (or confirming) the contact wire heights on both the sections that are dedicated to very high speed operation and on shared use corridors.
- The maximum allowable train rated current (600A for 25kV AC systems) and the train current graph as a function of the OCS line voltage, as per the figure below:



I_{max}= maximum current consumed by the train

A= no traction

B= current level exceeded

C= allowable current levels

Graph of the maximum train current against voltage

Note: Trains shall be equipped with an automatic device that adapts the level of the power consumption depending on the OCS line voltage in steady state conditions.

- The pantograph reaching height, e.g. the minimum and maximum operating heights of the pantograph.
- The pantograph (i.e. there should be only one type of pantograph used on the CHST) dimensions and physical characteristics which are necessary to confirm the pantograph clearance envelopes which are required for design and for testing of the overhead contact system. Please refer to the CHSTP “Pantograph Clearance Envelopes” Technical Memorandum.
- The number of pantographs in service per train and the pantographs spacing (e.g. 656 feet) spacing necessary to confirm the OCS phase break design arrangement) which have a fundamental impact on the collection quality since each pantograph can interfere with others on the OCS.
- The pantograph model and the pantograph static and dynamic characteristics which are necessary to simulate the pantograph OCS dynamic interaction at high speed in order to ensure, at the design stage, that minimum interruption of contact continuity between the

rolling stock pantographs and the overhead contact system will occur as required for the system performance and better assess the contact system maximum uplift. As previously stated, the static force shall be adjustable between 9 and 27 pound force and the nominal static force is to be 15.75 (+4.5,-2.25) pound force (70 N + 20 N/-10 N). Only pantographs designed and proven for very high speed performance shall be considered for the CHST.

- The pantographs details including the nature of the contact strip material to confirm its compatibility with the contact wire regarding limitation of wear on both components.
- Additional pantographs features, namely a safe dropping device (e.g. a device that drops the pantograph automatically to ensure the protection of the pantograph and overhead contact line equipment in case of a pantograph failure), a pantograph's uplift limiting device (e.g. in order to minimize risks, at very high speed, of abnormal excessive uplift resulting in bad current collection and possible damage), and insulated horns that are recommended so as to reduce the overall electrical clearance envelope around the dynamic pantograph gauge.

3.2.2.5 Interface with the Electrical Operational Control Center and DTN / SCADA System

These interfaces concern the OCS electrical equipments (motorized breakers, switches and isolators as well as voltage transformers, etc.) which are monitored and command-controlled from the Electrical Operational Control Center via the Data Transmission Network / SCADA system.

The interface between the OCS electrical equipment and the Electrical Operational Control Center is to ensure:

- That the power supply and OCS main electrical equipment as indicated on the relevant Feeding and Sectionalizing diagrams are correctly displayed by the Electrical Operational Control Center.
- That the monitoring information and alarm status, and control-command operation and status regarding the OCS electrical equipment are effectively taken into account by the Electrical Operational Control Center.
- A successful energization process during the testing and commissioning phase.
- That the emergency isolations and OCS isolation processes are correctly taken into account and operated satisfactorily.

The interface between the OCS electrical equipment and the Data Transmission Network / SCADA is to:

- Provide as requested by the designer of the DTN system, all the equipment information necessary to ensure the monitoring and control-command operation and status of the OCS electrical equipment.
- Ensure compatibility with the DTN system regarding the number and type of contacts, and physical connections at each type of OCS electrical equipment to correctly interface with the DTN system.
- Verify with the DTN system, at OCS equipment locations and remote unit locations, the successful transfer of information necessary for the monitoring and control-command operation and status of the OCS electrical equipment.

3.2.3 CONSTRUCTION REQUIREMENTS, TESTING AND COMMISSIONING REQUIREMENTS

3.2.3.1 Construction Requirements

3.2.3.1.1 Construction Design

In order to ensure that the OCS installation will be correctly installed in accordance requirements for OCS high speed, and with the high Assurance Quality policy, processes and programs required for the CHSTP, and it is necessary to produce in a phasing sufficiently in advance of the planned installation, a complete OCS construction detailed design.

This OCS construction design shall consist of detailed OCS layouts, OCS cross-section/data sheet books, OCS footing books, longitudinal auxiliary conductor profiles, OCS special droppering books, OCS calculations books for footings, masts and cantilever arrangements, detailed installation books for individual switching arrangements and OCS under bridge (or other structure) arrangements, as well as all the necessary detailed bill of quantities.

This OCS construction design shall be revised as necessary during the construction phase and be updated as an as-built record shortly after construction.

3.2.3.1.2 Requirements for the OCS construction

The OCS construction shall be carried out in accordance with a CHSTP OCS Construction Plan which shall demonstrate that, during the construction phase, the OCS technical and safety requirements of the CHSTP will be met in accordance with the high Assurance Quality policy, process and program required for the CHSTP, and necessary for OCS high speed.

Detailed OCS construction programs interfacing with other works shall be produced and monitored on a monthly and weekly basis to ensure that the OCS program of works is well managed and well integrated within the overall CHSTP program of works, and that the works are carried out in accordance with the program.

OCS works shall be in carried out in accordance with technical construction method statements providing detailed information on the organization, safety, utilized plant and personnel resources, together with the operating methods of the works and necessary checks (witness and eventual hold points) required to confirm the quality of the installation works.

Installation tolerances for high-speed are very restrictive, and the OCS equipment shall be installed in accordance with these tight tolerances to ensure that the catenary components including the contact wire are installed as required for a satisfactory current collection at high-speed and very high-speed.

3.2.3.2 Testing and Commissioning Requirements

The OCS Testing and Commissioning shall be carried out in accordance with a CHSTP OCS Testing and Commissioning Plan which shall demonstrate that, through the testing and commissioning phases, the necessary OCS technical requirements of the CHSTP and requirements for OCS high speed will be met in accordance with the high Assurance Quality policy, processes and programs required for the CHSTP.

The OCS Testing and Commissioning shall be carried out in phases to ensure:

- the quality surveillance of procured equipment, including factory acceptance of materials and OCS components,
- the technical verifications and static tests to confirm the correct installation of the OCS,
- the integrated testing of the OCS with other disciplines, including the OCS energization and short circuit tests,
- the dynamic testing of the OCS,
- the surveillance when trains are running during the period following the dynamic testing and prior to the operation and the line, and during the first weeks of the operation of the line.

The dynamic testing of the OCS is of primary importance at high-speed to verify the interaction between the overhead contact system and the pantograph, and thus the safety and quality of the current collection and the performance of the OCS at high-speed.

To check the dynamic performance capability of the OCS current collection system, at least the following data shall be measured:

- the percentage of arcing, and additionally the contact force
- the contact wire uplift at the support as the pantograph passes.

Concerning the measurement of arcing, the detector of arcs shall be sensitive to the wavelengths of light emitted by copper materials. For copper and copper alloyed contact wires a wavelength range shall be used that includes the range 220 nm to 225 nm or 323 nm to 329 nm. The measurement system shall be insensitive to visible light with wavelength greater than 330 nm.

The measurement of contact force shall be carried out using an instrumented pantograph equipped with force sensors located as near as possible to the contact points. The measurement system which shall be immune to electromagnetic interference, shall measure forces in the vertical direction, without interference from forces in other directions. The measurement deviation of the force sensors caused by the temperature shall be less than 10 N (for the sum of the force of all sensors) under all measuring conditions, and the maximum error of the measurement system shall be less than 10 %.

As a minimum, the system shall, during the OCS dynamic tests of a section not shorter than 6 miles, measure and record:

- the pantograph current (measured parts with a pantograph current below 30% of the nominal current of the pantograph shall be disregarded),
- the total time with a pantograph current greater than 30% of the nominal current per train per pantograph,
- the total run time,
- the number of arcs that are lasting longer than 1 ms (as arcs of a duration shorter or equal to 1ms shall be disregarded),
- the duration of each arc longer than 1 ms (the mileage position of the arc along the overhead contact line should also be recorded),
- the largest arc duration, and
- the sum of the durations of all arcs longer than 1 ms.

In addition to the measured values, the operating conditions (the train speed which shall be constant with a tolerance of ± 1.5 mph, the location, etc.) shall be recorded continuously and the environmental conditions (rain, ice, temperature, wind, tunnel, etc.) and test configuration (parameters and arrangement of pantographs, type of overhead contact system, etc.) during the measurement shall be recorded as well in a test report. This additional information shall ensure a repeatability of the measurement and a comparability of the results of the different tests.

4.0 SUMMARY AND RECOMMENDATIONS

- The CHSTP Overhead Contact System shall permit a maximum operational speed of 125mph in shared use corridors where high-speed passenger trains and American passenger trains operate on the same main line shared tracks.
- Elsewhere, on dedicated high-speed sections, the CHSTP Overhead Contact System shall permit a maximum operational speed of 220 mph with consideration that faster operation will not be unnecessarily precluded in the future.
- The CHSTP OCS shall be electrically divided into electrical sections and sub-sections. On the main line, Phase Break separations and Insulated Overlaps (OCS Standard Drawings ref. OCS 007 for very high-speed and OCS 017 for speeds up to 125 mph) only shall be used for sectionalizing purposes.
- Elsewhere, on diverted tracks and stabling tracks, Section Insulators performing at speeds up to 125 mph would be acceptable in lieu of insulated overlaps for sectionalizing purposes.
- Electric trains shall be able to go through the phase break arrangement without establishing an electrical continuity between the successive electrical sections which are fed from different phases. This shall be realized at the maximum operating speed and with the train pantographs raised and in contact with overhead catenary, but with the pantograph breaker off.
- On the CHSTP sections dedicated to very high speed, either a phase break design of at least 1319 feet long, or a shorter phase break separation of less than 466 feet long constituted by three insulated overlaps can be used. Adequate means shall be provided to allow a train that is stopped within the above phase break arrangements to be restarted; i.e. the neutral section shall be connectable to the adjacent sections by remotely controlled switches/isolators.
- On shared use corridors where the maximum operation speed is 125 mph, the designs of phase break separation sections for high speed sections can be adopted, but in addition, a third phase break design arrangement of an overall distance less than 27 feet using insulators and having its centre section connected to the current return path / ground may also be adopted.
- The design of the OCS phase break arrangement shall be interfaced with the rolling stock (for the number and for the spacing of pantographs which shall be 656 feet) and the signaling (for the exact mileage locations and lengths of the OCS phase break arrangements).
- Concerning the high speed overhead contact system / pantograph interaction, only pantographs designed and proven for very high speed performance shall be considered for the CHST.
- For the CHST, there should be only one type of pantograph current collector head used for all trains and carbon strip material is recommended to minimize wear.
- For the CHST, the pantograph static force shall be adjustable between 9 and 27 pound force (40 and 120 N) and the nominal static force is to be 15.75 (+4.5,-2.25) pound force (70 N + 20 N/-10 N).
- The CHST pantograph shall be equipped with a fail safe device that will detect any failures of the contact strips and will trigger the lowering of the pantograph in case of a failure.
- The current collection at the design stage shall be assessed at the maximum operational speeds, by the determinations of the mean value (Fm), of the standard deviation (σ) of simulated contact forces, of the statistical value $F_m - 3\sigma$, of the contact loss percentage (NQ), and of the vertical movement of the contact point.
- The design performance of the CHSTP high speed OCS shall allow guarantee and demonstration of a very high level of Reliability, Availability, Maintainability and Safety through a RAMS analysis.
- In order to ensure that the CHSTP catenary system will have a known and proven dynamic behavior that will make it suitable for an operational speed up to 220 mph on sections dedicated to very high speed and up to 125 mph on shared use corridors, the catenary characteristics including those of the contact and messenger wires and of their mechanical tensions, together with the droppering system shall be those of an existing proven high speed overhead contact system.

- The CHSTP OCS shall preferably consists in a simple auto-tensioned catenary system (OCS Standard Drawings ref. OCS 001 for very high-speed and OCS 011 for speeds up to 125 mph) using a bare bronze or other copper alloy messenger wire supporting a solid pre-sagged copper (or copper alloy) contact wire, by means of copper alloy current carrying dropper (ensuring no "hard spot" on the contact wire and providing the correct contact wire profile for high-speed current collection), an aerial negative longitudinal feeder (OCS Standard Drawings ref. OCS 002 and OCS 003 for very high speed and OCS 012 and 013 for speeds up to 125 mph), and an aerial ground wire, connecting each OCS supporting structure.
- In the sections dedicated to very high speed, tunnels should be of sufficient area so as to permit installation of bare feeder wires (OCS Standard Drawing ref. OCS 005 for very high speed). However, in the shared use corridors, tunnels of smaller sections (OCS Standard Drawing ref. OCS 015 for speeds up to 125 mph) would necessitate installation of pull off only reduced system height equipment and would not permit installation of bare longitudinal feeder. Insulated feeder cables would have to be used in lieu of bare feeder conductors.
- The overhead contact system shall be free running under overhead bridges. New bridges shall therefore be designed to accommodate a free height clearance. On dedicated shared use corridors, existing bridge height clearances shall be reviewed so as to accommodate free running OCS as well.
- The contact wire shall be installed and maintained at a nominal constant and minimum 17'-4.7"(5300mm). height at support all along the sections dedicated to very high-speed where the maximum vehicle static gauge height will be 14 ft 9 ¼ in accordance with the ''Structure Gauge'' technical Memorandum. Also, the height difference at each adjacent structure is to be less than 1/2 in so as to ensure a constant contact wire height as required for satisfactory pantograph current collection at high-speed.
- On shared use corridors where high-speed vehicles will share the track with other American passenger cars of a maximum vehicle static gauge height of 17 ft in accordance with the ''Structure Gauge'' Technical Memorandum, and where the maximum operating speed is 125 mph, the contact wire height shall generally be set up at a height 18'-8.4"(5700 mm) at support.
- The contact wire height transition between sections dedicated to very high-speed and shared use corridors shall be realized in areas where the speed does not exceed 125 mph. The maximum contact wire gradients and the corresponding maximum gradient changes shall not exceed, according to the maximum speed, the following values:

Maximum speed	Maximum contact wire gradient	Maximum contact wire gradient change
> 125 mph	0	0
125 mph	2/1000	1/1000
100 mph	3.3/1000	1.7/1000
75 mph	4/1000	2/1000
60 mph	6/1000	3/1000
45 mph	8/1000	4/1000
30 mph	13/1000	6.5/1000

- On tangent track (straight track), the contact wire shall be staggered at each location to alternate sides of the pantograph center line. The stagger shall normally be set at ±8 in. On curved track, the staggers shall be calculated on a case by case basis taking into account the track cant, radius track curvature, and wind speed.
- The method of auto-tensioning the messenger and contact wire conductors shall be by balance weight arrangements using tensioning devices. For very high speed, the tensions are to be applied to the contact and messenger wires individually by using separate balance weights, tensioning devices and anchoring positions (OCS Standard Drawing ref. OCS 008), while for speeds up to 125 mph in the shared use corridors, the messenger and contact wires will be auto-tensioned using one common balance weight arrangement and a yoke plate (OCS Standard Drawing ref. OCS 018).
- The CHSTP Overhead Contact System shall ensure reliable operation under the environmental and climatic conditions given in section 3.2.1.3.3 and the mechanical tension in each of the contact and messenger wires shall be automatically maintained over a 25°F to 170°F temperature range in above

grade sections, while after the first 1300 ft in tunnels, the temperature range for auto-tensioning the conductors shall be 35°F to 155°F.

- For OCS design, the operational wind speed (used to compute catenary support, catenary wire displacement for pantograph security and maximum span length calculations) should be taken as Vop = 60 mph, and the design wind speed (used to determine the ultimate strength requirements of the OCS) should be taken as Vbws = 85 mph corresponding to the ASCE and NESC basic wind speed for the CHSTP route.
- The wind velocity pressure qz shall be calculated by the NESC formula:

  $q_z = 0.00256\ V^2 K_z\ G_{RF}\ I\ C_f\ A$ in lb/sq ft (equivalent to $q_z = 0.613\ V^2 K_z\ G_{RF}\ I\ C_f\ A$ in N/m^2)
- Loads due to wind for OCS structural calculations shall be multiplied by the load factors given by table 253-1 of the NESC.
- Maximum tension lengths from anchor to anchor shall not exceed 4000 ft in tunnels and in front of power supply stations and 4600 ft in open route. Exceptionally for a specific case, a tension length of up to 5000 ft may be found acceptable. At approximately mid-distance between auto-terminated anchors, mid-point arrangements (OCS Standard Drawings ref. OCS 009 for very high speed and OCS 019 for speeds up to 125 mph) shall be installed such that maximum half tension lengths do not exceed 2000 ft in tunnels and 2300 ft in open route.
- The OCS static and dynamic electrical recommended clearance values to be used for the CHSTP are:

Clearances	For CHST sections dedicated to very high speed		For shared use corridors for speeds up to 125 mph	
	Static (in)	Dynamic (in)	Static (in)	Dynamic (in)
Normal	1’-0.6” (320mm)	8.7” (220mm)	1’-0.6” (320mm)	8.7” (220mm)
Minimum	1’-0.6” (320mm) .	8.7” (220mm)	10.6” (270mm)	6.7” (170mm)

- For pantograph security purposes, the permissible lateral deflection of the contact wire under the action of crosswind shall be ≤ 15 ¾”.
- At the maximum operational speed, the dynamic pantograph envelope shall consider twice the value of the estimated or simulated uplift S_0 at the support point, i.e. 9.8”(250 mm) minimum. In very high speed dedicated sections, the design of the OCS cantilever and registration shall consequently allow for a steady arm uplift clearing at least the dynamic pantograph envelope, and thus allow for a minimum uplift of 9.8”(250 mm).
- In shared use corridors where the maximum operational speed is 125 mph, the design of the OCS cantilever and registration shall allow for a steady arm uplift clearing at least the dynamic pantograph envelope for such speed, and thus allow for a minimum uplift of 7.9”(200 mm).
- The above grade sections’ OCS structures are to be galvanized Universal Column (U.C.)/H-beams and are to be designed and manufactured to the relevant steel standards.
- The OCS supporting structures shall be calculated in accordance with relevant American standards (NSCE, ASCE, ANSI) and in addition, the maximum mast deflection across track, including wind and ice loading, is not to exceed two (2) inches at contact wire level.
- Where the OCS is closely supported in above grade sections, such as at overlaps and turnouts, multiple cantilevers will be attached to a single structure of a heavier section as the applied loads shall not cause twisting of the structure by more than five (5) degrees.

- For multi track areas when independent masts cannot be installed between tracks, portal structures using drop tubes that will permit maintaining mechanical independence of the equipment related to individual tracks, are to be designed with respect to overall aesthetics of the complete OCS (OCS Standard Drawings ref. OCS 004 for very high speed and OCS 014 for speeds up to 125 mph). However, to equip maintenance yard multi track areas or in shared use corridors such as at passenger stations approach, headspans arrangement (OCS Standard Drawing ref. OCS 020) may be used if considerations dictate.
- In tunnels and cut and covers, or for wall fixings, galvanized steel supports shall be fixed using either C-channels or anchor expansion bolts of the undercut type.
- Each and every OCS support location shall be individually numbered for ease of identification on site.
- The overall 2x25kV grounding and bonding protection network for the CHSTP shall consist of OCS aerial ground conductors, connections from these aerial ground conductors to the general buried ground conductor/grounding pillars/impedance bonds connected to the track and connections between all the later and the SSTs, SWSs and PSs grounding bars.
- In addition, the OCS grounding and bonding system shall safely connect all OCS metallic non live parts and also safely bond overhead bridges.
- The bonding and grounding of the OCS and of other lineside equipment shall ensure, in accordance with IEC 479-1 that the touch potentials are not exceeding:
  - 60 V where accessible to the public under all power supply feeding conditions
  - 650 V for less than 200 ms under short circuit conditions.
- The OCS voltage drop shall be in accordance with IEC 60850 “Supply voltages of traction systems”, whose main voltage criteria are as follow:
  - Operating nominal system voltage: 25.0 kV
  - Highest permanent voltage U_{max1}: 27.5 kV
  - Highest non-permanent voltage U_{max2}: 29.0 kV
  - Lowest permanent voltage U_{min1}: 19.0 kV
  - Lowest non-permanent voltage U_{min2}: 17.5 kV
- In addition, the maximum short circuit current shall be 12kA for protection measurement purpose and accordingly for specification of the electrical equipment.
- The design and locations of voltage transformers that shall be installed on the Overhead Catenary System to monitor the voltage presence of each electrical section and sub-section shall be interfaced with the Power Supply and SCADA (or equivalent data transmission system) and Signaling to permit a satisfactory information monitoring management system.
- The OCS and the signaling systems shall interface:
  - the phase break separation together with the Civil Work (so as to ensure no or reduced track gradient at the phase break location) and the Traction Power Supply, for the exact mileage locations and lengths of the OCS phase break arrangements together with the locations of the associated signaling equipment.
  - the signaling visibility in order that trackside signals are not obstructed to train driver visibility by OCS masts and associated OCS equipment.
  - the traction return current and the grounding and bonding system which includes the design principles, as well as the signaling schemes, including the track connection (via impedance bonds) and buried ground conductor connections (with associated grounding plates), including details and locations.
- The Civil Work infrastructure shall interface with the OCS:
  - the design, construction tolerances and as built information of the track platforms and associated cross-sections including details and as-built information of track drainage, retaining walls, wind and sound walls, fencing, etc necessary to design and install the OCS in open route.

- the design, construction tolerances and as-built information of tunnels alignment together with cross-section details, niches, lining and segments details to which OCS equipment will be fixed.
- the track alignment at OCS phase break locations so as to ensure no (or reduced) track gradient at the phase break location.
- the track alignment providing all information related to track curves, spirals and superelevation necessary for the OCS basic and installation designs.
- the track construction and maintenance tolerances, as well as the as-built track information necessary to design and install the OCS all along the CHSTP alignment.
- the track turnout and crossover designs and as-built information necessary to design and install the specific OCS arrangements to the different type of points and crossings that would be used for the CHSTP.
- the design, construction tolerances and as-built information of the overhead bridges and associated elevation and cross-section information including details necessary to design and install the OCS (free running in sections of the CHSTP dedicated to very high speed) under overhead bridges.
- the design and as-built information of underbridges and viaducts together with cross-section details, OCS masts fixing arrangement details (preferably using civil manufactured bases with anchor bolts) and as-built information necessary to design and install the OCS on viaducts and underbridges.
- the dimensions and locations of the turnout and crossover construction and maintenance areas.
- the geotechnical information providing ground pressure values related to the platform ground and permitting to precisely size, calculate and further allocate the different types of OCS mast foundations (basically located between 10 ft and 14 ft from the closest track centerline).
- the alignment and platform surveys.
- the grounding and bonding continuity of alongside fences, wind and sound walls, gates, barriers and any other civil structures installed within the right-of-way fenced limits.

• The Rolling Stock shall interface with the OCS:
  - the manufacturer rolling stock static and dynamic gauges of the trains that will be operated on the electrified tracks of the CHSTP and which are required for the OCS design
  - the maximum allowable train rated current (600A for 25kV AC systems) and the train current graph as a function of the OCS line voltage.
  - the pantograph reaching height, e.g. the minimum and maximum operating heights of the pantograph.
  - the pantograph (i.e. there should be only one type of pantograph used on the CHST) dimensions and physical characteristics which are necessary to confirm the pantograph clearance envelopes which are required for design and for testing of the overhead contact system.
  - the number of pantographs in service per high-speed train and their spacing (e.g. 656 feet).
  - the pantograph model and the pantograph static and dynamic characteristics. Only pantographs designed and proven for very high speed performance shall be considered for the CHST.
  - the pantographs details including the nature of the contact strip material.
  - the existence of additional pantographs features, namely a safe dropping device, a pantograph's uplift limiting device (pantograph stop), and insulated horns.

• The OCS and the Electrical Operational Control Center shall interface all the relevant design information related to OCS electrical equipment consisting of motorized breakers/switches, isolators, voltage transformers, etc.

- The OCS and the Data Transmission Network / SCADA shall interface all the relevant design information related to the monitoring and control-command operation and status of OCS electrical equipment.
- The OCS construction design shall consist of detailed OCS layouts, OCS cross-section/data sheet books, OCS footing books, longitudinal auxiliary conductor profiles, OCS special droppering books, OCS calculations books for footings, masts and cantilever arrangements, detailed installation books for individual switching arrangements and OCS under bridge (or other structure) arrangements, as well as all the necessary detailed bill of quantities.
- The OCS construction design shall be revised as necessary during the construction phase and be updated as an as-built record shortly after construction.
- The OCS construction shall be carried out in accordance with a CHSTP OCS Construction Plan which shall demonstrate that, during the construction phase, the OCS technical and safety requirements of the CHSTP will be met in accordance with the high Assurance Quality policy, process and program required for the CHSTP, and necessary for OCS high speed.
- Detailed OCS construction programs interfacing with other works shall be produced and monitored on a monthly and weekly basis to ensure that the OCS program of works is well managed and well integrated within the overall CHSTP program of works, and that the works are carried out in accordance with the program.
- OCS works shall be in carried out in accordance with technical construction method statements providing detailed information on the organization, safety, utilized plant and personnel resources, together with the operating methods of the works and necessary checks (witness and eventual hold points) required to confirm the quality of the installation works.
- Installation tolerances for high-speed are very restrictive, and the OCS equipment shall be installed in accordance with these tight tolerances to ensure that the catenary components including the contact wire are installed as required for a satisfactory current collection at high speed and very high speed.
- The OCS Testing and Commissioning shall be carried out in accordance with a CHSTP OCS Testing and Commissioning Plan which shall demonstrate that, through the testing and commissioning phases, the necessary OCS technical requirements of the CHSTP will be met in accordance with the high Assurance Quality policy, process and program required for the CHSTP, and necessary for OCS high speed.
- The OCS Testing and Commissioning shall be carried out in phases to ensure:
  - the quality surveillance of procured equipment, including factory acceptance of materials and OCS components,
  - the technical verifications and static tests to confirm the correct installation of the OCS,
  - the integrated testing of the OCS with other disciplines, including the OCS energization and short circuit tests,
  - the dynamic testing of the OCS,
  - the surveillance when trains are running during the period following the dynamic testing and prior to the operation and the line, and during the first weeks of the operation of the line.
- The dynamic performance capability of the OCS current collection system shall be checked as part of the dynamic testing, and at least the following data shall be measured:
  - the percentage of arcing, and additionally the contact force,
  - the contact wire uplift at the support as the pantograph passes.
- Also, during the OCS dynamic tests, the following shall be measured and recorded:
  - the pantograph current (measured parts with a pantograph current below 30% of the nominal current of the pantograph shall be disregarded),
  - the total time with a pantograph current greater than 30% of the nominal current per train per pantograph,
  - the total run time,
  - the number of arcs that are lasting longer than 1 ms (as arcs of a duration shorter or equal to 1ms shall be disregarded),

- the duration of each arc longer than 1 ms (the mileage position of the arc along the overhead contact line should also be recorded),
- the largest arc duration, and
- the sum of the durations of all arcs longer than 1 ms.

5.0 SOURCE INFORMATION AND REFERENCES

- Energy Technical Specification for Interoperability of European High Speed Rail System
- CHSTP Basis of Design Policy – California High Speed Rail Program – Jan 08
- Technical Memorandum TM 1.1.10 Structure Gauge
- Technical Memorandum TM 3.2.3.3 Pantograph Clearance Envelopes
- California Public Utilities Commission General Order 26-D
- UIC 606-1 OR
- The Manual for Railway Engineering of the American Railway Engineering and Maintenance of Way Association (AREMA Manual)
- Amtrak guidelines and present practices
- OCS Standard Drawings:

- OCS 001 ''Typical Open Route High Speed OCS Configuration – 220 mph''
- OCS 002A ''Typical OCS Equipment for two Tangent Tracks in Open route – 220 mph''
- OCS 002B ''Typical OCS Equipment for two Curved Tracks in Open route – 220 mph''
- OCS 003A ''Typical OCS Equipment on Viaduct - Two Tangent Tracks – 220 mph
- OCS 003B ''Typical OCS Equipment on Viaduct - Two Curved Tracks – 220 mph
- OCS 004A ''Typical OCS Arrangement under Portal Beam - Two Tangent Tracks with Turnout – 220 mph
- OCS 004B ''Typical OCS Arrangement under Portal Beam - Three Curved Tracks– 220 mph
- OCS 005A ''Typical OCS Equipment for Circular Tunnels - Tangent Track – Alternative 1– 220 mph
- OCS 005B ''Typical OCS Equipment for Circular Tunnels - Tangent Track – Alternative 2 – 220 mph
- OCS 005C ''Typical OCS Equipment for Circular Tunnels - Curved Track – Alternative 1 – 220 mph
- OCS 005D ''Typical OCS Equipment for Circular Tunnels - Curved Track – Alternative 2 – 220 mph
- OCS 006A ''Typical OCS Uninsulated Overlap Arrangement - 220 mph
- OCS 006B ''Typical OCS Uninsulated Overlap – Cantilever Arrangement - 220 mph
- OCS 007A ''Typical OCS Insulated Overlap Arrangement - 220 mph
- OCS 007B ''Typical OCS Insulated Overlap – Cantilever Arrangement - 220 mph
- OCS 008 ''Typical Balance Weight Arrangement Termination for OCS in Open Route - 220 mph
- OCS 009 ''Typical Mid-Point Arrangement for OCS in Open Route - 220 mph
- OCS 010 ''Maximum Span and Tension Lengths – Speed ≤ 125 mph''
- OCS 011 ''Typical Open Route OCS Configuration – Speed ≤ 125 mph''
- OCS 012A ''Typical OCS Equipment for two Tangent Tracks in Open route – Speed ≤ 125 mph''
- OCS 012B ''Typical OCS Equipment for two Curved Tracks in Open route – Speed ≤ 125 mph''
- OCS 013A ''Typical OCS Equipment on Viaduct - Two Tangent Tracks – Speed ≤ 125 mph
- OCS 013B ''Typical OCS Equipment on Viaduct - Two Curved Tracks – Speed ≤ 125 mph
- OCS 014A ''Typical OCS Arrangement under Portal Beam - Two Tangent Track with Turnout – Speed ≤ 125 mph
- OCS 014B ''Typical OCS Arrangement under Portal Beam - Curved Tracks– Speed ≤ 125 mph
- OCS 015A ''Typical OCS Equipment for Circular Bore Tunnel - Tangent Track – Speed ≤ 125 mph
- OCS 015B ''Typical OCS Equipment for Circular Bore Tunnel - Curved Track – Speed ≤ 125 mph
- OCS 015C ''Typical OCS Equipment for Cut and Cover Tunnel - Tangent Track – Speed ≤ 125 mph
- OCS 015D ''Typical OCS Equipment for Cut and Cover Tunnel - Curved Track – Speed ≤ 125 mph
- OCS 015E ''Typical OCS Equipment for Cut and Cover Tunnel – Two Tangent Track – Speed ≤ 125 mph
- OCS 016A ''Typical OCS Uninsulated Overlap – Three Span Arrangement - Speed ≤ 125 mph
- OCS 016B ''Typical OCS Uninsulated Overlap – Four Span Arrangement - Speed ≤ 125 mph
- OCS 016C ''Typical OCS Uninsulated Overlap – Five Span Arrangement - Speed ≤ 125 mph
- OCS 016D ''Typical OCS Uninsulated Overlap – Three Span - Cantilever Arrangement - Speed ≤ 125 mph

- OCS 016E ‘’Typical OCS Uninsulated Overlap – Four and Five Span - Cantilever Arrangement - Speed ≤ 125 mph
- OCS 017A ‘’Typical OCS Insulated Overlap – Three Span Arrangement - Speed ≤ 125 mph
- OCS 017B ‘’Typical OCS Insulated Overlap – Four Span Arrangement - Speed ≤ 125 mph
- OCS 017C ‘’Typical OCS Insulated Overlap – Five Span Arrangement - Speed ≤ 125 mph
- OCS 017D ‘’Typical OCS Insulated Overlap – Three Span - Cantilever Arrangement - Speed ≤ 125 mph
- OCS 017E ‘’Typical OCS Insulated Overlap – Four and Five Span - Cantilever Arrangement - Speed ≤ 125 mph
- OCS 018 ‘’Typical Balance Weight Arrangement Termination for OCS in Open Route - Speed ≤ 125 mph
- OCS 019 ‘’Typical Mid-Point Arrangement for OCS in Open Route - Speed ≤ 125 mph
- OCS 020 ‘’Typical Headspan OCS Arrangement – Tangent Track - Speed ≤ 125 mph

6.0 DESIGN MANUAL CRITERIA

These design criteria are principally provided to support the environmental review process. Typical OCS arrangements and spacing guidelines are included in Directive Drawings TM 3.2.1-A through E and TM 3.2.1-G through J. The following design criteria are provided as information for consideration during the development of the CHSTP corridor as applicable.

- Electric trains shall be able to go through the OCS phase break arrangement without establishing an electrical continuity between the successive electrical sections which are fed from different phases. This shall be realized at the maximum operating speed and with the train pantographs raised and in contact with overhead catenary, but with the pantograph breaker off.
  - On the CHSTP sections dedicated to very high speed, either a phase break design of at least 1319 feet long, or a shorter phase break separation of less than 466 feet (142 m) constituted by three insulated overlaps can be used. Adequate means shall be provided to allow a train that is stopped within the above phase break arrangements to be restarted; i.e. the neutral section shall be connectable to the adjacent sections by remotely controlled switches/isolators.
  - On shared use corridors where the maximum operation speed is 125 mph, the designs of phase break separation sections for high speed sections can be adopted, but in addition, a third phase break design arrangement of an overall distance less than 27 feet using insulators and having its centre section connected to the current return path / ground may also be adopted.
- For the CHST, there should be only one type of pantograph current collector head used for all trains and carbon strip material is recommended to minimize wear. The pantograph static force shall be adjustable between 9 and 27 pound force (40 and 120 N) and the nominal static force is to be 15.75 (+4.5,-2.25) pound force (70 N + 20 N/-10 N). The CHST pantograph shall be proven for very high speed performance and equipped with a fail safe device that will detect any failures of the contact strips and will trigger the lowering of the pantograph in case of a failure. Also the CHST pantograph shall be equipped with an uplift limiting device (pantograph stop) and with insulated horns.
- The OCS-pantograph current collection at the design stage shall be assessed at the maximum operational speeds, by the determinations of the mean value (Fm), of the standard deviation (σ) of simulated contact forces, of the statistical value $F_m - 3\sigma$, of the contact loss percentage (NQ), and of the vertical movement of the contact point.
- The CHSTP OCS shall preferably consists in a simple auto-tensioned catenary system using a bare bronze or other copper alloy messenger wire supporting a solid pre-sagged copper (or copper alloy) contact wire, by means of copper alloy current carrying dropper, an aerial negative longitudinal feeder and an aerial ground wire connecting each OCS supporting structure.
- The contact wire shall be installed and maintained at a nominal constant and minimum 17'-4.7"(5300 mm) height at support all along the sections dedicated to very high-speed and the height difference at each adjacent structure is to be less than 1/2 in. so as to ensure a constant contact wire height required for satisfactory pantograph current collection at high-speed.
- On shared use corridors where high-speed vehicles operate on tracks shared with American passenger cars, the contact wire height shall generally be set up at a height 18'-8.4"(5700 mm) at support.
- The contact wire height transition between sections dedicated to very high-speed and shared use corridors shall be realized in areas where the speed does not exceed 125 mph. The maximum contact wire gradients and the corresponding maximum gradient changes shall not exceed, according to the maximum speed, the following values:

Maximum speed	Maximum contact wire gradient	Maximum contact wire gradient change
> 125 mph	0	0
125 mph	2/1000	1/1000
100 mph	3.3/1000	1.7/1000
75 mph	4/1000	2/1000
60 mph	6/1000	3/1000
45 mph	8/1000	4/1000
30 mph	13/1000	6.5/1000

- On tangent track (straight track), the contact wire shall be staggered at each location to alternate sides of the pantograph center line. The stagger shall normally be set at ±8 in. On curved track, the staggers shall be calculated on a case by case basis taking into account the track cant, radius track curvature, and wind speed.
- The method of auto-tensioning the messenger and contact wire conductors shall be by balance weight arrangements using tensioning devices. For very high speed, the tensions are to be applied to the contact and messenger wires individually by using separate balance weights, tensioning devices and anchoring positions, while for speeds up to 125 mph in the shared use corridors, the messenger and contact wires will be auto-tensioned using one common balance weight arrangement and a yoke plate.
- The CHSTP Overhead Contact System shall ensure reliable operation under the California specified environmental and climatic conditions and the mechanical tension in each of the contact and messenger wires shall be automatically maintained over a 25^{o}F to 170^{o}F temperature range in above grade sections, while after the first 1300 ft in tunnels, the temperature range for auto-tensioning the conductors shall be 35^{o}F to 155^{o}F.
- For OCS design, the operational wind speed is Vop = 60 mph, and the design wind speed is Vbws = 85 mph. The wind velocity pressure qz shall be calculated by the NESC formula:
  $q_z = 0.00256\ V^2\ K_z\ G_{RF}\ I\ C_f\ A$ in lb/sq ft (equivalent to $q_z = 0.613\ V^2\ K_z\ G_{RF}\ I\ C_f\ A$ in N/m^2), and the loads due to wind for OCS structural calculations shall be multiplied by the load factors given by table 253-1 of the NESC.
- For pantograph security purposes, the permissible lateral deflection of the contact wire under the action of crosswind shall be ≤ 15 ¾”.
- Maximum tension lengths from anchor to anchor shall not exceed 4000 ft in tunnels and in front of power supply stations and 4600 ft in open route.
- The overhead contact system shall be free running under overhead bridges.
- The OCS static and dynamic electrical recommended clearance values to be used for the CHSTP are:

Clearances	For CHST sections dedicated to very high speed		For shared use corridors for speeds up to 125 mph	
	Static (in)	Dynamic (in)	Static (in)	Dynamic (in)
Normal	1’-0.6” (320mm)	8.7” (220mm)	1’-0.6” (320mm)	8.7” (220mm)
Minimum	1’-0.6” (320mm)	8.7” (220mm)	10.6” (270mm)	6.7” (170mm)

- At the maximum operational speed, the dynamic pantograph envelope shall consider twice the value of the estimated or simulated uplift S_0 at the support point, i.e. 9.8” (250 mm) minimum. In very high speed dedicated sections, the design of the OCS cantilever and registration shall consequently allow for a steady arm uplift clearing at least the dynamic pantograph envelope, and thus allow for a minimum uplift of 9.8”(250 mm).
- In shared use corridors where the maximum operational speed is 125 mph, the design of the OCS cantilever and registration shall allow for a steady arm uplift clearing at least the dynamic pantograph envelope for such speed, and thus allow for a minimum uplift of 7.9”(200 mm).
- The above grade sections’ OCS structures are to be galvanized Universal Column (U.C.)/H-beams and are to be designed and manufactured to the relevant steel standards.

- The OCS supporting structures shall be calculated in accordance with relevant American standards (NSCE, ASCE, ANSI) and the maximum mast deflection across track, including wind and ice loading, is not to exceed two (2) inches at contact wire level.
- Where the OCS is closely supported in above grade sections, such as at overlaps and turnouts, multiple cantilevers will be attached to a single structure of a heavier section as the applied loads shall not cause twisting of the structure by more than five (5) degrees.
- For multi track areas when independent masts cannot be installed between tracks, portal structures using drop tubes permitting to maintain mechanical independence of the equipment related to individual tracks, are to be designed with respect to overall aesthetics of the complete OCS.
- In tunnels and cut and covers, or for wall fixings, galvanized steel supports shall be fixed using either C-channels or anchor expansion bolts of the undercut type.
- Each and every OCS support location shall be individually numbered for ease of identification on site.
- The overall 2x25kV grounding and bonding protection network for the CHSTP shall consist of OCS aerial ground conductors, connections from these aerial ground conductors to the general buried ground conductor/grounding pillars/impedance bonds connected to the track and connections between all the later and the SSTs, SWSs and PSs grounding bars. In addition, the OCS grounding and bonding system shall safely connect all OCS metallic non live parts and also safely bond overhead bridges.
- The bonding and grounding of the OCS and of other lineside equipment shall ensure, in accordance with IEC 479-1 that the touch potentials are not exceeding:
  - 60 V where accessible to the public under all power supply feeding conditions
  - 650 V for less than 200 ms under short circuit conditions.
- The OCS voltage drop shall be in accordance with IEC 60850 “Supply voltages of traction systems”, whose main voltage criteria are as follow:
  - Operating nominal system voltage: 25.0 kV
  - Highest permanent voltage Umax1: 27.5 kV
  - Highest non-permanent voltage Umax2: 29.0 kV
  - Lowest permanent voltage Umin1: 19.0 kV
  - Lowest non-permanent voltage Umin2: 17.5 kV
- In addition, the maximum short circuit current shall be 12kA for protection measurement purpose and accordingly for specification of the electrical equipment.
- OCS voltage transformers shall be installed on the Overhead Catenary System to monitor the voltage presence of each electrical section and sub-section.
- The dynamic performance capability of the OCS current collection system shall be checked and at least the following data shall be measured:
  - the percentage of arcing, and additionally the contact force,
  - the contact wire uplift at the support as the pantograph passes.