California High-Speed Train Project

TECHNICAL MEMORANDUM

Geologic and Seismic Hazard Analysis Guidelines
TM 2.9.3

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Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to:

- Ensure technical consistency and appropriateness
- Check for integration issues and conflicts

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

System Level Technical Reviews by Subsystem:

Systems:	_Not Required___________________ Rick Schmedes	___________ Date
Infrastructure:	Signed document on file_____________ Bob Valenti	20 Jun 11 Date
Operations:	_Not Required___________________ Joe Metzler	___________ Date
Maintenance:	_Not Required___________________ Joe Metzler	___________ Date
Rolling Stock:	_Not Required___________________ Frank Banko	___________ Date

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ABSTRACT

This technical memorandum (TM) provides guidance for geologic and seismic hazard screening evaluations based primarily on existing guidance documents and key references. The evaluations are intended to be performed using existing geologic and seismic hazards data and during the 15% design stage. These guidelines supplement other guidelines and references, where applicable.

These guidelines are generally consistent with other key guidance documents prepared by the California Board of Geologists and Geophysicists, California Geologic Survey (CGS), and California Department of Transportation. All geologic and seismic hazards reports shall be prepared under the direct supervision of and signed by a California Certified Engineering Geologist and in close collaboration with the responsible Geotechnical Engineer (GE) of record. Based on the above key references, geologic hazards and hazardous minerals addressed herein include:

- Surface rupture along hazardous faults
- Liquefaction and other seismically induced ground deformation
- Tsunami or seiche
- Static and seismically triggered and slope stability
- Karst terrain and abandoned mines
- Volcanic hazards
- Erosion
- Land subsidence
- Collapsible soils
- Expansive soils
- Hazardous minerals

This TM has been prepared to supplement other available data developed during the programmatic environmental impact report (PEIR) in advance of the 15% design process and provides guidance on methods for identifying and evaluating the geologic and seismic hazards. For more specific guidance on geotechnical design or ground motion analyses, refer to other related technical guideline memoranda.

1.0 INTRODUCTION

1.1 PURPOSE OF TECHNICAL MEMORANDUM

The purpose of this 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 on 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)
- Federal Emergency Management Agency (FEMA)

This TM 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
- TM 2.9.10 - 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 (CHSTP) 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):

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

Expansive Soils	Soils that undergo swelling and shrinkage when wetted and dried
Hazardous Fault	A fault that meets the following criteria: ≥ 1.0 mm/year Slip Rate (SR) and/ or ≤ 1,000 year Recurrence Interval (RI)
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
Liquefaction	Reduction of soil strength because of excess pore water pressure due to earthquake ground shaking when saturated
Potentially Hazardous Fault	Fault having known or documented Holocene activity or known Quaternary faults with suspected Holocene activity
Seismic Hazards	Earthquake-induced conditions such as vibratory ground motion, liquefaction, lateral spreading, dynamic compaction, seismically induced slope failures, and ground rupture
Slope Failures	Mapped or otherwise known slope failures such as rock falls, mud flows, debris flows, landslides, and other forms of slope failures
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 CHSTP is based on United States Customary Units consistent with guidelines prepared by the California Department of Transportation and defined by the National Institute of Standards and Technology (NIST). U.S. Customary Units are officially used in the United States and are also known in the U.S. as “English” or “Imperial” units. In order to avoid confusion, all formal references to units of measure shall be made in terms of U.S. Customary Units.

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 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 TM. In general, these include the input to the design of system elements to accommodate or mitigate:

- Surface rupture along hazardous faults
- Liquefaction and other seismically induced ground deformation
- Tsunami or seiche
- Static and seismically triggered and slope stability
- Karst terrain and abandoned mines
- Volcanic hazards
- Erosion
- Land subsidence
- Collapsible soils
- Expansive soils
- Hazardous minerals

Other geologic and seismic hazards such as potential seismically induced lateral spreading and 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 TM; 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 TM 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 TM.

2.1.3 Codes, Regulations, and Applicable Guidelines

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

The California Building Code (CBC) 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 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 CGS guidance documents. Guidance provided by 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 PEIR/S when geologic, soils, and seismic hazards were mapped using geographic information system (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, United States Geological Survey (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 high speed train (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 will 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 cannot 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 cannot 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 TM shall be reviewed prior to evaluating the geologic and seismic hazards associated with this project. 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/
24. FEMA, 2008, Flood Insurance Rate Maps (FIRM), http://msc.fema.gov/
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 prior to completion of 15% design and in advance of quantitative geotechnical and seismic hazard analyses and mitigation design. The guidance provided in this TM is principally for screening potential geologic hazards. This will enable designers to develop investigation and analysis program work plans based on a broader understanding of local geologic or seismic hazards that may impact the design elements of the CHSTP. Geologic and seismic evaluations shall be performed under the direct supervision of a Certified Engineering Geologist (CEG) and also a California registered GE qualified in the specific geologic hazards being evaluated. Geologic and seismic hazards 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

Data specific to the design segment shall be based on the data developed during the PEIR process augmented but newly discovered, localized information of higher quality.

Where possible, interpretation of geologic and/or seismic hazards shall be based largely on their significance to the vulnerability (risk) of the varying design features for each design component. With each iteration of a design feature, the risk from an identified seismic hazard may vary.

Although initial assessment and identification of ground rupture and seismic sources are discussed in this document, quantitative evaluation of ground motions and seismic design criteria as well as estimation of fault displacement to meet the CHSTP performance criteria are addressed in other TMs. Quantitative analysis and mitigation design of hazards such as liquefaction or slope stability to address the hazards and significance to design features are addressed separately. Because of the close relationship between these quantitative analyses and geologic and seismic hazard evaluations, it is critical that the qualified individuals responsible for the geologic and seismic hazards evaluations be included in any decisions and subsequent evaluations that rely on these data. This includes review of key documents and findings related to how these hazards are treated in the design of the system elements.

6.1.1 Potentially Hazardous and Hazardous Fault Classifications

These guidelines address faults and fault zone displacement. The hazard of fault displacement is distinguished from other tectonically induced ground deformation processes such as broad-surface warping and folding. Fault displacement may occur as a single-principle fault trace or as distributive faulting in a fault zone. The identification and characterization of fault hazards relative to ground rupture is an iterative process beginning with the identification of potentially hazardous faults. “Potentially hazardous” faults are defined as those faults either having known or documented Holocene activity or known Quaternary faults with suspected Holocene activity. These faults are largely identified in the National Fault Database available through the USGS and/or CGS and should be further evaluated based on available, local information such as Fault Evaluation Reports (FERs) and existing paleoseismic data. Potentially hazardous faults will be considered screening-level faults requiring further consideration in evaluating their impact on the proposed project design elements.

A “hazardous” fault is defined as a potentially hazardous fault that has slip rates or recurrence intervals that are documented in peer-reviewed reports and that have the following hazardous fault criteria:

- ≥ 1.0 mm/year Slip Rate (SR)
- ≥ 1,000 year Recurrence Interval (RI)

All potentially hazardous and hazardous faults shall be identified as early in the 15% design process as possible and communicated to the design and program team in order to consider the possible impacts to each of the possible design elements affected within the vicinity of the hazardous fault. If data are available to make a definitive conclusion that a potentially hazardous fault should be defined as a hazardous fault or not, then it shall be made during the 15% design phase. Other potentially hazardous faults identified during the 15% design phase shall be characterized during the 30% design phase. Hazardous faults shall be characterized and mitigated in accordance with the Fault Displacement Evaluation and Mitigation Guidelines contained in the most recent version of TM 2.10.6.

6.1.2 Liquefaction and Other Seismically Induced Ground Deformation

Guidelines for screening level or qualitative evaluation of seismic hazards are provided here. Liquefaction guidelines provided in SP 117 (CGS, 2008) are applicable for identifying potentially liquefiable areas. Where liquefaction zones have been identified by the CGS, the designer shall address this potential in the project design unless or until physical subsurface data can be obtained and analyzed in accordance with the methods described in TM 2.9.10, Geotechnical Analysis Guidelines. For purposes of the geologic and seismic hazards evaluations, potentially liquefiable sites shall be identified using the screening procedures described in SP 117 and as clarified in Southern California Earthquake Center (SCEC, 1999), “Recommended Procedures for Implementation of SP-117 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 criterion shall be identified as potentially liquefiable requiring further investigation and analysis.

6.1.3 Tsunami and Seiche

The potential for tsunami occurrences along the California coastline is available from the CGS, the USC Tsunami Research Center, NOAA, SCEC, PEER, Doyle Drive, URS, Humbolt State, and the USGS. These hazards zones shall be assessed 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 (slope failures, 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 natural or proposed cut slopes shall be identified and evaluated in the geologic and seismic hazards evaluation. This evaluation shall consider static as well as seismically induced slope failure potential. Guidance documents that provide evaluation guidelines for landslides and potentially unstable slopes and that 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 GE, and the guidelines for Geotechnical Investigations and Geotechnical Analyses shall be followed. Both the supervising Geologist and GE shall be experienced in slope failure recognition, investigation, and mitigation.

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

1. Background research
2. Field mapping and investigations
3. Data evaluation
4. Presentation of findings

Background research includes the use of existing documentation of mapped or otherwise recognized slope failures. These data are available from the CGS and Caltrans and generally consist of maps and databases (i.e., GIS) cataloguing known slope failure locations. The CGS maps showing slope failures 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 slope failures and shall also be consulted. Background research also includes the evaluation of aerial photographs, light detection and ranging (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 slope failure 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 mechanisms, including surface drainage conditions and subsurface groundwater conditions. This evaluation shall include development of maps and cross sections providing three-dimensional interpretation of the slope failure limits and conditions.

In addition to existing landslides 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 a landslide shall effectively document the methods, findings, and interpretation of landslide geometry and failure mechanisms and shall provide general conclusions addressing the relative likelihood of reactivation.

6.1.5 Karst Terrain and Abandoned Mines

Sink holes are surface manifestations of near-surface openings/voids/cavities that have collapsed. They can occur as a result of mine workings and karst features. Karst topography (area of sink holes) occurs when solution cavities develop in rock having a high solubility such as limestone, dolomite, gypsum, or halite-rich rock, and a pathway to the surface is established. 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 Mineral Resources Database System (MRDS) for the 11 western United 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, maps, and field reconnaissance. If present, the conditions shall be identified by maps and cross sections and shall be communicated to the designer. If the features 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 HST 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 Note 52 (2001) indicates that evaluation of volcanic hazards shall include an evaluation of the potential for lava flow, ash fall, and volcanic eruption. CGS Note 48 (2007) 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 HST 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 and analog studies of field observations. If there is a potential for a significant accumulation of ash that may impact HST operations, the potential hazard should be reported in the technical documentation.

Geothermal activity is another hazard associated with volcanic areas, but hot ground and hot springs can also be associated with faults in California. Although isolated, geothermal activity associated with faults is hazardous for underground excavations and must be identified and taken into consideration for construction and design.

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 could have adverse effects 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, thereby 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 TM 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 address qualitatively 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 are 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 typically a design factor in other projects. However, given the tight design and track tolerance of the CHSTP, this hazard will warrant more in-depth consideration. Subsidence in California has long been recognized in areas of withdrawal of petroleum, gas, groundwater, and/or, in some cases, settlement 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. Recent USGS studies utilizing Interferometric Synthetic Aperture Radar (InSAR) remote sensing methods have identified several regions where ground subsidence of as much as 5 centimeters per year (cm/yr) continues to occur. This degree of subsidence could substantially influence the long-term (i.e., 100-year design life) of the CHSTP and shall be addressed in the geologic and seismic hazards evaluations as well as by the designer in assessing the impact to the CHSTP design.

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 low moisture content and on debris flow deposits where soils were deposited rapidly and have not achieved natural compaction. 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 GE.

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 GE.

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 Special Publication 124 (2002) 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, oil field operations, and some mining activities. Guidance for mercury evaluation is provided by CGS (2008), and threshold values and mitigation are 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).

Other gases can be hazardous in excavations and underground openings and commonly include the following: methane (CH_4), hydrogen sulfide (H_2S), carbon monoxide (CO), carbon dioxide (CO_2), and ethane (C_2H_6). These gases can derive from geologic formations containing coal beds, oil and sulfide minerals, swampy ground, or other sources of decomposing organic materials.

6.2 GEOLOGIC AND SEISMIC HAZARD EVALUATION REPORTS

Geologic and seismic hazards reports shall be prepared to summarize data, methodologies, analyses, and conclusions. Geologic and seismic hazards 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 CEG. Geologic and seismic hazards evaluation reports shall be reviewed by similarly qualified geologists and engineering geologists based on the above-referenced guidance documents and CGS Note 41 Guidelines for Reviewing Geologic Reports (1986). Because the hazards reports will be relied on by GEs, they shall also be reviewed by the project GE.

For consistency with the ground motion analyses, the results of geologic and seismic hazard evaluations shall be provided to the GE 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 HST performance, or the method of in-situ, and/or project mitigations employed. The GE 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 GE. 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 hazards evaluation shall be summarized in a report entitled Geologic and Seismic Hazards Evaluation Report and shall be submitted accompanying the Geotechnical Data Report (GDR) along with an updated database and the proposed work plan for future investigation and analysis activities, in accordance with TM 2.9.2 Geotechnical Report Guidelines.

- 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, slope failures, 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
- 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 as 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.