California High-Speed Train Project

TECHNICAL MEMORANDUM

Geologic and Seismic Hazard Analysis Guidelines
TM 2.9.3

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System Level Technical and Integration Reviews

The purpose of the review is to ensure:
- Technical consistency and appropriateness
- Check for integration issues and conflicts

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

System Level Technical Reviews by Subsystem:

Systems: _Not Required__________________ ___________
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ABSTRACT

This Technical Memorandum provides guidance for geologic and seismic hazards evaluations based primarily on existing guidance documents and data on geologic and seismic hazards, and supplements these guidelines with additional clarification and scope where applicable.

These guidelines are generally consistent with other key guidance documents prepared primarily by the California Board of Geologists and Geophysicists and Department of Transportation. Based on these documents, geologic hazards and hazardous minerals addressed herein include:

- Ground rupture along active faults
- Liquefaction and other seismically-induced ground deformation
- Tsunami and seiche
- Static and seismically triggered landslides and slope stability
- Karst terrain and abandoned mines
- Volcanic hazards
- Erosion or scour
- Land subsidence
- Collapsible soils
- Expansive soils
- Flooding and dam inundation
- Hazardous minerals

This technical memorandum has been prepared to highlight available data developed during the Programmatic EIR/S and provide guidance on methods for identifying and evaluating the geologic and seismic hazards for preliminary engineering. Slope stability and seismic ground motion hazards are addressed separately in TM 2.9.1 - Geotechnical Investigations Guidelines and TM 2.9.6 – Interim Ground Motion Analysis Technical Memoranda.

1.0 INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

The purpose of this Technical Memorandum(TM) is to provide reference to existing guidance and literature on geologic and seismic hazards, and to supplement the guidance with additional clarification and scope, as needed. The scope of geologic and seismic hazards is based upon existing guidelines provided by the following:

- California Department of Consumer Affairs, Board of Geologists and Geophysicists (BGG),
- California Department of Transportation (Caltrans)
- California Geological Survey (CGS),
- Association of Engineering Geologists (AEG), and
- Federal Emergency Management Agency (FEMA).

This Technical Memorandum provides guidelines for identification, evaluation, data analysis, and presentation of findings for geologic and seismic hazards. This document is intended to be a stand alone document for performing Geologic and Seismic Hazards Analyses (GSHA) but relates closely with other technical memoranda. Additionally, the output from the geologic and seismic hazard evaluation provides input to the geotechnical investigations, ground motion analysis, and design teams. The related technical memoranda are:

- TM 2.9.1 - Geotechnical Investigation (GI) Guidelines
- TM 2.9.2 - Geotechnical Report (GR) Guidelines
- TM 2.9.6 - Interim Ground Motion Analysis (GMA) Guidelines
- Geotechnical Analysis (GA) Guidelines

These guidelines receive input from the GSHA Guidelines to quantify the hazards for input to design parameters for mitigation by Designers. It shall be noted that the guidelines for liquefaction and slope stability quantitative hazard analyses and mitigation are addressed in the GA Guidelines. Where applicable, risk-based or risk-informed methods are recommended for hazard analysis.

1.2 STATEMENT OF TECHNICAL ISSUE

It is necessary for Designers to be informed of and design for geologic and seismic hazards to ensure that the California High-Speed Train Project can be constructed and operated to meet the defined performance requirements and objectives. This document provides guidelines for identifying and evaluating these hazards for input to project design criteria.

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 the California High-Speed Rail system. These definitions are based on and adapted where needed from the Glossary of Geology (AGI, 2005):

<u>Abandoned Mines</u>	A collective term referring to the mapped or otherwise known presence of subsurface voids resulting from man-made mining or other subsurface tunnelling activities.
<u>Active Fault</u>	A fault that has either known or is suspected of having had tectonic movement within Holocene time (past 11,000 years).
<u>Erosion</u>	The loosening, dissolving, or wearing away of earth materials in response to weathering, interaction with flowing water, wave action, or wind.
<u>Expansive Soils</u>	Soils that undergo swelling and shrinkage when wetted and dried.

Hazardous Minerals	Naturally occurring minerals contained within soil or rock that contain minerals known to be harmful if inhaled, ingested, or in contact with skin.
Karst Terrain	A type of topography that is formed by subsurface dissolution of minerals, including mapped or otherwise known subsurface naturally occurring or man-induced voids.
Land Subsidence	The gradual downward settlement or sinking of the ground surface.
Landslide	Mapped or otherwise known rock falls, mud flows, debris flows, landslides, and other forms of slope failures.
Liquefaction	Reduction of soil strength because of excess pore water pressure due to earthquake ground shaking when saturated.
Seismic Hazards	Earthquake-induced conditions such as vibratory ground motion, liquefaction, lateral spreading, dynamic compaction, seismically-induced slope failures, and ground rupture.
Slope Stability	The ability of slopes to resist movement.
Volcanic	Mapped or otherwise known volcanic centers and/or hydrothermal activity associated with volcanic activity.

Acronyms

AEG	Association of Environmental and Engineering Geologists
AGI	American Geological Institute
ANSS	Advanced National Seismic System
ATCM	Asbestos Airborne Toxic Control Measure
BGG	Board of Geologists and Geophysicists
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CEG	Certified Engineering Geologist
CGS	California Geologic Survey
CHSTP	California High-Speed Train Project
DBE	Design Basis Earthquake
EIR	Environmental Impact Report
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
GIS	Geographic Information Systems
LDBE	Lower-level Design Basis Earthquake
LiDAR	Light Detection and Ranging
MRDS	Mineral Resources Database System
NOA	Naturally Occurring Asbestos
OPL	Operability Performance Level
PMT	Project Management Team
PFDHA	Probabilistic Fault Displacement Hazard Analysis
PG	Professional Geologist
SCEC	Southern California Earthquake Center
SER	Standard Environmental Reference
SP	Special Publication
SPL	Safety Performance Level
SSC	Seismic Source Characterization
TM	Technical Memorandum
TRB	Transportation Research Board
USGS	United States Geological Survey

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 US as “English” or “Imperial” units. In order to avoid confusion, all formal references to units of measure shall be made in terms of U.S. Customary Units.

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

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 GENERAL

The geologic and seismic hazards need to be identified and evaluated to assess their potential impact on the design, construction, and operation of the high-speed train project (CHSTP). In some instances, these hazards will have significant impact on the design, construction, and/or operation of high-speed trains and therefore will require mitigation measures that may be achieved through avoidance and/or design modifications. Hazardous minerals are unique to these other hazards in that they do not affect the operation of the high-speed trains but may influence construction.

2.1.1 CHSTP Design Considerations

Following are design considerations related to the geologic and seismic hazards discussed in this Technical Memorandum. In general, these include the input to the design of system elements to accommodate or mitigate:

- Surface rupture along active faults
- Liquefaction or other seismically-induced ground deformation
- Tsunami or seiche
- Static and seismically triggered landslides
- Karst terrain or abandoned mines
- Volcanic eruptions
- Erosion or scour
- Land Subsidence
- Collapsible soils
- Expansive soils
- Flooding or dam inundation
- Hazardous minerals
- Soft and/or weak foundation materials

Other geologic and seismic hazards such as liquefaction potential, lateral spreading, seismically induced ground cracking may exist along rail segments or facilities and shall be identified and evaluated to assess significance to the rail system and/or its components. Ground motion hazards are not addressed in this Technical Memorandum; however, the information related to active faults will be used for the analysis of ground motion. The guidelines for ground motion hazard analysis are addressed in the TM 2.9.4 – Interim Ground Motion Guidelines.

2.1.2 CHSTP Design Parameters

This technical memorandum focuses on identification and evaluation of geologic and seismic hazards. The output of these studies will support the quantitative analyses described in other CHSTP technical guidance documents including TM 2.9.1 - Geotechnical Investigations and TM 2.9.4 - Interim Ground Motion Guidelines. Design parameters will be provided in a separate technical memorandum.

2.1.3 Codes, Regulations and Applicable Guidelines

Specific references to key guidance documents are cited in the Section 5.0 of this Technical Memorandum as they relate to addressing specific geologic hazards.

The California Building Code identifies guidance documents that are required to be addressed for the CHSTP. These guidance documents include addressing the identification and evaluation of geologic and seismic hazards in California and are principally accessed through the California Board of Geologists and Geophysicists (BGG), Geologist and Geophysicist Act. The BGG provides guidance for Preparing and Reviewing Geologic, Engineering Geologic, Seismologic, and Geophysical Reports. These guidelines are primarily based on similar California Geologic Survey (CGS) guidance documents. Guidance provided by California Department of

Transportation (Caltrans) is also used as a basis for the subject guidance. These guidelines are considered appropriate and applicable to the design of the major systems of the high-speed train project.

Independent technical reviews of geologic and seismic hazard data and reports will be performed by the subject matter experts.

3.0 ASSESSMENT AND ANALYSIS

The assessment and analysis of geologic and seismic hazards require identification (i.e. recognition) and evaluation. Recognition of these hazards begins with review of available and applicable maps, literature, and databases that identify geologic and seismic hazards. A preliminary assessment was performed during the Programmatic EIR/S when geologic, soils, and seismic hazards were mapped using GIS. This preliminary assessment shall be reviewed as a starting point for the detailed evaluation of geologic hazards. In addition, available hazard analyses, particularly for those areas of California where the geologic or seismic hazard is known to be significant shall be used to the extent practicable. Additional mapping is available from the CGS, Caltrans, USGS, and local county and city offices and shall be fully exploited to avoid duplicating efforts. Existing data, such as remote sensing imagery, aerial photographs, and topographic interpretation by Geologists experienced in the evaluation of geologic and seismic hazards, will serve as the basis for further evaluation of hazards. Where these methods are insufficient to rule out the presence of geologic and seismic hazards, and in the areas where the hazards have not been evaluated, field reconnaissance will be necessary to more accurately locate the condition and/or further evaluate the suspected hazard in order to assess its potential influence on the HST system elements.

Where geologic or seismic hazards are identified and hazard analyses are not available, it will be the responsibility of the Geologist to clearly evaluate the hazard and its significance so that the Designer can either avoid the hazard or mitigate the hazard through design measures as necessary. If the hazard poses a significant impact on the performance criteria but can not be avoided, a design solution will be necessary. This will likely require additional investigation and analysis by the Designer to confirm or refute the potential significance of the hazard to the system element. If the hazard is found to be of substantial impact to a system element and can not be avoided and the possible design solution is financially unreasonable or uncertain, the Designer will need to evaluate options, including the possibility of probabilistic hazard and risk assessment. The design options for mitigating the hazard shall be prepared by the Designer working with the Lead Geologist and Lead Geotechnical Engineer.

In order to meet the performance criteria established in the TM 2.10.4 – Interim Seismic Design Criteria Technical Memorandum, geologic and seismic hazards will need to be avoided or mitigated to meet the Safety Performance Level (SPL) and Operability Performance Level (OPL) criteria. For the SPL, the system will need to be designed to sustain only limited structural damage from the hazard such that the structure can be quickly repaired and operations can resume within a time frame to be determined. For the OPL, system elements critical to operation of the train will need to be designed so that structural damage from a hazard event will not impact the safe operation of the train to allow for the maximum operating speed. These two performance levels are defined as the Design Basis Earthquake (DBE) and the Lower-level Design Basis Earthquake (LDBE). This nomenclature is developed from design probabilistic risk assessments.

4.0 SUMMARY AND RECOMMENDATIONS

Identification and evaluation of the geologic and seismic hazards that may impact the CHSTP is a critical step in design and long term performance of the system. The guidelines presented in this technical memorandum shall be reviewed prior to evaluating the geologic and seismic hazards associated with this project. The Guidelines for TM 2.9.1 - Geotechnical Investigations and TM 2.9.6 - Ground Motion Analysis Technical Memoranda shall also be consulted as part of the geologic and seismic hazard evaluation. Guidelines for geologic and seismic hazard evaluation are presented in Section 6.0.

5.0 SOURCE INFORMATION AND REFERENCES

1. AEG, 1993, Professional Practice Handbook
2. Annandale, 1995, Erodibility Index Method
3. AGI, 2005, Glossary of Geology
4. Bray, 2005, Engineering to Accommodate Ground Deformation Associated with Surface Fault Rupture
5. CARB, 2004, Asbestos Airborne Toxic Control Measure (ATCM) for Construction, Grading, and Surface Mining Operations
6. Caltrans, 2007, Draft Guidelines for Preparation of Geotechnical and Geologic Reports
7. Caltrans, 2008, Chapter 7, Topography, Geology, Soils, and Seismic Guidelines in Standard Environmental Reference (SER) EH Volume 1
8. Coppersmith and Youngs, 1992, Modeling Fault Rupture Hazard for the Proposed Repository at Yucca Mountain, Nevada
9. BGG, 1998, Guidelines for the Preparation of Geologic and Engineering Reports
10. BGG, 1998, Guidelines for the Preparation of Geophysical Reports
11. BGG, 1998, Guidelines for the Preparation of Groundwater Investigation Reports
12. California Department of Health Services, 2003, Geologic Controls on the Distribution of radon in California
13. CGS, 1986, Note 41, Guidelines for Reviewing Geologic Reports
14. CGS, 1986, Note 44, Recommended Guidelines for Preparing Engineering Geologic Reports
15. CGS, 2000, OFR 2000-19, A General Location Guide for Ultramafic Rocks in California – Areas More Likely to Contain Naturally Occurring Asbestos
16. CGS, 2001, Note 52, Geologic Reports for Regional-Scale Projects
17. CGS, 2002, Note 49, Guidelines for Evaluating the Hazard of Surface Fault Rupture
18. CGS, 2002, SP 124, Geologic Investigation of Naturally Occurring Asbestos
19. CGS, 2003, Working Draft SP, Engineering Geology and Seismology for Public Schools and Hospitals in California
20. CGS, 2007, Note 42, Guidelines to Geologic and Seismic Reports
21. CGS, 2007, Note 48, Checklist for the Review of Engineering Geology and Seismology for Public Schools and Hospitals in California
22. CGS, 2008, SP 117, Guidelines for Evaluating and Mitigating Seismic Hazards in California
23. CGS, 2008, Hazardous Minerals, http://www.conservation.ca.gov/cgs/geologic_hazards/hazardous_minerals/
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25. Ireland, 1966, Land Subsidence in California
26. SCEC, 1999, Recommended Procedures for Implementation of SP 117 Guidelines for Analyzing and Mitigating Liquefaction Hazard in California
27. SCEC, 2002, Recommended Procedures for Implementation of CGS SP 117 Guidelines for Analysis and Mitigation of Landslide Hazards in California
28. State of California 1958, Geologist and Geophysicist Act, Business and Professions Code, Chapter 12.5
29. TRB, 1996, Landslide Investigation and Mitigation, SP 247
30. USC, 2008, Tsunami Research Center http://www.usc.edu/dept/tsunamis/2005/index.php
31. USGS, 2000, Mercury in the Environment, Fact Sheet 146-00
32. USGS, 2002, Mineral Resource Database System (MRDS) for 11 of the Western US States
33. Youngs et al., 2003, A Methodology for Probabilistic Fault Displacement Hazard Analysis (PFDHA), Earthquake Spectra, Vol. 19, No. 1, p 191-219

6.0 DESIGN MANUAL CRITERIA

6.1 GEOLOGIC AND SEISMIC HAZARD IDENTIFICATION AND EVALUATION

Preliminary qualitative evaluation of geologic and seismic hazards shall be performed in advance of geotechnical and seismic hazard analyses. This will enable Designers to develop investigation and analysis programs based on an understanding of any geologic or seismic hazards identified to have a potential impact to the elements of the CHSTP. Geologic and seismic evaluations of potential hazards shall be performed under the direct supervision of a professional geologist or engineering geologist. The Geologist shall work in close communication with the project Designer and Geotechnical Engineer to consider the hazard implications to the elements of the design, construction, and/or operation. Geologic and seismic hazard evaluations shall generally address the following conditions:

- Geologic setting
- Physiography and topography
- Surface and groundwater conditions
- Surface soil and rock conditions
- Presence and influence of geologic hazards
- Conceptual avoidance or mitigation alternatives
- Recommendations for future investigations if necessary

Discrepancies, if any, between the CHSTP fault database and the results of segment specific evaluations shall be presented in the geologic and seismic hazard reports.

Where applicable, risk-based or risk-informed methods are recommended for hazard analysis.

The quantitative analysis and mitigation design of hazards such as liquefaction or slope stability are addressed separately. Although seismic source characterization is discussed in this document, development of quantitative ground motion hazard values for input to seismic design parameters for the CHSTP will be provided separately in the TM 2.9.6 – Ground Motion Analysis Guidelines. No attempt is made to duplicate the guidelines. Because of the close relationship between these quantitative analyses and geologic and seismic hazard evaluations, it is critical that the Geologists responsible for the geologic and seismic hazard evaluations be included in any decisions and subsequent evaluations that rely upon this data. This includes review of key documents and findings related to how these hazards are treated in the design of the system elements.

The geologic and seismic hazard evaluations shall be performed under the supervision of a California licensed Professional Geologist or Certified Engineering Geologist. The project Geologist shall be involved with subsequent evaluations and site investigations. In addition, each geologic and seismic hazard evaluation shall, at a minimum, include a site visit and preliminary field mapping as appropriate and where ever practical.

The following subsections provide specific guidance and reference the relevant guidance documents from which the specific guidance was developed. The guidance discussed in the following subsections is preferential to Caltrans guidance where appropriate.

6.1.1 Ground Rupture

Four steps are recommended for fault and ground rupture evaluations. These steps are literature review, reconnaissance, paleo-seismic trenching, and mitigation design, as needed. For the high-speed train project, rupture of the ground surface shall be addressed at any location where a mapped or otherwise suspected Holocene fault (i.e. most recent movement within the past 11,000 years) consistent with current California regulations contained in Note 49 (CGS, 1996), SP 42 (CGS, 2007), and Note 48 (CGS, 2007). These faults are hereafter referred to as active faults. These guidelines provide minimum standards for evaluations of faults.

6.1.1.1 Compilation and Review of Available Data

Ground rupture evaluations shall commence with review of the Geologic and Seismic Hazards GIS Database that was compiled for this project. This database is in GIS format and will be made available concurrent with the issuance of this document. The database includes a Quaternary fault database, which was prepared by appending the California Quaternary fault database Bryant (2005) with fault data from the USGS National Fault Database. A second fault database was obtained for pre-Quaternary structures (CGS, 2000) and includes faults and fold geologic structures. Historic earthquakes are contained in the ANSS (2008) database. All three databases are available in GIS format.

The attributes contained in the appended fault database include the fault name, displacement behavior, length, reference number (relative to CGS and USGS external databases), age of faulting, length of most recent rupture segments, slip rate, and dip direction. The attributes contained in the appended ANSS earthquake database include date (year, month, day, hour, second), location (latitude/longitude), and magnitude. Although these databases are comprehensive, local faults or splays, and unrecorded earthquake data may be missing. As such, research along specific alignments shall include review of local geologic maps and reports, including review of CGS Fault Evaluation reports (FER) where available.

These databases shall be reviewed as a screening evaluation to identify all possible active faults within one mile of any design element of the CHSTP. The ANSS database has been included to identify potential seismic alignments where unmapped or otherwise unknown faults may exist in proximity to the CHSTP elements. A pre-Quaternary fault database is included to allow identification of pre-Quaternary faults that may have Quaternary activity elsewhere along a tectonically related structure. Collectively, these locations shall be identified and digitized at a Program Level and disbursed to Designer for their further evaluation based on local and more comprehensive evaluation. It is provided to the Designer for initial identification and evaluation of seismic sources for development of the seismic source model (earthquake magnitude from source and distance to CHSTP system element(s) for input into developing the ground motion model and hazard curves for input to Project specific seismic design criteria.

6.1.1.2 Geologic Reconnaissance

At locations where active faulting is suspected to be coincident with or within the area of CHSTP operations and facilities, a geologic reconnaissance will be needed to ground-truth mapped fault traces. This reconnaissance shall begin with review of available aerial photographs, LiDAR data, satellite imagery, and topographic information. The locations shall then be reviewed in the field to assess the presence of geomorphic features associated with faulting such as escarpments, pressure ridges, sag ponds, seeps/springs, vegetation contrasts, or deflected drainages. All such features shall be documented on a geologic field map. If sufficient field data is available to document that the fault or fault zone is outside of the area of high-speed train operations, no further fault evaluation is required. Otherwise, a site specific investigation possibly including paleo-seismic trenching will be necessary.

6.1.1.3 Paleo-Seismic Trenching

If existing paleo-seismic trenching data is available, it may be reviewed and used as a basis for locating the fault and providing its rupture characteristics to the design team; however, if either a known active fault or suspected active fault is located near to or at the location of a CHSTP facility, exploratory trenching across the fault may be necessary to assess its rupture characteristics for input to design. The objective of paleo-seismic trenching is to provide the Designer with fault location and rupture characteristics that may influence the design elements. In general, these characteristics may include but are not limited to location of strands with Quaternary activity, secondary zones of displacement, displacement sense of movement, displacement per event, and displacement orientation(s). This evaluation shall also address the degree of certainty of information as a basis for determining the extent of movement and locations affected.

6.1.1.4 Ground Rupture Mitigation Design

The high-speed train alignment and project facilities shall avoid all active faults to the extent possible. If these faults cannot be avoided, to the extent possible, the CHSTP system components at that location shall be designed to accommodate potential rupture including both primary and secondary rupture zones. In order to meet the CHSTP performance criteria, ground rupture will need to be mitigated to meet the Safety Performance Level (SPL) and Operability Performance Level (OPL) criteria. For the SPL, the system shall be designed to accommodate fault rupture and sustain limited structural damage such that the structure can quickly be repaired and the train operations can resume within a specified time frame. For the OPL, system elements critical to operation of the train will need to be designed so that structural damage from an earthquake where surface fault rupture occurs is minimal and trains can operate safely, at the maximum operating speed. These two performance levels are defined as the Design Basis Earthquake (DBE) and the Lower-level Design Basis Earthquake (LDBE), respectively for ground rupture. This nomenclature is adopted from the seismic design criteria in order to provide consistency between the design for earthquake and fault rupture conditions.

Buildings – Stations and Storage/Maintenance Facilities)

At a minimum, terminal and intermediate stations and other buildings key to operation of the high-speed train shall avoid active fault zones. Therefore, for surface fault displacement neither the SPL nor OPL criteria need to be achieved under these circumstances. If faults have been identified at the planned locations of stations and key operational buildings but whose most recent faulting is unknown, the fault shall be evaluated. If confirmed that the last movement was pre-Holocene mitigation would not necessarily be required.

At-Grade Track Sections

In general terms, the DBE condition can be mitigated using early warning and shutdown telemetry systems to achieve the SPL criteria. Ballast and track shall be designed to accommodate fault rupture that with allow restoration of operation within a reasonable time frame (to be defined by Project team). The LDBE can also be mitigated by design of ballast and track section to accommodate LDBE displacement. This may require alignment of track perpendicular to the fault alignment to reduce the zone of influence. Where high slip rate faults are crossed (i.e., large displacements), the rail may need to be designed so that it can readily tolerate such ground displacements or the potential range of ground displacements shall be treated probabilistically (see discussion under “Mitigation of Fault Rupture”).

Tunnels

The Basis of Design report has identified that it is desirable for the horizontal and vertical alignment to cross major fault zones at-grade without structures at active fault crossings where mitigating designs can be more cost-effectively employed. Faults shall be crossed perpendicular to reduce the extent of damage. Expert seismologists, tunnel Designers and contractors concluded that major fault crossings would require “fault chambers” that are extremely costly. However, for low slip rate faults and smaller displacements, normal tunnel design standards may accommodate limited fault displacement (maximum displacement to be determined by Designers). The Designer shall identify the presence of any major faults irrespective of age of movement in that these zones will need to be evaluated from a seepage and boring condition standpoint.

Structures – Aerial and Bridge Segments

Structures carrying high-speed trains shall avoid paralleling or crossing active fault locations. Where not avoidable, structures will need to be designed to accommodate the DBE fault displacement in a manner that allows restoration of operation in a reasonable period of time meeting the SPL performance criteria. The LDBE fault rupture will also need to be considered in the design of structures so that structural damage will be minimal or non-existent and trains can continue operating safely at the maximum operating speed.

Mitigation of Fault Rupture

Where ground rupture along active faults immediately adjacent to or crossing high-speed train system elements cannot be accommodated through design measures, fault displacement will need to be characterized probabilistically. The following displacement characteristics shall be addressed:

- Sense or direction of movement
- Orientation of displacement
- Magnitude of displacement
- Displacement history
- Rupture length and depth

These analytical results will be needed to support Probabilistic Fault Displacement Hazard Analysis (PFDHA) method to address the SPL (DBE) and OBL (LDBE) probability scenarios within the design life of the high-speed train structures. The PFDHA shall be performed in general accordance with methods described by Youngs et al (2003) and Coppersmith and Youngs (1992). The *displacement approach* method described in Youngs et al (2003) is the preferred approach. Secondary rupture shall be estimated using direct observation methods (i.e. paleo-seismic trenching) or probabilistic methods provided by Bray (2005).

6.1.1.5 Other Uses of the Ground Rupture Hazard Analyses Data

The information compiled in the preliminary fault hazard studies and the analyses performed from this hazard assessment will be used as input to the development of seismic source characterization model(s) for the quantification of vibratory ground motion hazards. The parameters from the fault hazard studies provide key input to the development of the seismic source characterization model(s) and calculation of earthquake magnitudes from those seismic sources most significant to the CHSTP system. The guidance for the seismic source characterization (SSC), ground motion characterization, and probabilistic seismic hazard analysis will be provided in the TM 2.9.6 – Ground Motion Analysis Guidelines.

6.1.2 Liquefaction and Other Seismically-Induced Ground Deformation

Liquefaction guidelines provided in SP 117 (CGS, 2008) are applicable for identifying liquefaction and other seismically-induced ground deformation for project design. Guidance for appropriate ground motion parameters to utilize in liquefaction analyses is provided in the TM 2.9.6 – Ground Motion Analysis Technical Memorandum. Quantitative liquefaction analysis methods are described in the Geotechnical Investigation and Geotechnical Analysis Guidelines Technical Memorandums. For purposes of the Geologic and Seismic Hazards Evaluations, potentially liquefiable sites shall be identified using the screening procedures described in SP 117 (CGS, 2008) and also as clarified in Southern California Earthquake Center (SCEC) (1999), “Recommended Procedures for Implementation of SP117 Guidelines for Analyzing and Mitigating Liquefaction Hazard in California.” These two guidelines generally require a conservative assessment of portions of the CHSTP that coincide with areas of present and/or future potential groundwater within 50 feet of the ground surface and the presence of Holocene deposits. Since the majority of the CHSTP footprint exists within areas of relatively high ground motions, all areas that meet this groundwater and surface earth material criteria shall be identified as potentially liquefiable requiring further investigation and analysis.

Guidelines for evaluation of lateral spreading shall also follow those available in SP 117 (CGS, 2008). Distances to open channels and other free faces shall be measured along with embankment slope heights and ratios and included in geologic and seismic hazard assessment reports for use in conjunction with liquefaction analyses. The potential for other types of seismically-induced ground deformation, such as differential compaction and seismic settlement, shall also be evaluated. Areas underlain by dry, unconsolidated sediments may be prone to this type of deformation and shall be noted in the geologic and seismic hazard report.

6.1.3 Tsunami and Seiche

Tsunami and seiche evaluation guidelines are not generally available. Potential for tsunami occurrences along the California coastline is available from the CGS, the USC Tsunami Research Center, and USGS. It shall be reviewed in conjunction with the project footprint to identify locations where potential tsunami inundation may influence operation. Similar mapping is not available for seiche. Therefore, it will be necessary for the geologic and seismic evaluation to identify any locations where large bodies of water exist or are planned upstream of the CHSTP and its components. The potential for seiche shall be discussed relative to source (landslide, fault displacement, etc.) available freeboard and general drainage conditions between the water body and high-speed train facilities.

6.1.4 Landslide and Slope Stability

The potential for reactivation of existing landslides and potentially unstable slopes shall be identified and evaluated in the geologic and seismic hazards evaluation. This evaluation shall consider static (i.e. non-seismic) as well as seismically induced slope failure potential. Existing landslide databases are presently being catalogued by the CGS and others, but are not yet available for coverage of the entire project. Guidance documents that provide evaluation guidelines for landslides and potentially unstable slopes and are applicable to the CHSTP include those from CGS, Caltrans, BGG, and SCEC. The most applicable of these guidance documents is the “Recommended Procedures for Implementation of CGS Special Publication 117 Guidelines for Analysis and Mitigation of Landslides in California” (SCEC, 2002).

The evaluations shall focus on those portions of the alignment that coincide with moderately steep or steeper topography. If potential instability exists and warrants further quantitative analysis and/or mitigation design, the Geologist shall work closely with the project Geotechnical Engineer and the guidelines for Geotechnical Investigations and Geotechnical Analyses shall be followed. Both the supervising Geologist and Geotechnical Engineer shall be experienced in landslide recognition, investigation, and mitigation.

The evaluation of landslides and unstable slopes requires four fundamental steps:

- Background research
- Field mapping and investigations
- Data evaluation
- Presentation of findings

Background research entails the use of existing documentation of mapped or otherwise recognized landslides. These data are available from the CGS, Caltrans, and generally consist of maps and databases (i.e. GIS) cataloguing known landslide locations. CGS maps showing landslides are available at the two-degree sheet detail (1:250,000) and are locally available at more detailed scale. In some instances, cities and counties have inventoried landslides and shall also be consulted. Background research also includes the evaluation of aerial photographs, LiDAR and other remote imagery and interpretation of topographic maps for evidence of landslide-related geomorphic features.

Field mapping is typically performed in advance of and independent to field investigations. Where background research identifies known or suspected landslide features, field mapping is required to confirm the presence and approximate limits of landslides. Photographs and notes are needed to document the presence or absence of landslide features observed during field mapping.

Investigation of landslides will be needed where background research and mapping suggest the presence of a landslide within the area of influence of the CHSTP design. This determination will need to be made by the Designer subsequent to any attempt to avoid the landslide hazard. The many investigation methods are clearly defined in Landslide Investigation and Mitigation Special Report 247 (TRB, 1996). Additional regulations and guidance may be available at a city or county level and shall be adhered to where available.

Data evaluation generally consists of interpretation of the landslide geometry and failure mechanism(s) including surface drainage conditions and subsurface groundwater conditions.

This evaluation shall include development of maps and cross sections providing three-dimensional interpretation of the landslide limits and conditions.

In addition to existing landslide and their potential for reactivation, unstable formations and steep terrain shall be evaluated to assess areas of potential instability. This evaluation shall not be limited to natural slopes adjacent to the alignments and or supporting facilities and stations but shall also address the potential adverse influence of construction activities such as excavations.

Reports addressing the evaluation of landslide shall effectively document the methods, findings, and interpretation of landslide geometry, failure mechanism(s), and provide general conclusions addressing the relative likelihood of reactivation.

6.1.5 Karst Terrain and Abandoned Mines

Sink holes can occur as a result of a number of types of near surface voids including mine workings and karst topography. Karst topography occurs when solution cavities develop in rock having a high solubility such as limestone, dolomite, or halite rich rock. Earth materials suspected to be susceptible to development of karst features shall be evaluated based on available geologic maps. Mine workings are generally shown on USGS topographic quadrangles and have been digitized by the USGS on the MRDS (Mineral Resources Database System) for the 11 western U.S. states including California (USGS, 2002). While this database does not address the potential for surface deformation or collapse of mine workings, it does provide a comprehensive listing in GIS format of all known and documented mine facilities.

Guidance provided for karst terrain and abandoned mines evaluation is based on CGS Note 48 (2007). If an area of known or suspected karst terrain or mine workings is suspected, it shall be further reviewed based on available literature and maps and field reconnaissance. If present, the conditions shall be identified by maps and cross sections and communicated to the Designer. If the feature(s) cannot be avoided, detailed investigation and geotechnical analysis of the subsurface voids and overlying soil and/or rock will be required. This analysis shall address the ability of the overlying roof soil and/or rock to bridge over the feature given the design load conditions. These analyses would also be needed when designing possible mitigations to protect the construction and operation of the high-speed train from the collapse of subsurface voids.

6.1.6 Volcanic Hazards

For purposes of the CHSTP, there are several California volcanic hazard zones (USGS, 1998) including the Cascade, Lassen Peak, Clear Lake, Long Valley-Mammoth, Amboy Crater, and the Salton Buttes. These volcanic centers appear to be sufficiently removed from the CHSTP footprint and likely do not pose a hazard to the HST system: however, this shall be confirmed in subsequent evaluations. Guidelines for the evaluation of volcanic hazards in California are not well defined. CGS (2001) Note 52 indicates that evaluation of volcanic hazards shall include an evaluation of the potential for lava flow, ash fall, and volcanic eruption. CGS (2007) Note 48 Checklist for the Review of Engineering Geology and Seismology Reports for California Public Schools, Hospitals, and Essential Services Buildings provides a brief explanation of evaluation guidelines and expectations. This guidance emphasizes the use of existing literature and maps identifying the location of known or potential volcanic hazards. Since the high-speed train alignment is not in close proximity of known active volcanic centers, the only potential volcanic hazard to consider is that of ash fall. This potential hazard shall be addressed by determining the expected accumulation of ash at the nearest HST facility based on existing information, analog studies of field observations. If there is a potential for accumulation of ash then that shall be reported in the technical documentation.

6.1.7 Soil and Rock Erosion

Erosion of soil and/or rock due to runoff, stream flow, wave action, or severe wind could remove soil and rock support for infrastructure components and have adverse affects on the CHSTP. This includes potential cases where the alignment may parallel a water course, and high water could erode the side embankment of the riverbed threatening or undermining the trackbed by sustained or cumulative erosion. Because this condition requires an understanding of both the soil and rock conditions as well as the runoff and drainage conditions, it will be imperative that this evaluation is performed with a hydrologist and the Designer. The evaluation of erodible soil and rock shall be initiated by defining locations where drainage remains uncontrolled coincident with exposed soil or rock such as natural drainages, bridges, and coastal locations adjacent to project facilities. Scour analysis is not considered in this technical memorandum and will be assessed independently. The preliminary erosion/scour evaluation shall provide an initial evaluation of soil and rock conditions where flow/wave action is anticipated and shall qualitatively address the soil or rock parameters provided by Annandale (1995) as a screening process. If qualitative evaluation suggests erosion/scour is highly unlikely given conservative assumptions, no further action will be required. If the potential cannot be ruled out, subsequent erosion/scour analyses is required to quantify the potential and, if needed, the design of armament systems.

6.1.8 Land Subsidence

Land subsidence is unique from other potential geologic hazards in that it is a long term condition that is not likely mitigated at a project level. Subsidence in California has been induced by withdrawal of petroleum and gas or groundwater and in some instances compaction of organic rich sediments that have decayed with time, such as in the Delta region. Although the majority of subsidence has ceased or decelerated significantly, some subsidence continues in the Central Valley and Delta regions. This may be of consequence since such subsidence would have long term influence on the surface elevation of track and supporting facilities and therefore shall be further evaluated on a local basis. The evaluation shall begin with a review of records documenting ground surface subsidence and shall generally focus on those areas of historic subsidence as shown on maps provided by Ireland (1966).

Regulatory guidance for the evaluation of subsidence is not available. CGS Note 48 (2007) provides a cursory discussion of evaluation methods. In most instances, subsidence has not historically occurred or has strong documentation for cessation in recent history and a strong case can be made for the absence of subsidence during the project life expectancy. Locations where future subsidence cannot be ruled out shall be carefully evaluated with available geodetic information and an estimate of future subsidence potential and rate shall be assessed for the affected CHSTP element’s tolerance to this settlement.

6.1.9 Collapsible Soil

Collapsible soils are those soils that tend to undergo rapid consolidation when wetted (i.e. hydro-consolidation). A number of publications and maps identify areas where these soils are most likely to occur. Collapsible soils are generally located in arid climate areas where soils have not experienced high moisture contents and debris flow deposits where soils were deposited rapidly. Based on a review of publications, the potential occurrence shall be evaluated from a geologic perspective and identified for further investigation and analysis by the Geotechnical Engineer.

6.1.9 Expansive Soils

Expansive soils will be evaluated during geotechnical investigations as defined in the Geotechnical Investigation Guidelines. Expansive soils are known to coincide with high plasticity and fine grained clays typical to delta, lacustrine, and marine deposits that shall be qualitatively identified by the geologic and seismic hazards evaluation. Locations where these types of deposits may occur shall be identified in the geologic and seismic hazards evaluation report and communicated to the project Geotechnical Engineer.

6.1.10 Hazardous Minerals

Hazardous minerals evaluations shall consider the potential occurrence of naturally occurring asbestos (NOA), mercury, or radon. NOA tends to occur in mafic or ultramafic rock or sediments derived from ultramafic rock. The CGS (2008) website provides currently available maps depicting the extent of NOA where it is most likely to occur. Evaluations shall be performed in accordance with CGS (2002) Special Publication 124 for geologic evaluations of NOA. Threshold values and mitigation requirements are provided by the California Air Resources Board (CARB) for quarrying, earthwork, and surface mining operations in the Asbestos Airborne Toxic Control Measure (ATCM, 2004).

Natural sources of mercury include volcanoes, hot springs, and natural mercury deposits. Sources related to human activities include coal combustion, waste incineration, certain industrial activities and some mining activities. Guidance for mercury evaluation is provided by CGS (2008) and threshold values and mitigation is provided by the USGS in the report, “Mercury in the Environment (USGS, 2000).”

Radon gas is a naturally-occurring, radioactive gas that is invisible and odorless. It forms from the radioactive decay of small amounts of uranium and thorium naturally present in rocks and soils. Radon gas may be harmful if concentrated in enclosed spaces where ambient conditions are not available to disperse the gas. Radon is most commonly associated with plutonic rocks and shale. Information addressing the locations where radon is most likely to occur is provided by the CGS (2008) and further regulatory information is provided in Geologic Controls on the Distribution of Radon in California (California Department of Health Services, 2003).

6.1.11 Flood Hazard and Dam Inundation

Areas of potential flood hazard have been mapped by FEMA (2008) Flood Insurance Rate Maps (FIRM) and shall be reviewed and summarized in the geologic and seismic evaluation report. These locations shall be communicated to the project hydrologist for further quantitative evaluation, as needed. FIRM maps are available at the FEMA Map Service Center on the internet at http://msc.fema.gov/. Dam inundation maps are available from various sources and can be obtained for most areas. Such maps are commonly available in city and county general plans as part of their safety elements. Areas of potential dam inundation hazard shall be reviewed and summarized in the geologic and seismic evaluation report.

6.2 GEOLOGIC AND SEISMIC HAZARDS GIS DATABASE

The geologic and seismic hazards addressed herein will be accompanied by a Geospatial Database that provides uniform, project-wide data intended for use by Designers in conjunction with this Technical Memorandum. In general, this GIS Database includes:

- Active Fault and Related Source Characteristics
- Pre-Holocene, Inactive Faults Locations
- Statewide Landslides
- Geologic and Soil Units
- Statewide Groundwater Depths
- Potential Tsunami Locations
- Soil Profile Types
- Volcanic Hazards
- Hazardous Minerals (e.g. Naturally Occurring Asbestos)

These data are contained within the Geologic and Seismic Hazards GIS Database,located on the ProjectSolve website:

https://ww2.projectsolve2.com/eRoom/SFOF/CAHSRProgramMgmt/0_66e71

6.3 GEOLOGIC AND SEISMIC HAZARD EVALUATION REPORTS

Geologic and seismic hazard reports shall be prepared to summarize data, methodologies, analysis, and conclusions. Geologic and seismic hazard evaluation reports shall be prepared in advance of other geotechnical reports in order to provide a geologic framework for future geotechnical studies. Reports shall be prepared in a manner consistent with CGS Note 52 (2001); BGG (1998); AEG (1993) guidance for preparation of geologic, engineering geologic, and geophysical reports; and in general accordance with Chapter 7 of Standard Environmental Reference (SER) addressing topography, geology, seismic, and soils studies (Caltrans, 2007). In accordance with these guidance documents, all geologic and seismic hazard evaluation reports shall be prepared under the direct supervision and bearing the signature and stamp, of a California licensed Professional Geologist (PG) or Certified Engineering Geologist (CEG). Geologic and seismic hazard evaluation reports shall be reviewed by similarly qualified geologists and engineering geologists based on the above-referenced guidance documents and CGS (1986) Note 41 Guidelines for Reviewing Geologic Reports. Because the hazard reports will be relied upon by Geotechnical Engineers, they shall also be reviewed by the project Geotechnical Engineer.

For consistency with the ground motion analyses, the results of geologic and seismic hazard evaluations shall be provided to the Geotechnical Engineer and seismic design engineer for their evaluation at a quantitative level as input to the geotechnical investigation and analysis progresses. In addition, the preparation of geotechnical reports shall utilize the information contained in these geologic and seismic hazard evaluations from a qualitative standpoint and shall address how the geologic and seismic hazards have been both quantified and determined to be inconsequential to the high-speed train performance, or the method of in-situ and/or project mitigations employed. The Geotechnical Engineer will evaluate each of the identified geologic or seismic hazards to determine whether they are within the tolerance of the CHSTP elements. If these hazards are found to exceed project tolerances, subsequent and more detailed analysis is warranted and shall be performed by the responsible Geologist and project Geotechnical Engineer. This will ensure that geotechnical investigations and analyses performed under separate guidance are consistent with characterized geologic conditions and hazards.

The results of each Geologic and Seismic Hazard Evaluation shall be summarized in a Geologic and Seismic Hazard Evaluation Report. Following is a general report format that can be used for report preparation:

- An introduction, including the scope of work, project description, site description, and summary of previous investigations (if any);
- A summary of the regional and local geologic and seismic conditions, providing descriptions of local geologic units, geologic structure, faulting, historical seismicity, landslides, and groundwater conditions;
- A summary of geologic and seismic hazards that have the potential to adversely impact the project;
- Conclusions regarding the impact of identified hazards and potential mitigation measures;
- Recommendations for future studies, and
- A list of references.

In addition, each report shall include a site location map, regional and local geologic maps, geologic cross-section(s), and other maps and figures where deemed appropriate. Faults depicted on the geologic maps shall coincide with those from the CHSTP database. Discrepancies between the CHSTP database and the results of the study shall be presented in the hazard evaluation report.