California High-Speed Train Project

TECHNICAL MEMORANDUM

Geotechnical Investigation Guidelines
TM 2.9.1

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0	20 May 09	Initial Release
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Note: Signatures apply for the latest technical memorandum revision as noted above.

Prepared by PB

for the California High-Speed Rail Authority

System Level Technical and Integration Reviews

The purpose of the review is to:

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

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

System Level Technical Reviews by Subsystem:

Systems: Not Required ________________________ ______________
Rick Schmedes Date

Infrastructure: Signed Document on File ______________ 08 June 11
Bob Valenti Date

Operations: Not Required ________________________ ______________
Paul Mosier Date

Maintenance: Not Required ________________________ ______________
Paul Mosier Date

Rolling Stock: Not Required ________________________ ______________
Frank Banko Date

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ABSTRACT

Considerable geotechnical site characterization, including exploration and field and laboratory testing, is required for design and construction of the California High-Speed Train Project (CHSTP). In addition to the existing geologic, geotechnical, seismic, soil and rock, and groundwater information available for California, additional site-specific subsurface data will be needed for design and construction of the project. It is important that geotechnical practitioners responsible for planning and conducting geotechnical investigations use standardized methodology, terminology, and procedures to maintain consistency in geotechnical investigations and reporting practices. This consistency will facilitate collaboration among technical and design teams throughout the design and construction stages of the project.

Geotechnical investigation elements subjected to these guidelines and standards include:

- Field preparation
- Field exploration
- Laboratory testing
- Design documents

Recommendations for subsurface exploration methods, in-situ testing, and laboratory testing of samples as part of geotechnical investigations shall be provided on the basis of these guidelines and systems. In addition to soil and rock identification, testing, description, or classification, this technical memorandum (TM) contains instructional guidelines that present project standards on identification (e.g., for test bores, sampling, testing) and subsurface log presentation formats.

The data collection efforts associated with these activities shall occur during the design phases of the project and shall build on existing information. Geotechnical investigations during preliminary engineering are required to validate the preferred alignment, establish the location and type of aerial or underground guideways, prepare construction cost estimates, and support design-build bidding. Supplemental geotechnical investigation activities will be necessary for the final engineering design phases. All geotechnical investigation and laboratory data shall be identified in a geotechnical database and updated as new data becomes available.

The subsurface exploration and laboratory testing programs shall be carefully planned to ensure that the information collected in the field and the laboratory will be sufficient to develop subsurface soil and rock properties for phased design, bidding, and construction. Since the selection of sampling and testing methods will be driven by project and geologic conditions, critical project-related issues must be understood prior to field and laboratory planning activities.

The geotechnical investigations are interdependent within the geotechnical discipline to other analyses, reporting, and evaluation tasks that are performed during preliminary design. These geotechnical investigation guideline standards supplement associated criteria for geologic and seismic hazards exploration, and additional guidelines specific to tunnel segments are provided in separate technical memoranda.

1.0 INTRODUCTION

The importance and benefit of performing adequate geotechnical investigations and preparing geotechnical reports cannot be overstressed. The geotechnical information communicates the site and subsurface characterization conditions as well as design and construction recommendations to the design and construction personnel. The geotechnical information is referred to frequently during design, construction, and after completion of the project in resolving claims or for operational issues that are geotechnical related. This TM describes the link of geotechnical investigations with other contract documents, including reports, design plans, specifications, and databases in order to promote compatibility among contractual documents for the project.

In order to provide a consistent and dependable design, it is important that the project use a standardized investigation approach, as well as reporting and documentation practices and procedures across all project segments. Uniformity and consistency for geotechnical investigation methods and documents will facilitate interface and sharing among technical and design teams throughout the design and construction stages of the project. The geotechnical investigations and reports must be prepared by knowledgeable personnel with considerable geotechnical, geological, design, and construction experience relevant to the project.

1.1 PURPOSE OF TECHNICAL MEMORANDUM

This TM reviews best practices and provides guidelines for uniform geotechnical investigation methodologies for the CHSTP. The guidance in this document is intended to accompany the supplemental investigation guidance for geologic and seismic hazards evaluation and tunneling investigations that are provided in separate documents.

The information presented in this TM is based predominantly on established standards (e.g., American Society for Testing and Materials [ASTM]) and other reference publications. These references provide standardized methods for collecting, identifying, describing, classifying, and testing soil and rock; however, they do not always provide adequate descriptive terminology and criteria for identifying soil and rock for engineering purposes. Consequently, this manual extends, and in some cases modifies, these standards to include additional descriptive terms and criteria.

Geotechnical investigation elements subjected to these guidelines and standards include:

- Field preparation (work plans, permits, etc.)
- Field exploration
- Laboratory testing
- Report documents

Efforts have been made to present the general state of the practice of subsurface exploration and geotechnical site characterization. As the procedures discussed in this TM are subject to some local variations, the practitioners should become thoroughly familiar with the local practices. This guidance document focuses on the scope and specific elements of geotechnical investigation programs for design and construction of high-speed train (HST) infrastructure and facilities. The information collected in the investigation (existing data, field explorations, laboratory tests, etc.) will be presented in the Geotechnical Data Report (GDR), which will serve as the basis for developing the Geotechnical Baseline Report (GBR). Guidelines for preparing the geotechnical reports are presented in a separate technical memorandum.

1.2 GENERAL INFORMATION

For this TM, efforts have been made to present the general state of the practice of performing geotechnical Investigations. The information presented in this TM is based predominantly on documented well-known methodologies and other established reference publications and standards. These references provide generally accepted methods of geotechnical explorations and laboratory testing. Recommendations for subsurface exploration methods, in-situ testing, and laboratory testing of samples as part of geotechnical investigations for the HST project will be provided on the basis of these existing guidelines and standards. The information in this TM extends and, in some cases, modifies these common geotechnical investigation methods to include additional criteria. In addition to soil and rock identification, testing, description, or classification, this TM contains instructional guidelines that present project standards on identification (e.g., for test bores, sample) and subsurface log presentation formats.

1.2.1 Definition of Terms

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

<u>Acronyms</u>

AASHTO	American Association of State Highway and Transportation Officials
AREMA	American Railway Engineering and Maintenance of Way Association
ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CEG	Certified Engineering Geologist
CFR	Code of Federal Regulations
CGS	California Geological Survey
Authority	California High-Speed Rail Authority
CHST	California High-Speed Train
CHSTP	California High-Speed Train Project
CPT	Cone Penetration Test
EIR	Environmental Impact Report
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GBR	Geotechnical Baseline Report
GDR	Geotechnical Data Report
GE	California Registered Geotechnical Engineer
GTGM	FHWA Geotechnical Technical Guidance Manual
IEEE	Institute of Electrical and Electronics Engineers
ISRM	International Society for Rock Mechanics
LOTB	Logs of Test Borings
MPH/mph	Miles per hour
NHI	National Highway Institute
NIST	National Institute of Standards and Technology
PCPT	Piezocone Penetrometer Test
PDDM	FHWA Project Development and Design Manual
PS&E	Plan Specification and Estimate
SPT	Standard Penetration Test
TM	Technical Memorandum
USCS	United Soil Classification System
USGS	United States Geological Survey
VST	Vane Shear Test

1.2.2 Units

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

2.0 DEFINITION OF TECHNICAL TOPIC

2.1 GENERAL

The focus of phased geotechnical investigations and reports that provide input for design, construction, and long-term maintenance support is for avoidance and mitigation of major geologic hazards and to ensure that the soil and/or rock underlying and alongside the CHSTP alignments can support the loads and conditions placed on them by project infrastructure facilities. The geotechnical investigations for the project definition phase shall be performed to provide recommendations for conceptual alignments and feasibility studies and for developing project cost estimates. Geotechnical investigations during preliminary engineering are required to validate the preferred alignment, establish the location and type of aerial or underground guideways, prepare construction cost estimates, and support design-build bidding. Supplemental geotechnical investigation activities will be necessary for the final engineering design phases. Key components of the geotechnical design for the preliminary design phase of the project include investigations to identify potential fatal flaws with the project alignment, potential constructability issues, and geotechnical hazards such as earthquake sources and faults, liquefaction, landslides, rockfall, and soft ground. Geotechnical design shall provide conceptual hazard avoidance or mitigation plans to address the identified geotechnical issues. An assessment of the effect geotechnical issues have on construction staging and project constructability, cost, and schedule can be made at this time.

2.1.1 CHSTP Design Considerations

Once the preliminary project elements and alignments for the alignments are established, the geotechnical designer will perform phased subsurface investigations to assess feasible foundation types, cut and fill slopes, retaining wall types, and other key geotechnical and/or structural design features such as embankment foundations, tunnels, tunnel portals, culverts, bridge and embankment scour, and to establish the final right-of-way and easement needs for the project. Recommendations for preliminary and final design and construction, as well as special provisions and plan details to incorporate the geotechnical design recommendations as the project advances through various design levels, are provided in the geotechnical memoranda and reports based on results of phased geotechnical investigations and testing.

2.2 LAWS AND CODES

There is no existing law, code, or design standard that can be followed in the development of GBRs for the CHSTP. The Federal Railroad Administration (FRA) does not regulate the preparation of geotechnical reports, and the European Technical Specifications for Interoperability (TSI) do not define requirements for preparing geotechnical reports.

The development of these geotechnical investigation guidelines was based on review and assessment of available information, including the following:

- Existing ASTM standards and guidelines per Federal Highway Administration (FHWA), Caltrans, and American Railroad Engineering and Maintenance of Way Administration (AREMA)
- Existing vendor source guidelines including but not limited to gINT (for subsurface logs and laboratory tests) and global positioning system (GPS)

A listing of references considered in preparation of this memorandum is included in Section 5.0.

In the case of differing values or conflicts in the various requirements, the standard followed shall be that which results in the highest level of satisfaction for all requirements or that is deemed as the most appropriate by the Authority. The standard shall be followed as required for securing regulatory approval.

3.0 ASSESSMENT AND INVESTIGATION REQUIREMENTS

By considering the data from geotechnical investigations which will be presented in phased geotechnical reports, participants to the project are provided with an understanding of the key project geologic conditions that contributed to identifying the geotechnical issues and constraints that then shaped the design and construction requirements. With this background, they are better prepared to understand the rationale behind the requirements of the drawings and specifications, and better prepared to offer innovative ideas for improvements in the form of value engineering change proposals. In some cases, an accepted value engineering change proposal could warrant a modification to the baseline(s) in the geotechnical reports.

A California registered Geotechnical Engineer will perform the geotechnical investigations and prepare the GDR document that contains the factual information data that has been gathered during the initial exploration and preliminary design phases of the project. A Certified Engineering Geologist shall collaborate with the Geotechnical Engineer for geotechnical investigation. Further discussion of the content and format of GDR is described in a separate technical memorandum.

3.1 GUIDING POLICIES

Geotechnical work shall be performed in accordance with the geotechnical and engineering geology policies presented in Section 2.1 of the Geotechnical Technical Guidance Manual (GTGM) reference, including the following:

- Meet the technical requirements defined by the CHST design guidelines and criteria, and this TM.
- Advance the state of practice by seeking and implementing new technology.
- Demonstrate environmental stewardship in investigations and designs.
- Demonstrate financial, cultural, and natural resource stewardship.
- Conduct work safely and seek safety improvement solutions.
- Achieve quality through established quality assurance and oversight procedures.

The geotechnical investigations are interdependent within the geotechnical discipline to other analyses, reporting, and evaluation tasks that are performed in accordance with separate technical memoranda, including TM 2.9.2, Geotechnical Report Preparation Guidelines, TM 2.9.3, Geologic and Seismic Hazards Evaluations, and TM 2.9.6, Ground Motion Analyses. Because these are interdependent, it will be essential that these TMs are available and reviewed by the project geotechnical engineer.

3.2 COMMENTARY ON STANDARDS AND KEY REFERENCES

This TM presents standards and standard practices addressing investigation, sampling, and testing to achieve the guiding principles of the referenced policies. This TM recognizes that standards are not always appropriate for geotechnical work and can lead to inefficient design, insensitivity to the context of the project, and lack of innovation. Deviations from the standards should be justified, and impacts on risk management, quality, and efficiency should be addressed.

Established standards and geotechnical guidelines do not exist for HST projects. FHWA manuals are considered the most comprehensive and applicable guideline documents for geotechnical investigation for the CHSTP as well as federal transportation projects. Caltrans Soil and Rock Logging, Classification, and Presentation Manual (2010) is also applicable, although its use is primarily limited to highway- and bridge-type projects. While many of the HST infrastructure elements are somewhat similar to those for highway projects or other commercial and commuter rail projects, some specialized features and performance criteria for such major heavy-civil works needed for HST infrastructure require higher standards in some areas. For example, the HST operation has lower tolerance with respect to embankment settlement or heave from expansive soils.

Chapter 6 of the 2008 FHWA Project Development and Design Manual (PDDM) provides an overview of practice for geotechnical work and direction for understanding policies and standards for geotechnical work performed by the Federal Lands Highway (FLH). The PDDM also provides a portal to technical information and presents a high-level source of technical guidance with regard to what needs to be accomplished. The corresponding 2007 FHWA Geotechnical Technical Guidance Manual (draft GTGM) provides guidance as to how the work should be done. The draft GTGM also provides guidance for activities where standards and standard practices do not exist and provides access to and guidance for the use of new technologies.

4.0 SUMMARY AND RECOMMENDATIONS

The guidelines and requirements for geotechnical investigations are presented in Section 6 of this TM.

5.0 SOURCE INFORMATION AND REFERENCES

The development of the geotechnical investigation guidelines and geotechnical report requirements was based on a review and assessment of available information, including the following:

1. AASHTO, Manual on Subsurface Investigations, MSI-1, 1988
2. AASHTO, Standard Recommended Practice for Decommissioning Geotechnical Exploratory Boreholes, AASHTO R 22-97, standard Specifications, 2005
3. AASHTO, Specification for Transportation Materials and Methods of Sampling and Testing, Part II: Tests, HM-28-M, 2008
4. American Society of Civil Engineers (ASCE) reference titled "Geotechnical Baseline Reports for Construction – Suggested Guidelines", ASCE 2007
5. AREMA, American Railway Engineering and Maintenance of Way Association – Manual for Railway Engineering, 2008 Edition
6. ASTM, Annual Book of ASTM Standards, 2008 Edition
7. Caltrans, Soil and Rock Logging, Classification, and Presentation Manual, June 2007
8. Cornforth, D.H., Landslides in Practice: Investigations, Analysis, and Remedial/Preventive Options in Soils, Chapter 4, John Wiley & Sons 2005
9. FHWA, Geotechnical Technical Guidance Manual (Draft), May 2007
10. FHWA, Project Development and Design Manual – Chapter 6 - Geotechnical, March 2008
11. FHWA, Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications, FHWA-ED-88-053, 1988, revised February 2003
12. FHWA, Road Tunnel Design Guidelines, FHWA-IF-05-023, 2004
13. FHWA, Geophysical Methods - Technical Manual (Application of Geophysical Methods to Highway Related Problems, cooperatively with Blackhawk Geosciences), DTFH68-02-P-00083, 2003
14. FHWA, Soils and Foundations Workshop, NHI Course No. 132012, Volumes I and II FHWA-NHI-06-088, and FHWA-NHI-06-089, 2006
15. FHWA, Subsurface Investigations – Geotechnical Site Characterization, NHI Course Manual No. 132031, FHWA-NHI-01-031, 2002
16. FHWA, Evaluation of Soil and Rock Properties, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034, 2002
17. FRA, High-Speed Ground Transportation Noise and Vibration Impact Assessment, FRA Report No. 293630-1, December 1998
18. ISRM, Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses, 1981
19. Kulhawy, F.H. and Mayne, P.W., Manual on Estimating Soil Properties for Foundation Design, EPRI Report EL-6800, 1990
20. U. S. Army Corps of Engineers (USACE), Geotechnical Investigations, Engineering Manual, EM 1110-1-1804, Department of the Army, 2001
21. U. S. Army Corps of Engineers, Soil Sampling, Engineering Manual, EM 1110-1-1906, Department of the Army, 1996

6.0 DESIGN MANUAL CRITERIA

6.1 GEOTECHNICAL INVESTIGATION REQUIREMENTS AND GUIDELINES

Geotechnical investigations are required to be performed by a geotechnical engineer with collaboration of an engineering geologist. The level of geotechnical investigation performed for preliminary and final phases shall consider the engineering design needs and amount of information necessary to reduce project costs, as well as design, construction, and performance risks. Guidelines for advancing the geotechnical investigations are described in the following sections. Supplemental guidelines for CHSTP tunnel segments will be provided in Tunneling Investigation Guidelines.

The geotechnical engineer will be required to present the investigation results in a GDR document that contains the factual information data that has been gathered during the initial exploration and conceptual to preliminary design phases of the project. Further discussion of the content and format of GDR is described in a separate technical memorandum. At a minimum, the GDR of geotechnical investigations shall contain the following general information:

- Summarize and reference to separate geologic hazards report
- Description and discussion of the site exploration program
- Logs of all borings, trenches, and other site investigations
- Description and discussion of field and laboratory test programs
- Results of field and laboratory testing

6.1.1 Standards and Key Geotechnical Investigation Reference Documents

The ASTM test methods and FHWA manuals are considered the most comprehensive and applicable guideline documents for geotechnical investigation of the CHSTP as well as federal transportation projects. Chapter 6 of the 2008 FHWA PDDM provides an overview of practice for geotechnical work and direction for understanding policies and standards for geotechnical work performed by the FLH. The PDDM also provides a portal to technical information and presents a high-level source of technical guidance with regard to what needs to be accomplished. The corresponding 2007 FHWA draft GTGM provides guidance as to how the work shall be done. The draft GTGM also provides guidance for activities where standards and standard practices do not exist and provides access to and guidance for the use of new technologies. Additional key reference documents are listed in Section 5.

6.1.2 Geotechnical Investigation Goals

The goals of geotechnical investigations for the CHST project are to:

1. Identify the distribution of soil and rock types within the project limits and assess how the material properties will affect the design and construction of the project elements.
2. Define the groundwater and surface water regimes, especially, the depth, and seasonal and spatial variability of groundwater or surface water within the project limits. The locations of confined water-bearing zones, artesian pressures, and seasonal or tidal variations shall also be identified.
3. Identify and characterize any geologic hazards that may be present within or adjacent to the project limits (e.g., faults, landslides, rockfall, debris flows, liquefaction, soft ground or otherwise unstable soils, seismic hazards). These items are vital pieces of the overall geotechnical exploration process, and the investigators must ensure that these elements are addressed.
4. Assess the feasibility of the proposed alignments, including the feasibility and conceptual evaluation of retaining walls and slope angles for cuts and fills.

5. Assess the feasibility of surface hydrological features (infiltration or detention facilities) that may be needed, as well as provide, conceptual recommendations for pond slope angle and infiltration rates to enable estimation of the approximate size and number of those facilities required for the project.
6. Identify potential suitability of onsite materials as fill and/or the suitability of nearby materials sources.
7. For structures including bridges and cut-and-cover tunnels, large culverts, signs, signals, walls, or similar structures, provide adequate subsurface information for design and cost estimating.
8. For tunnels, trenchless technology, or ground improvement, provide adequate information to assess the feasibility of various construction methods and potential impacts to adjacent facilities.
9. For landslides, rockfall areas, and debris flows, provide adequate information to evaluate the feasibility of various stabilization or containment techniques.
10. Develop design soil properties for engineering evaluations, including dynamic analysis.
11. Perform chemical assessment of groundwater and soil for the impact evaluation of existing soil and groundwater on foundation materials.

6.2 SEQUENCE OF GEOTECHNICAL INVESTIGATIONS

Details on performing geotechnical investigations are provided in Section 6.3 and shall follow the general sequence listed below.

1. Review the scope of project requirements to obtain a clear understanding of project goals, objectives, constraints, values, and criteria. This information may consist of:
   - Project location, size and features
   - Project element type (bridge, tunnel, station, embankment, retaining wall, etc.)
   - Project criteria (alignments, potential structure locations, approximate structure loads, probable bridge span lengths and pier locations, and cut and fill area locations)
   - Project constraints (context-sensitive design issues, right-of-way, environmental and biological assessments and permitting)
   - Project design and construction schedules and budgets
2. Research and review of available geologic and geotechnical data, and aerial photographs.
3. Initiate and prepare preliminary scope of the geotechnical investigation. Identify the anticipated required analyses and key engineering input for the analyses.
4. Perform field reconnaissance and geological mapping. Obtain right-of entry where required.
5. Finalize the exploration work plan and submit to Authority for review.
6. Obtain permits and rights-of-entry.
7. Perform preliminary exploration and laboratory testing for initial design phase.
8. Perform supplemental exploration and laboratory testing for final design phases.
9. Compile and summarize data for use in performing engineering analyses, and prepare geotechnical data reports.

6.3 COMPONENTS OF GEOTECHNICAL INVESTIGATIONS

The components of geotechnical investigations are similar for all of the project features addressed in Section 6.4, with specific criteria developed based on the project feature and site characteristics. The following general components are included in the scope of work for all tasks.

6.3.1 Preliminary Planning and Reconnaissance

Standards for performing preliminary studies and reconnaissance are provided in PDDM Section 6.3.2.1. Technical guidance is provided in draft GTGM Section 3.2.1.

- Review Available Data - All relevant available information on the project site shall be collected and reviewed. Available data may consist of reports, maps, journal articles, aerial photographs, historical records of previous investigations, as-built plans from construction of existing facilities, and communication with individuals with local knowledge. A Geologic Hazards Report shall be prepared by a California Certified Engineering Geologist under separate cover in advance of geotechnical investigations. The report shall be reviewed in detail and utilized as a basis for geologic characterization and potential geologic hazards, and also for siting of proposed subsurface exploration points. It is critical that the results of the geologic and seismic hazard evaluation be collaborated with the project Geotechnical Engineer. Other sources of available information include the CHSTP database and GIS system, California Geological Survey (CGS), the United States Geological Survey (USGS), Caltrans archived Logs of Test Borings (LOTBs), the GIS database developed as part of the CHSTP Programmatic EIR phase, and data in individual city and county records and archives.
- Field Reconnaissance - The following factors shall be evaluated by the field reconnaissance:
    - Geologic Report Reviews – The geotechnical engineer and engineering geologist responsible for the geotechnical investigations shall review and become familiar with geologic site characterizations and any identified geologic hazards provided in geologic hazards evaluation reports.
    - Environmental Considerations - Potential impacts the project may have on subsurface materials, landforms, and the surrounding area shall be identified, and assessed to determine if project areas are governed by special regulations or have protected status.
    - Explorations - The type(s) and amount of exploration, as prioritized for preliminary and then final phases, and the kinds of samples that would best accomplish the phased project needs shall be evaluated.
    - Drilling Logistics - The type, approximate locations, and depths of geotechnical borings shall be defined, and approximate routes of access to each drilling location shall be determined. Make note of any feature that may affect the boring program, such as accessibility, structures, overhead utilities, evidence of buried utilities, or property restrictions. Evaluate potential water sources for use during drilling operations. Evaluate potential concerns that may need to be addressed while planning an exploration program (permits, buried or overhead utilities clearance, equipment security, private property, etc.).
    - Permits - The various types of permits that may be required shall be assessed, and all applicable jurisdictions shall be considered, which could include partner agencies, adjoining properties including railroads, Caltrans, regulatory agencies, and state and local government agencies. Local government agencies requirements could include regulations, codes, and ordinances from city, county, and departments of public works having jurisdiction. Permits could include right-of-entry, drilling and well permits, special use permits, lane closure and traffic control plans, utility clearances, etc.

6.3.2 Surface Explorations

Standards for surface exploration methods are provided in PDDM Section 6.3.2.2, and technical guidance is provided in draft GTGM Section 3.2.2. Geologic field mapping of surficial soil and rock units and measurements of rock discontinuities shall begin by observing, measuring, and recording of exposed rock structure data at existing road cuts, drainage courses, and bank exposures, as well as portal locations where HST profiles transition from underground segments to elevated structures or at-grade reaches. Where rock exposures exist, mapping shall include initial characterization of rock mass rating, weathering, texture, overall quality, and discontinuity characteristics.

The main objective of these observation and data collection efforts is to confirm the general types of soil and rock present, and topographic and slope features. For rock slopes, performance of slopes and the rockfall history are important indicators of how a new slope in the same material will perform. In addition to plotting data on a site plan or large-scale topographic map, preparation of field-developed cross sections is a valuable field method.

6.3.3 Subsurface Exploration

The planning process (by the geotechnical engineer along with engineering geologists) for phased investigations requires evaluating the appropriate number, depth, spacing, and type of exploration holes, as well as sampling intervals and testing frequencies. The involvement of engineering geologists (supporting the geotechnical engineer) is critical throughout the investigation process, from initial exploration planning through the characterization of site conditions, to assure consistency for geologic interpretation of subsurface conditions in support of developing parameters for use in phased engineering design and construction.

Relative advantages (economy, data quality, data collection time) of various methods of subsurface investigation should be considered in selecting the exploration plan. For example, cone penetration tests and geophysical methods may offer advantages over conventional test borings in specific situations.

Standards for performing subsurface explorations are provided in PDDM Section 6.3.2.2, and technical guidance is provided in GTGM Section 3.2.2. A guideline for the type of equipment and frequency of use for various types of investigations is presented in GTGM Exhibit 3.2-E. Additional guidance is contained in Caltrans (2007) logging manual.

In addition, the scope of the preliminary and final investigations for the CHSTP facilities shall reflect the anticipated subsurface and surface conditions and the preliminary results of the related Geologic and Seismic Hazard Evaluations TM). Some factors that may impact the prioritization (sequence order ranking), method, number, and depth of subsurface explorations include the potential geologic hazards identified and geology (soil and rock units), landslides, slope stability, rockfall, rip-ability, fill suitability, expansive soils, compressible or collapsible soils, groundwater and hydrogeology, ground-borne vibration and noise transmissivity, erosion, temporary shoring, and excavation slopes. The level of investigation, priority, and scope of work for each component shall be developed in accordance with the phased design requirements of the CHSTP and general guidelines contained in Exhibit 3.1-B of the GTGM.

- <u>Test Borings</u> - Guidance for selection of the applicable exploration methods is presented in PDDM Exhibit 6.3-A (borings). Methods for exploratory borings shall be in accordance with AASHTO and ASTM standards. Detailed information on drilling and sampling methods is given in NHI132031 which lists applicable American Association of State Highway and Transportation Officials (AASHTO) and ASTM drilling and sampling specifications and test methods. Additional references include AASHTO MSI-1, FHWA GEC-5, FHWA-ED-88-053, National Highway Institute (NHI) 132012, NHI132035, USACE EM 1110-1-1804, USACE EM 1110-1-1906, FHWA-FL-91-002, and Caltrans (2007).

  For the rotary wash drilling method, the drilling fluid in boreholes shall be kept above the groundwater level at all times. Rapid fluctuations in the level of drilling fluids shall be avoided. The boreholes shall be thoroughly cleaned prior to taking samples. Drill cuttings shall be collected in drums and disposed of in accordance with applicable regulations.

  Disturbed samples can be used for determining the general lithology of soil deposits, for identifying soil components and general classification purposes, and for determining grain size, Atterberg limits, and compaction characteristics of soils. The most commonly used in-situ test for surface investigations is the Standard Penetration Test (SPT), AASHTO T 206. The use of automatic hammers for SPT is highly recommended, and standard drop height and hammer weight must be maintained. The SPT values obtained with non-automatic hammers are discouraged and are allowed when calibrated by field comparisons with standard drop hammer methods. The SPT dynamic analyzer shall be used to calibrate energy of the SPT equipment at the site at least at the start of the project and bi-weekly for long-duration site investigations. More frequent use of the SPT dynamic analyzer is encouraged. For automatic hammers, calibrate the system to provide approximately 60% energy so that an energy correction is not required and N60 values will be obtained directly.

Undisturbed samples shall be obtained in fine-grained soil strata for use in laboratory testing to determine the engineering properties of those soils. Specimens obtained by undisturbed sampling methods may be used to develop the strength, stratification, permeability, density, consolidation, dynamic properties, and other engineering characteristics of soils. Disturbed and undisturbed samples can be obtained with a number of different sampling devices, as summarized in Table 7 of FHWA GEC-5 and Table 3-4 of NHI 132031.

It will be the responsibility of the geotechnical investigation consultant to obtain enough testable samples of rock and soil to complete the agreed-upon laboratory testing program. The quantity of each type of test conducted shall be proposed by the geotechnical investigation consultant to adequately characterize each soil or rock unit encountered. Therefore, adequate subsurface exploration and sampling will be necessary to obtain sufficient sample quantity for subsurface characterization.

All samples collected should be retrieved by extracting the sample in the same direction it was pushed to avoid unnecessary disturbance.

<u>Sandy or Gravely Soils Sampling</u> – The SPT (split-spoon) samples shall be taken at 5-foot intervals or at significant changes in soil strata. Continuous SPT samples with a gap of at least 6 inch between two consecutive tests are recommended in the top 15 feet of borings made at locations where spread footings may be placed in natural soils. SPT bagged samples shall be sent to lab for classification testing and verification of field visual soil identification. Modified California (MC) and/or California (C) samplers shall not be used in these soils, unless approved by the Program Management Team (PMT).

<u>Silt or Clay Soils Sampling</u> – The SPT and undisturbed thin wall tube samples shall be taken at 5-foot intervals or at significant changes in strata. Take alternate SPT and tube samples in same boring or take tube samples in separate undisturbed boring. Tube samples shall be sent to lab to allow consolidation testing (for settlement analysis) and strength testing (for slope stability and foundation-bearing capacity analysis). Field vane shear testing is also recommended to obtain in-place shear strength of soft clays, silts, and rotted peat.

<u>Rock Sampling</u> - Continuous cores shall be obtained in rock or shales using double- or triple-tube core barrels. In structural foundation investigations, core a minimum of 10 feet into rock to ensure it is bedrock and not a boulder. Core samples shall be sent to the lab for possible strength testing (unconfined compression) if for foundation investigation. Percent core recovery and rock quality designation (RQD) value shall be determined in field or lab for each core run and recorded on the boring log. Additional guidelines for rock coring are described later in this section and in the reference manuals.

<u>Groundwater in Borings</u> - Water level encountered during drilling, at completion of boring, and at 24 hours after completion of boring shall be recorded on the boring log. In low-permeability soils such as silts and clays, a false indication of the water level may be obtained when water is used for drilling fluid and adequate time is not permitted after boring completion for the water level to stabilize (more than one week may be required). In such soils, a plastic pipe water observation well shall be installed to allow monitoring of the water level over a period of time. Seasonal fluctuations of water table shall be

determined where fluctuation will have significant impact on design or construction (e.g., borrow source, footing excavation, excavation at toe of landslide). Artesian pressure and seepage zones, if encountered, shall also be noted on the boring log. In landslide investigations, slope inclinometer casings can also serve as water observation wells by using leaky couplings (either normal aluminum couplings or PVC couplings with small holes drilled through them) and pea gravel backfill. The top 1 foot or so of the annular space between water observation well pipes and borehole wall shall be backfilled with grout, bentonite, or sand-cement mixture to prevent surface water inflow, which can cause erroneous groundwater level readings.

- Probes, Test Pits, Trenches, and Shafts - Guidance for selection of the applicable exploration methods is presented in PDDM Exhibit 6.3-B (probes, test pits, trenches, and shafts), and GTGM Section 3.2.3.5. The recommended primary reference is NHI 132031. Additional guidance is contained in AASHTO MSI-1 and Caltrans 2007. Exploration pits and trenches performed by hand, backhoe, or dozer allow detailed examination of the soil and rock conditions at shallow depths and relatively low cost. Exploration pits can be an important part of geotechnical explorations where significant variations in soil conditions occur (vertically and horizontally), large soil and/or non-soil materials exist (boulders, cobbles, debris) that cannot be sampled with conventional methods, or buried features must be identified and/or measured. Upon completion, the excavated test pit shall be backfilled and compacted with the excavated material or other suitable soil material, and the surface shall be restored to its previous or approved condition.
- Geophysical Methods - Standards for geophysical methods are provided in PDDM Section 6.3.2.3.2. The primary source supporting the guidance is FHWA DTFH68-02-P-00083 Geophysical Methods Technical Manual (2003). Secondary sources are NHI 132031 and USACE EM 1110-1-1802. Generally, geophysical methods are used as a reconnaissance investigation to cover large areas and/or to supplement information between boreholes. These exploration techniques are most useful for extending the interpretation of subsurface conditions beyond what is determined from small-diameter borings. The methods presented in FHWA (2003) shown as Exhibit 3.2-F of the GTGM are some of the most common. The reliability of geophysical results can be limited by several factors, including the presence of groundwater, non-homogeneity of soil stratum thickness, gradation or density, and the range of wave velocities within a particular stratum. Subsurface strata that have similar physical properties can be difficult to distinguish with geophysical methods. Geophysical methods are also applicable for testing ground-borne vibration transfer mobility of subsurface conditions, and assessment of this parameter is considered important for HST systems. The reference document for this testing is titled, "High-Speed Ground Transportation Noise and Vibration Impact Assessment," FRA Report No. 293630-1, December 1998.
- Soil Resistivity Testing - The ability of soils to conduct electricity can have a significant impact on the corrosion of buried structures and the design of grounding systems. Accordingly, subsurface investigations shall include conducting appropriate investigations to obtain soil resistivity values. The following information and methodologies are recommended.

    a) Soil resistivity readings shall be obtained to determine the electric conduction potential of soils at each traction power facility (supply/paralleling/switching station), which is spaced at approximately 5-mile intervals.
    b) Resistivity measurements shall be obtained in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 81-1983 - IEEE Guide for Measuring Earth Resistivity using the four-point method for determining soil resistivity. IEEE states that the four-point method is more accurate than the two-point method.

- Standards for Boring Layout and Depth - Standards for boring layout and depth with respect to structure types, locations and sizes, and proposed earthwork are provided in

Section 6.4.2 to 6.4.7 of this TM in Exhibit 6.3-C of the PDDM, and Section 3.2.3.3 of GTGM.

- Standards for Sampling and Testing From Borings - Minimum standards for disturbed and undisturbed soil and rock are presented in Exhibit 6.3-D of PDDM, and Section 3.2.3.3 of GTGM.
- Rock Coring - Standards for soil and rock classification are provided in PDDM Section 6.3.2.3.4, and technical guidance is provided in GTGM Section 3.2.3.4. The International Society of Rock Mechanics (ISRM) classification system shall be followed for rock and rock mass descriptions, as presented in GEC-5. The primary source supporting the standards and guidance is NHI 132031, and a secondary source is AASHTO MSI-1. Because single-tube core barrels generally provide poor recovery rates, the double- or triple-tube core barrel systems shall be used. To protect the integrity of the core from damage (minimize extraneous core breaks), a hydraulic ram shall be used to expel the core from the core barrel. Rock cores shall be photographed in color as soon as possible after being taken from the bore hole and before laboratory testing.

  If rock is encountered in boreholes within the planned depth of drilling, continuous rock coring shall be performed in accordance with the following procedures. Rock coring shall be performed using a triple tube HQ coring system or a larger-diameter, triple-tube coring system. The HQ system produces cores 2.4 inches in diameter. The advantage of the triple tube system is that a split liner is used to contain the core, which results in relatively minimal disturbance to the core. Where weak rock zones are encountered, soil sampling techniques may be used instead of coring to recover samples that would be relatively undisturbed and suitable for testing. These techniques include the use of samplers such as the Pitcher or MC samplers. The potential difficulty with these samplers is that they can be easily damaged by hard, gravel-size particles that are often mixed with the softer, clay-like matrix of the weathered rock. These difficulties will need to be considered when planning the exploration program.

  Rock core samples shall be placed in plastic core bags or double wrapped in plastic wrap and placed in wooden core boxes and transported to a storage facility at the end of each day. An adequate number of core boxes shall be maintained on site at all times during field exploration activities. The core shall be photographed, taking at least one photo for each core box, and close-ups taken of special features such as shear zones or other features of special interest. The core box label shall be clearly visible within the photo. An experienced geologist shall study the core and edit the borehole log based on their observations. Cores boxes shall be maintained in the project area throughout the design process and through bidding, with cores that have been removed for testing duly indicated in the appropriate locations in each box.

  In some rock slope applications, it is important to understand the precise orientation of rock discontinuities for the design. Standards for using orienting-recovered rock core are presented in NHI 132031. In special cases, boreholes can be photographed/imaged to visually inspect the condition of the sidewalls, distinguish gross changes in lithology, and identify fracture zones, shear zones, and joint patterns by using specialized television cameras. Refer to AASHTO MSI-1, Section 6.1.2.
- Care and Retention of Samples - Standards for soil and rock retention are provided in PDDM Section 6.3.2.3.7, and technical guidance is provided in GTGM Section 3.2.3.7. Soil samples and rock cores obtained represent a considerable investment of time and money. The samples shall be properly labeled, transported, and stored. A detailed treatment of procedures for handling and storing samples is provided in NHI132031 and AASHTOMSI-1. Refer to ASTM D 4220 and ASTM D 5079 for practices of preserving and transporting soil and rock core samples (ASTM Standards).

  The geotechnical investigation consultants shall maintain all untested soil and rock samples recovered from the geotechnical and geological field exploration programs in a readily accessible storage facility within 100 miles of the project site until the completion of construction and afterward, as required by the PMT. These samples shall be available for viewing by the Authority or its designees within one business day of a request. The Authority may elect to allow prospective bidders to view the samples. Upon completion of construction bidding and award, the Authority will be given the option to take possession of the samples and shall have at least 30 days to exercise that option. If the Authority elects not to take possession of the samples, the investigation consultants shall be responsible for sample handling and disposal at that time. Untested samples shall not be disposed of or released to any other party at any time without the written authorization of the Authority. Depending on requirements of the design-build team, rock core may also be held until construction is complete and it is clear that claims related to the rock are not forthcoming. Additional guidance is provided in Caltrans (2007) logging manual.

6.3.4 Soil and Rock Classification

Standards for soil and rock classification are provided in PDDM Section 6.3.2.4, and technical guidance is provided in GTGM Section 3.2.4. Soils shall be classified in accordance with the ASTM Unified Soil Classification System (USCS). Rock and rock mass descriptions and classification shall follow the ISRM classification system presented in GEC-5. Material descriptions are based on the visual-manual method, and materials classifications are based on laboratory index tests (ASTM D 2487). Additional guidance is contained in Caltrans Soil and Rock Logging, Classification, and Presentation Manual (2007).

6.3.5 Exploration Logs

Standards for preparing exploration field logs are provided in PDDM Section 6.3.2.5, and technical guidance is provided in GTGM Section 3.2.5.

Field Logs - Field logging shall be performed by a geologist or engineer under the direct supervision of a California Registered Geotechnical Engineer (GE) or Certified Engineering Geologist (CEG). Logging shall be performed in accordance with ASTM D 5434. The location information (e.g., station, offset, elevation, and/or state plane coordinates) of all the explorations are to be recorded on the field logs. Exploration locations shall be located at the time of drilling by GPS with at least sub-10-foot accuracy. The explorations shall eventually be located by a licensed land surveyor. Required documentation for test pits shall include a scale drawing of the excavation, and photographs of the excavated faces and spoils pile. Drilling and sampling methods and in-situ measurement devices that were used shall also be documented. The field logs shall contain basic reference information at the top, including project name, purpose, specific location and elevation, exploration hole, number, date, drilling equipment, procedures, drilling fluid, etc. In addition to the logging descriptions of soil and rock encountered during exploration, the depth of each stratum contact, discontinuity, and lens shall be recorded. The reason for terminating an exploration hole and a list/description of instrumentation (if any) or groundwater monitoring well installed shall be written at the end (bottom) of each exploration log.

Final Logs - Exploration logs shall be prepared with the gINT boring/test pit log software platform, using the formatted boring record template standardized by Caltrans (illustrated as Figures 5-12 and 5-13 in the Caltrans logging manual, 2007 version). An explanation key, known as the Boring Record Legend shall always accompany exploration logs whenever they are presented. The standardized legends to be used for CHSTP are illustrated as figures 5-14 through 5-16 of Caltrans (2007). The final edited log shall be based on the initial field log, visual classification, and the results of laboratory testing. The final log shall include factual descriptions of all materials, conditions, drilling remarks, results of field and lab tests, and any instrumentation. Where groundwater observation wells or piezometers are installed, several measurements are usually necessary within a one-week timeframe following drilling to verify that measured groundwater levels or pressures have achieved equilibrium. As a minimum, final boring logs shall contain the information shown in NHI132031. AASHTO MSI-1 provides additional guidance regarding documentation for boring logs.

6.3.6 In-Situ Testing

Standards for performing in-situ testing are provided in PDDM Section 6.3.2.6, and technical guidance is provided in GTGM Section 3.2.6. The primary reference is NHI1 32031. In-situ testing is very beneficial for projects where obtaining representative samples suitable for laboratory testing is difficult. Field in-situ borehole tests can be correlation tests, strength and deformation tests and permeability tests. Correlation tests primarily consist of SPTs performed in accordance with ASTM D 1596 and AASHTOT 206, and Dynamic Cone Penetration Tests (CPTs) are performed in accordance with ASTM D 3441.

- In-situ soil tests may consist of:
  - Cone Penetration Test (CPT) and Piezocone Penetration Test (PCPT) - The cone penetrometer is used for tests in sands or clays, but not in rock, very dense sands, or soils containing appreciable amounts of gravel. Piezocone penetrometers are electric penetrometers that are capable of measuring pore water. Tests are conducted in accordance with ASTM D 3441 (mechanical cones) and ASTM D 5778 (piezocones). References: TRB-NCHRP synthesis report 368 (2007), and FHWA-SA-91-043.
  - Pressuremeter Test - This test measures state of stress in-situ and stress/strain properties of soils by inflating a probe placed at a desired depth in a borehole. Tests are completed in accordance with ASTM D 4719. Reference FHWA-IP-89-008.
  - Flat-Plate Dilatometer Test - This test uses pressure readings from an inserted plate at the base of a borehole to determine stratigraphy and obtain estimates of at-rest lateral stresses, elastic modulus, and shear strength of loose to medium dense sands (and to a lesser degree, silts and clays). Tests are completed in accordance with ASTM D 6635. Reference FHWA-SA-91-044.
  - Field Vane Shear Test (VST) - This test is used on very soft to medium stiff cohesive soil or organic deposits to measure the undrained shear strength, remolded strength of the soil and soil sensitivity. Field vane shear test may provide more reliable estimate of peak and residual shear strength in cohesive soils, as disturbance from sampling and testing in laboratory is avoided. Tests are completed in accordance with ASTM D 2573 and AASHTO 223.
- Hydrogeologic testing in-situ may consist of:
  - Permeability Tests - Several in-situ hydraulic conductivity tests exist, with the most commonly used methods being the pumping test and the slug test. The selection of the appropriate aquifer test method for determining hydraulic properties by well techniques is described in ASTM D 4043. In general, refer to NHI1 32031, BOR Geology Manual, and NAVFACDM-7.1.
  - Pumping Test - The pumping test requires not only a test well to pump from, but also one to four adjacent observation wells to monitor the changes in water levels as the pumping test is performed. Pumping tests are typically used in large-scale investigations to more accurately measure the permeability of an area for the design of dewatering systems. Refer to ASTM D 4050.
  - Slug Test - The slug test is quicker to perform and much less expensive, because observation wells are not required. It consists of affecting a rapid change in the water level within a well by quickly injecting or removing a known volume of water or solid object, known as a slug. The natural flow of groundwater out of or into the well is then observed until equilibrium in the water level is obtained. Refer to ASTM D 4044.
  - Packer Tests - These tests are performed in a borehole by placing packers above and below the soil/rock zone to be tested. One method is to remove water from the material being tested (Rising Water Level Method). Another method is to add water to the borehole (Falling Water Level Method and Constant Water Level Method). A third method utilizes water under pressure rather than gravity

flow. The coefficient of permeability that is calculated provides a gross indication of the overall mass permeability. Refer to FHWA-TS-89-045 and NHI1 32031.

- Open Borehole Seepage Tests - Methods include "Falling Water Level," "Rising Water Level," and "Constant Water Level" and are selected based on the relative permeability of the subsurface soils and groundwater conditions. Further detail is provided in Chapter 6 of NHI1 32031.
- Infiltration Tests - Two types of infiltrometer systems are available: sprinkler type and flooding type. Sprinkler types attempt to simulate rainfall, while the flooding type is applicable for simulating runoff conditions. Applications for these tests include the design of subdrainage and dry well systems. The most common application is the falling head test, performed by filling (flooding) a test pit hole and monitoring the rate at which the water level drops. Refer to ASTM D 4043.

Handling and disposal (or permitted discharge to storm sewer system) of water generated from hyrdrogeologic field testing shall be the responsibility of the geotechnical consultant conducting the investigation work.

If the geotechnical investigation consultant intends to use field tests not covered in the current ASTM or referenced standards, the proposed test methods shall be submitted to the Authority prior to start of testing.

6.3.7 Laboratory Testing of Soil and Rock

Standards for performing laboratory testing are provided in PDDM Section 6.3.2.7 and technical guidance is provided in GTGM Section 3.2.7. Sufficient laboratory testing shall be performed to represent in-situ conditions. Exhibit 3.2-J of the GTGM provides a guideline for estimating laboratory test requirements for the different types of geotechnical analysis. Chapters 7 through 10 of NHI 132031, GEC-5, and Chapters 2 and 3 of NHI 132012 provide overviews of testing and correlations, as well as criteria to consider when planning the scope of testing programs. Additional references include AASHTO MSI-1, NHI 132012, NHI 132035, USACE EM 1110-2-1906, FHWA-FL-91-002; and Kulhawy and Mayne (1990). Exhibits 3.2-K (soil) and Exhibit 3.2-L (rock) of GTGM present a summary of the predominant laboratory tests. The proposed workplans for laboratory testing programs shall be submitted for review.

If the geotechnical investigation consultant proposes to use laboratory tests not covered in the current ASTM or referenced standards, the geotechnical consultant shall submit test methods to the Authority for approval prior to commencement.

6.3.8 Instrumentation and Monitoring

Standards for installing and monitoring geotechnical instrumentation are provided in PDDM Section 6.3.2.8, and technical guidance is provided in GTGM Section 3.2.8. Instrumentation is used to augment standard investigation practices and visual observations where conditions would otherwise be difficult to evaluate or quantify due to location, magnitude, or rate of change. The quantity and locations of proposed geotechnical instrumentation shall be selected to suit the anticipated conditions consistent with project objectives and design requirements. The geotechnical exploration work plan shall include instrumentation work detailing locations, installation procedures, and methods to be used. The work plan shall be submitted to and approved by the Authority prior to commencement. Additional information about inclinometers and piezometers are presented in Cornforth (2005).

6.4 PROJECT FEATURES REQUIRING GEOTECHNICAL INVESTIGATION

6.4.1 General

The CHSTP will require geotechnical investigations of the various project features listed below. The referenced standards and technical guidance documents shall be utilized, in addition to the primary and secondary references, where listed. Guidelines for the approximate number and depth of various exploration methods are also included. Supplemental guidelines for CHSTP tunnel segments will be provided in a separate Tunneling Investigation and Design Guidelines document.

In addition to the general guidelines, the scope of the investigation for the various project features shall also reflect the anticipated subsurface and surface conditions, as well as the design phase level (whether preliminary or final). Some factors that may impact the method, number, depth, and prioritization of subsurface explorations include type of soil or rock, landslides, slope stability, rockfall, rippability, fill suitability, expansive soils, compressible soils, groundwater and hydrogeology, ground-borne vibrations, erosion, engineering design needs, temporary shoring, and excavation slopes.

The scope of investigation work for each component shall be developed in accordance with the guidelines contained in this section. The quantity, locations, and depths of proposed geotechnical exploration shall be selected to suit the anticipated conditions consistent with phased project objectives and design requirements. The geotechnical exploration work plan shall include information detailing methods to be used and proposed schedule. The preliminary work plan shall be submitted to and approved by the Authority prior to commencement. If the geotechnical investigation consultant proposes to use exploration methods or frequencies that differ from these guidelines or are not covered in the current reference standards, the geotechnical consultant shall submit the proposed alternate exploration plans to the Authority for review and approval prior to commencement.

6.4.2 Rail Alignment and Earthwork

Standards for investigations for the at-grade rail alignment and earthwork are provided in PDDM Section 6.3.1.2.1, and technical guidance is provided in GTGM Section 3.1.2.1. Explorations are made along the proposed at-grade rail alignment for the purpose of defining the geotechnical properties of materials. This information is used to:

- Design cut and fill slopes
- Assess material suitability for embankment construction
- Define the limits of potential borrow materials
- Assess the suitability of foundation materials
- Evaluate settlement or slope stability problems
- Quantify the depths of topsoil and volumes of material to be removed
- Design remedial measures in areas of poor materials
- Aid the designer of the rail roadbed subgrade section
- Identify geologic hazards such as liquefaction and landslides

The CPTs may provide advantages over conventional test borings under specific situations and should be considered. For cuts and fills, test borings shall be advanced every 400 to 800 feet along the project alignment where cuts or fills are anticipated. For large cuts or fills (e.g., 30 feet or more in height) an additional boring near the top of the proposed cut or toe of the proposed fill to evaluate cut/fill feasibility and overall stability may be necessary. Depths of the borings shall be at least three times the vertical height of the fill (or 40-foot minimum depth) and at least 15 feet below the base of the cut. If soft or poor soils are encountered, additional depth will be needed to define the subsurface conditions.

6.4.3 Structures

Standards for structures are provided in PDDM Section 6.3.1.2.3, and technical guidance is provided in GTGM Section 3.1.2.3. Structures will primarily consist of the following:

- Bridge/viaduct
- Station
- Building

- Retaining wall
- Tunnels, portals, and subway
- Large culverts
- Mast-arm supports (signals, message signs)

For bridge structures, a minimum of one boring shall be completed at each abutment and pier location. For cut-and-cover tunnels, a minimum of one boring shall be completed at portal and at least every 300 to 500 feet of cut-and-cover tunnels. Borings for structures shall be a minimum of 100 feet in depth unless rock or other very dense material is encountered. If rock is encountered, the rock shall be cored for at least 10 feet. For structures founded on piles or shafts, a good rule of thumb is to obtain at least 30 feet of soil that has a standard penetration resistance of 30 blows per foot or more, or a 100-foot depth (minimum).

For noise walls or retaining walls, at least one boring per wall shall be completed at the most likely wall face location. Walls longer than 200 feet shall have additional borings spaced every 200 to 300 feet. For taller retaining walls (e.g., 30 to 40 feet or more in height) or retaining walls that may be soil-nail or tie-back walls, borings shall be completed behind the wall face to evaluate overall stability and ground-anchor feasibility. The spacing on these borings shall be twice the spacing of the borings along the wall face. The depth of borings for noise walls shall be a minimum of 20 feet. Borings for retaining walls in fill situations shall extend below the ground surface at least twice the wall height, or a 100-foot depth (minimum). Borings for retaining walls in cut situations shall extend below the ground surface at least three times the exposed height of the wall.

For buildings, one boring shall generally be made at each corner and one in the center. This may be reduced for small buildings. For extremely large buildings or highly variable site conditions, one boring shall be taken at each support location. Refer to building foundation manuals and CBC (codes) for additional guidance in planning geotechnical investigations. In addition, areas of influence of the building and/or of surrounding geologic or geotechnical issues shall be considered in defining the extent of explorations.

Due to the extreme variability of conditions under which tunnels are constructed and the complexity of the projects, it is difficult to provide specific recommendations for tunnel investigation criteria. In general, boring footage is typically on the order of 1.5 linear feet of borehole per route foot of tunnel, and site exploration budgets are typically on the average of three percent of the estimated tunnel cost. Criteria shall be established for each project reach on an individual basis and be based on the complexity of the geology and the length and depth of the tunnel. FHWA-IF-05-023 and U. S. National Committee on Tunneling (USNCTT, 1995) shall be considered the primary references. Supplemental guidelines for tunnel investigations are provided in separate technical memoranda.

Standard foundations for sign bridges, cantilever signs, cantilever signals, and strain pole standards are based on allowable lateral bearing pressure and angle of internal friction of the foundation soils. The determination of these values may be estimated by Standard Penetration Test (SPT) and CPT. One boring shall be made at each designated location. Borings shall extend 50 feet into suitable soil or 5 feet into competent rock. Deeper borings may be required for posts with higher torsional loads or if large boulders are anticipated. Other criteria are the same as for bridges.

In addition to the above structures, any structure such as signage or other design features shall be addressed with regard to their potential influence on the Right-Of-Way of the CHST and evaluated, as needed.

6.4.4 Landslide – Slope Stability

Standards for investigations for landslides are provided in PDDM Section 6.3.1.2.4, and technical guidance is provided in Section 3.1.2.4 and Exhibit 3.1-B of the GTGM. A minimum of three borings shall be advanced along a line perpendicular to centerline or planned slope face to establish geologic cross sections for stability analysis. The number of cross sections depends on the extent of the slope stability problem. For active slides, place at least one boring each above and below the sliding area. The borings shall be extended to an elevation below active or potential failure surfaces and into hard stratum, or to a depth for which failure is unlikely because of geometry of the cross section. If slope inclinometers are used to locate the depth of an active slide, they must extend to a depth below the base of the slide. Supplemental guidelines for investigation of slopes, landslides, and other geologic hazards are provided in Geologic and Seismic Hazard Evaluation Guidelines.

6.4.5 Materials Sources

Standards for investigations for materials sources are provided in PDDM Section 6.3.1.2.2, and technical guidance is provided in Section 3.1.2.2 and Exhibit 3.1-B of the GTGM. Borings shall be spaced every 100 to 200 feet. The depth of exploration shall extend to the base of the deposit, or to a depth required to provide the needed quantity of borrow material. These investigations shall evaluate the quality and quantity of materials available at existing and prospective sources within the vicinity of a project. These materials could include gravel base, crushed surfacing materials, pavement and concrete aggregates, riprap, wall backfill, borrow excavation, and select backfill materials. The evaluation may consider existing government-owned material sources, existing commercial material sources, expansion of existing sources, and development of new material sources.

6.4.6 Hydrological Features - Infiltration and Detention Facilities

For surface hydrological features (infiltration or detention facilities) that may be needed, at least one boring per site shall be obtained to assess feasibility and define groundwater conditions. Boring depths will depend on the nature of the subsurface conditions encountered and the depth of influence of the geotechnical feature. Borings shall extend at least 20 feet below the likely base elevation of the facility, or five times the maximum anticipated ponded water depth, whichever is greater. It is desirable to install piezometers and monitor them for at least one year prior to bid advertisement to assess yearly highs and lows for the groundwater.

6.4.7 Pavement

Pavements are not a significant component of the HST guideway alignment design but will be an extensive design element for station areas, access roads, grade separations, and surface road reconstruction. Standards for investigations for pavement subgrade are provided in PDDM Section 6.3.1.2.5 and Chapter 11, and technical guidance is provided in GTGM Section 3.1.2.5. Other sources supporting investigation standards and guidance are NHI 132031, AASHTO MSI-1, and GEC-5.