Chapter 6 – GEOTECHNICAL

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CHAPTER 6

GEOTECHNICAL

6.1 GENERAL

This chapter provides an overview of practice for geotechnical work performed by the Federal Lands Highway (FLH) Divisions. It provides direction for understanding policies, standards and criteria in recognition of the need to manage financial and public safety risk and accomplish the missions of FHWA Federal Lands Highway and partner agencies. Specific topics include reconnaissance, site and subsurface investigation, analysis and design, reporting, PS&E involvement, construction support, monitoring, and consultant roles.

There are a few principles that guide all geotechnical work for FLH and they are represented by existing policy. Chapter 1 presents interpretations of existing policy in a way that is relevant to all project delivery disciplines. Section 6.2.1 of this chapter presents interpretations of these policies that are particularly relevant to geotechnical practice. The policies are as follows:

- Support the mission, vision and program management objectives of FLH and FHWA;
- Meet the technical scope requirements defined by the *PDDM*;
- 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; and
- Achieve quality through established quality assurance and oversight procedures.

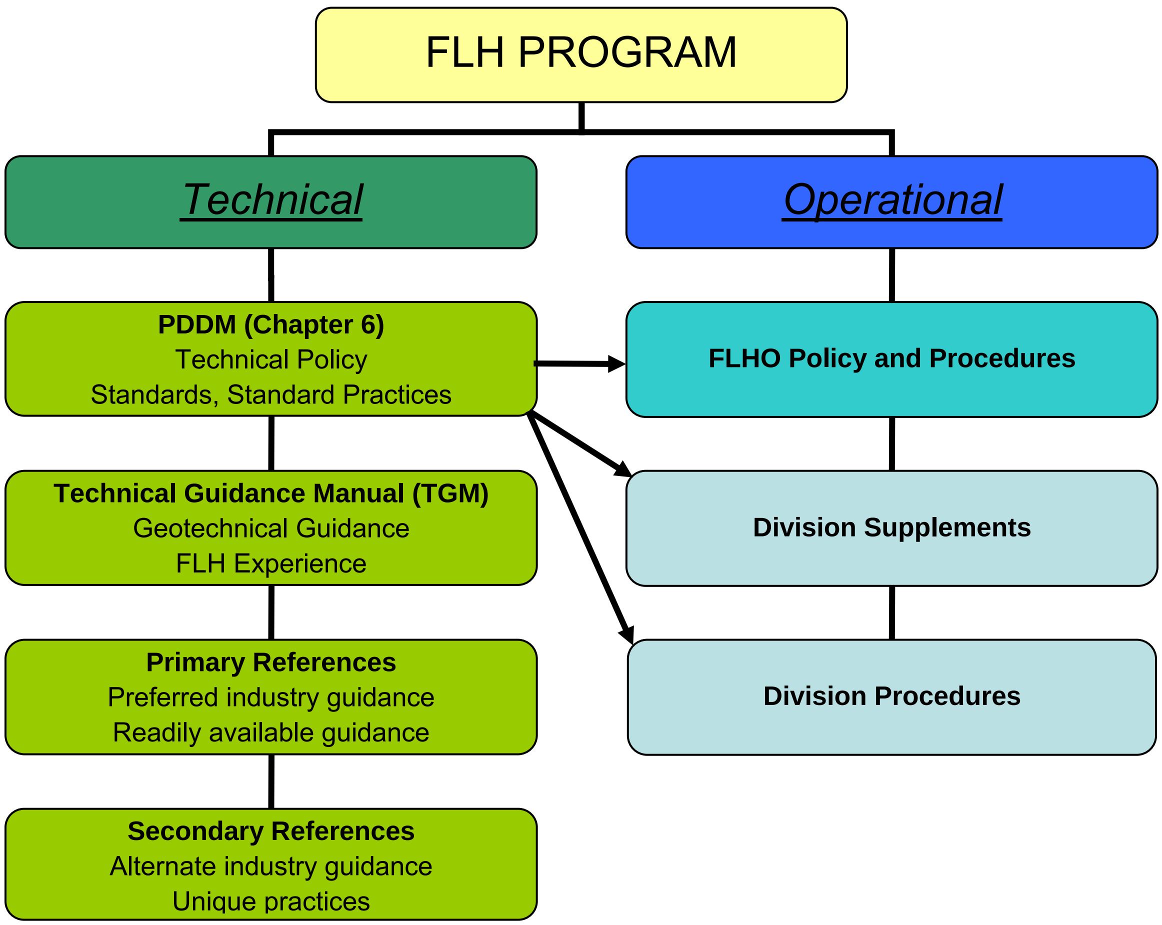
This chapter also serves as a "portal" to technical information and resources required for conducting geotechnical services for Federal Lands Highway. It presents standards for tasks and activities to be delivered, not technical guidance of how to perform them. For assistance with how-to guidance the reader is directed through links to FLH guidance in the *Geotechnical Technical Guidance Manual (TGM)* and through citations and links to more widely published technical guidance reference documents.

Technical guidance references in this chapter are classified as either "Primary", or "Secondary". When guidance beyond that presented in the TGM is required, Primary sources are refered to first. Primary sources either present preferred guidance on how to accomplish a task or, when equal guidance is available through many sources, the Primary source is most widely available. "Secondary" sources are additional documents that are often relied on for FLH work; they present guidance to augment the Primary source. Guidance sources do not constitute standards unless they are specifically identified as standards in this chapter. Tertiary-level references are additional references that are needed less often but are of particular value for certain specific needs. They are contained in the TGM Bibliography.

This chapter provides general direction on "what" should be performed, whereas guidance at the technical level (TGM and technical references) provides requirements, recommendations, and options for "how" to perform the technical aspects of each geotechnical task. The TGM is an important companion manual to this *PDDM* chapter and provides greater detail and institutional guidance. **It is FLH policy to perform geotechnical work in accordance with the *PDDM* and to review TGM guidance**; practitioners involved in FLH projects are responsible for knowing and using both manuals.

Other documents exist within FLH to provide guidance on unique technical practices or procedures at the FLH Division level; where these exist they should be followed for work within that Division. Also, although the organization of each of the Divisions is similar, there are differences. For this reason, the project delivery process, and how the Geotechnical Discipline works within that process, is described at the Division level. The relationship between the *PDDM* (this chapter) and other available guidance and manuals is shown in Exhibit 6.1–A.

Exhibit 6.1–A RELATIONSHIP OF PDDM TO OTHER GUIDANCE, REFERENCES, AND PROCEDURES



Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

6.1.1 GEOTECHNICAL DISCIPLINE

The FLH Geotechnical Discipline in each of the three Division offices provides geotechnical engineering and engineering geology services for geotechnical related aspects of design, emergency response and construction support. The discipline is comprised of in-house and contracted geotechnical engineers, engineering geologists, and geologists collectively named 'Geotechnical Professionals'. The FLH Headquarters office provides administrative direction and policy related assistance to the Division offices, including the Geotechnical Discipline.

The state-of-the-practice of the geotechnical field involves engineering judgment to provide the most efficient and economical investigations and designs. While this chapter provides standards and direction to specific guidance, it is not intended to limit the individual Geotechnical Professional from exercising their professional judgment and experience. Dealing with the variability of FLH projects, terrains, climates and partner agency constraints requires flexibility and resourcefulness. Geotechnical work is to be conducted in accordance with accepted geotechnical standards-of-care by engineers or engineering geologists who possess adequate geotechnical training and experience.

6.1.2 GEOTECHNICAL ROLE IN PROJECT DEVELOPMENT

The role of the Geotechnical Discipline is generally to provide geotechnical recommendations to a Project Manager or other designated members of a interdisciplinary (cross-functional), and possibly multi-agency, project team. The Project Manager and other team members need geotechnical recommendations at multiple stages of project development and delivery, so the Geotechnical Discipline is an integral part of a interdisciplinary work plan. In general there is a chronology to geotechnical tasks, as shown in Exhibit 6.1–B, and work is planned accordingly.

Exhibit 6.1–B PLANNING GEOTECHNICAL TASKS

Initiate and Scope the Project (Section 6.3.1)

- Participate in early project planning with the Project Manager and cross-functional team, defining the objectives and general scope of the project.

Study Available Geotechnical Data (Section 6.3.1)

- Assemble and review pertinent geotechnical information prior to site scoping, including available ground survey data, aerial photos, "as-built" plans for the existing roadway and/or structures, new construction features, geology information, USDA soils data, etc.

Perform Field Reconnaissance (Section 6.3.2.1)

- Conduct reconnaissance-level site investigation, generally not including subsurface investigation.

Perform Preliminary Project Investigations (Section 6.3.2.1 and Section 6.3.2.2)

- Conduct preliminary site investigations supporting line and grade planning, including observational assessment of roadway conditions, hazards, structures, and drainage, and limited sampling of material sources, soil/rock cuts, and subexcavation locations.

- Prepare a preliminary geotechnical memorandum characterizing earthwork requirements, available material sources, geotechnical hazards, corrosive soil/rock/water conditions, drainage issues, candidate structure foundation types, and construction issues, all based on the preliminary work. Make recommendations for supplemental investigations.

Perform Supplemental Project Investigations (Section 6.3.2.2 and Section 6.3.2.3)

- Conduct surface/subsurface investigations in support of intermediate and final PS&E packages, including soil/rock surface mapping, drilling and sampling programs, geophysical investigations, in situ testing, and instrumentation deployment
- Develop and implement a testing program supportive of project requirements.

Compile and Summarize Data (Section 6.4.1)

- Compile subsurface exploration logs, geophysical logs, materials data, soil surveys, groundwater/subexcavation problem areas, field and laboratory test results, instrumentation monitoring data, and soil/rock profile data

Perform Geotechnical Analyses (Section 6.4)

- Determine the scope of the analyses,
- Evaluate the accuracy and relevance of the available geotechnical data.
- Select values for design with an understanding of uncertainty and variability.
- Conduct the range of geotechnical analyses required to support the project, including assessment of construction options.
- Provide preliminary recommendations.

Prepare Geotechnical Report (Section 6.5.1)

- Review applicable FHWA report checklists to properly summarize relevant project investigation and design analyses information.
- Prepare a Geotechnical Report for the project, including a description of investigations, findings, analyses, and recommendations.
- Follow accepted QA/QC procedures for ensuring the quality of the analyses, recommendations, and final report.

Provide Design (Section 6.5.2) and Construction (Section 6.5.3) Support

- Attend project meetings concerning geotechnical issues, checking that all geotechnical recommendations are being adequately incorporated into designs.
- Review PS&E packages (Exhibit 6.5–A).
- Assist Construction with monitoring and troubleshooting of geotechnical related construction issues and activities (Exhibit 6.5–B).

The Geotechnical Discipline is responsible for participating in an interdisciplinary team approach, lead by the Project Manager, for evaluating geotechnical issues and developing geotechnical solutions for the project delivery. The Geotechnical Discipline is responsible for evaluating alternatives and for informing stakeholders of the geotechnical risks and benefits of various alternatives. The Geotechnical Discipline is responsible for collaborating with other disciplines to assure that risks and benefits are understood and that recommendations are incorporated in designs and actions. The following briefly summarizes the role and responsibility of the Geotechnical Discipline in relation to some other disciplines described in this manual.

- Chapter 4 – **Environmental Stewardship.** Environmental documents will include the decisions and commitments made for mitigation of impacts and concerns of the project. The Geotechnical Discipline will review or be briefed on environmental documents for decisions, mitigation measures and commitments made during the conceptual studies and preliminary design phase that affect development and construction of the project or operation of the highway following construction. Any proposed deviation from the decisions, mitigation measures and commitments will be coordinated through the Project Manager with the Environmental and Highway Design Disciplines, and affected resource agencies.

  The Geotechnical Discipline's role is to convey geotechnical recommendations in such a way that designers can evaluate whether or not they satisfy the environmental documents.

- Archive 4 – **Conceptual Studies and Preliminary Design.** Chapter 4 covers the highway design activities done as part of the conceptual and preliminary design phase, which is typically through approximately the 30 percent level of design detail. Refer to Chapter 4 for the development of conceptual studies and preliminary design, including the development of the recommended roadway location, design concepts and the basic design criteria for the facility, including geotechnical constraints. These engineering studies and preliminary designs are developed in conjunction with the environmental process using an interdisciplinary and interagency team approach, lead by the Project Manager. Conceptual studies and preliminary design development include significant input from the highway owner agency, Federal land management agency, project stakeholders, the public and from other interested parties.

  The Geotechnical Discipline's role is to consider this input during development of geotechnical recommendations. Chapter 4 includes explicit references to geotechnical work generally pertaining to project scoping reports, investigations at the conceptual project phase, and scoping of future investigations.

- Chapter 5 – **Survey and Mapping.** The Survey and Mapping Discipline provides information on the field survey, property ties, right-of-way and utility locations and related data. The data collected are used to provide topographic maps, site maps, aerial imagery, right-of-way exhibits, land boundary and ownership information, utility maps and control information for developing the design.

The Geotechnical Professional's role is to work with the Project Manager, Design Discipline and Survey and Mapping Discipline to closely coordinate the survey and mapping with the geotechnical needs and determine the type and limits of the survey and mapping required to complete the geotechnical work. Coordinate closely with the Survey and Mapping Discipline to identify any additional information needs for developing the geotechnical investigation and recommendations, and for locating geotechnical explorations. When field reviews specifically for this coordination purpose are not possible, it is especially important for the Geotechnical Discipline and Survey and Mapping Discipline to discuss the field information required.

- Chapter 7 – **Hydrology and Hydraulics.** The Hydrology and Hydraulics Discipline provides estimates of runoff data, and recommendations for developing the roadside drainage design to be used around major geotechnical project features. This unit also provides scour depth recommendations to the Structural Design Discipline for major drainage structures, walls and bridges.

  The Geotechnical Discipline's role is to communicate with Hydrology/Hydraulics with respect to hydrology and scour depth, and layout of major drainage structures, walls, and bridges. This can be an iterative process, as initial recommendations may prompt design and layout changes that impact geotechnical recommendations and, once again, hydrology/hydraulics recommendations. The Geotechnical Discipline's role is to be part of this ongoing communication during design development.

- Chapter 9 – **Highway Design.** The Highway Design Discipline provides the geometric design and incorporates structural designs and recommendations from all other disciplines into the Plans, Specifications, and Estimate (PS&E) package ready for advertisement.

  The Geotechnical Professional's role is to coordinate with the Highway Design Unit during the development of the geometric design. For example, provide recommendations and preferences for moving into cut or fill sections, geotechnical criteria for wall layouts, risk associated with different alternatives, rockfall risk mitigation features, constructability sequencing and other issues. Assist with writing Special Contract Requirements (SCRs) and preparing cost estimates for geotechnical features.

- Chapter 10 – **Structural Design.** The Structural Design Discipline designs bridges, major retaining structures and special structural elements. The Structural Unit will provide preliminary structural plans, loads, settlement and other criteria early in the design process and will finalize designs only after geotechnical recommendations have been incorporated.

  The Geotechnical Discipline's role is to work with the structural unit during the investigation phase so that explorations are appropriately located and sufficient for the loads envisioned and other criteria, such as deformation limits. The Geotechnical Professional provides geotechnical recommendations for final design, and the Structural Unit finalizes the design and passes the design to the Highway Design Unit for inclusion in the PS&E. The Geotechnical Professional reviews the PS&E to ensure geotechnical recommendations are addressed.

- **Chapter 11 – Pavements.** The Pavement Discipline performs investigations, analysis and design for pavements, including subgrade considerations, except where subgrade conditions are related to broader issues such as geologic setting. There is some overlap between the investigation needs of the Pavement Discipline and the Geotechnical Discipline and collaboration, including shared resources, is accomplished in different ways by the different Divisions.

  The Geotechnical Discipline's role is to coordinate with the Pavement Discipline to minimize investigation costs and impacts. Additionally, the Geotechnical Professional provides support to the Pavement Discipline when pavement design and performance issues may be related to subsurface conditions and settings that are deep and influenced by geological setting.

6.1.3 INTENDED CHAPTER USE

The *PDDM* is intended for interdisciplinary use by FLH staff and contractors. This chapter of the *PDDM* is written primarily for the Geotechnical Discipline, though it will also be of value to those practicing in related disciplines. Similarly, the Geotechnical Professional will find important guidance for other disciplines in other chapters of the manual and familiarity with this guidance will help in the collaborative, cross-functional team approach to project delivery.

This chapter is intended to be used primarily in two ways. First, it is the source of the highest-level FLH technical guidance and should be used to educate or reacquaint the Geotechnical Professional with the guiding principles, standard practices, and standards of FLH geotechnical work. It identifies "what" needs to be done. If not explicitly included in the chapter, all FLH geotechnical standards can be identified and, in many cases, downloaded from links within the chapter. Second, this chapter is a portal to topic-based information of interest to the Geotechnical Discipline. Within specific topics, this chapter provides links to the appropriate sections of the TGM for institutional experience and guidance on "how" to accomplish certain tasks. Also within these topical areas, the chapter provides convenient and prioritized links and references to primary and secondary sources of technical guidance.

It is the responsibility of all FLH Geotechnical Professionals and consultants to become familiar with the materials presented in this chapter and the TGM and apply them appropriately while performing Geotechnical Discipline work. Any questions involving interpretation of or exception to the content of this chapter are to be referred to the Geotechnical Functional Discipline Leader or Division Geotechnical Team Leaders. Any properly authorized exceptions to the standards in this chapter are to be considered as "one time only" changes, unless otherwise directed. See Section 6.2.3 for making exceptions to standards.

See the Division Supplements for differences in standards or guidance between Divisions and for divisional guidance on processes, and quality control and assurance.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

6.2 GUIDANCE AND REFERENCES

This section provides guidance on technical policies for the geotechnical discipline, risk management, and standards and standard practices. Direction is given on how to use the TGM for technical guidance and for where standards are not applicable. A hierarchy of other technical references is also presented.

6.2.1 POLICIES FOR FLH GEOTECHNICAL DISCIPLINE

The seven technical policies presented in Section 1.1.2 provide high level guidance for the Geotechnical Discipline and are followed without exception. The policies are summarized as follows:

1. **Support the mission, vision and program management objectives of FLH and FHWA**
2. **Meet the technical scope requirements defined by the PDDM**
3. **Advance the state of practice by seeking and implementing new technology**
4. **Demonstrate environmental stewardship in investigations and designs**
5. **Demonstrate financial, cultural and natural resource stewardship**
6. **Conduct work safely and seek safety improvement solutions**
7. **Achieve quality through established quality assurance and oversight procedures**

The policies are general guiding principles and serve the purpose of defining a philosophy, rather than defining specifically what to do. Policies often guide in somewhat different directions. When policies guide in different directions the Geotechnical Professional should use the policies to keep their work and recommendations centered.

The policies are interpretations of agency directives and objectives based on legislation and federal regulations pertaining to FLH project delivery. The following policy sources are most relevant to the Geotechnical Discipline and, in support of the discussion in Section 1.1.2. These sources will help the Geotechnical Professional understand the context of FLH geotechnical work:

1.	23 CFR 625	Code of Federal Regulations Highways Title 23 Part 625.4 specifies that *AASHTO Standard Specifications for Highway Bridges* be followed
2.	NS 23 CFR 635	Federal Aid Policy Guide Transmittal 16 NS 23 CFR 635 (1996) specifies that a differing site conditions clause be incorporated in contracts and directs towards *Geotechnical Engineering Notebook Issuance GT-15* for guidance.

3. FLH Business Plan — *FLH Business Plan* specifies goals of improving safety and of evaluating, reporting and promoting new technology deployment.

4. FLH Safety Memo — *FLH Safety Philosophy* (2004) describes the philosophy of enhancing safety and collaborating with partner agencies relating to safety, which is further explained in Chapter 8.

5. FLHM 3-C-2 — Federal Lands Highway Manual, Chapter 3, Section C, Subsection 2, Transmittal 12 (1983) provides guidelines for deviating from standards if deviation is desirable.

6. FLHM 1-A-1 — Federal Lands Highway Manual, Chapter 1, Section A, Subsection 1, Transmittal 18 (1983) provides overall FLH history, mission, capabilities and program direction.

7. FLHM 1-A-2 — Federal Lands Highway Manual, Chapter 1, Section A, Subsection 2, Transmittal 21 (1983) provides roles and responsibilities, including that policy is issued by FHLO (Headquarters).

Policies are most often followed by using standards and standard practices, but sometimes project specific methods are required to deliver a context-sensitive solution, or otherwise be responsive to our partners' needs. Situations where standards are deviated from in order to follow policy and provide centered recommendations may occur at any project stage. For example, during the investigation phase it may be too invasive or expensive to conduct the full scope of investigations in accordance with AASHTO guidance. After evaluating, communicating and documenting the risks of not doing so, the project may elect to go forward with a non-standard investigation scope. Conversely, a similar process on a different project might arrive at the decision to investigate the subsurface more thoroughly than the AASHTO guidance provides for. These are deviations in standards, not policy.

6.2.2 RISK MANAGEMENT

Risk is inherent in geotechnical work and FLH projects, and it comes in several forms. Risk is incurred with respect to cost when, for example, decisions are made regarding the scope of a geotechnical investigation. A greater investigation scope generally means fewer unknowns are carried into construction, thereby reducing the risk of construction cost escalation. Risk is incurred with respect to serviceability when designs are advanced that do not fully address all possible modes of failure. For example, a slump repair along a road that crosses a much larger, but more slowly moving landslide. Risk is incurred with respect to safety when geotechnical recommendations are incorporated into critical structures such as bridges, walls, and rock slopes. The Geotechnical Discipline's responsibility lies in identifying risks incurred through geotechnical issues, informing project team members and partners of these risks, and assisting in evaluating whether the risks are tolerable.

Risks are more tolerable when they are low relative to the potential benefit of the action incurring the risk. Risk assessment is the process of assessing the probability of adverse consequences associated with activities, recommendations or designs, and for geotechnical matters it is a Geotechnical Discipline responsibility. Risk is also incurred in other disciplines and risk assessment is discussed for all disciplines in Section 1.1.3.

The evaluation of potential benefit of a geotechnically-based risk is not solely a Geotechnical Discipline responsibility as it is an interdisciplinary process requiring involvement of the Project Manager and other disciplines that have knowledge of other project aspects and different perspectives on the value of a potential benefit. The responsibility of the Geotechnical Discipline is to inform and educate the Project Manager, and other team members and stakeholders, as appropriate, of risk based on geotechnical issues and to participate in evaluation of the tolerability of that risk.

The geotechnical policies presented in the previous section help assure that projects have a tolerable level of risk associated with them because they prescribe seeking safety, quality, and following the standards in the *PDDM* and consulting the guidance in the TGM. In fact, on most projects, where standards and standard practices are used, risk assessment and evaluation is often implicit and does not require further attention. For this reason, standards and standard practices are used wherever possible. Standards and standard practices are introduced in Section 6.2.3 and presented throughout the rest of this chapter.

6.2.3 STANDARDS AND STANDARD PRACTICE

Standards are defined in Chapter 1 as a fixed reference to guide the approach (standard practice) and content (standard) of FLH work. Geotechnical standards and standard practices address investigation, sampling, testing, analysis, reporting, design details and special contract requirements. Standards are based on many things, including successful past precedent on FLH projects and they help achieve FLH goals related to risk management, quality and efficiency.

Standards have been established where it has been found that a single approach or product works well in most cases. Standards have a history of use where quality has been demonstrated through successful completion and performance of projects. Standards tend to reduce time during design development and review, reduce bid prices because of familiarity developed within the construction industry, and reduce FLH oversight needs during construction. Project delivery and construction are team endeavors and standards improve efficiency because team members gain greater understanding of what to expect and how to work with what is delivered. Standards also acknowledge an understanding and acceptance of a certain, consistent level of risk.

Standards are not always appropriate in the Geotechnical Discipline. Over standardization can lead to inefficient designs, insensitivity to the context of individual projects, and lack of innovation. Given the wide variety of FLH projects, project constraints, and stakeholder interests, considerable flexibility is needed. This *PDDM* chapter presents a hierarchy of policy, standards, and guidance (through the TGM) to allow flexibility when needed and to also keep the geotechnical practice as standard as possible so that the goals of risk management, quality, and efficiency are realized.

For example, the subsection on "Structure Foundations" (in section "6.4 Analysis and Design") includes the standard to design structure foundations in accordance with the current edition of the AASHTO Standard Specifications for Design of Highway Bridges (AASHTO HB-17). This is a widely accepted standard in the industry and it should be used whenever possible. Note, however, that designing in accordance with AASHTO HB-17 is not a policy and there are occasions where in order to satisfy a centered approach to the policies in Section 6.2.1, the AASHTO HB-17 standard should not be followed.

Another example would be with respect to investigation. Most FLH projects are low volume roads (NPS, USFS Forest Highway, USFS recreation roads, US Fish and Wildlife Service, Forest Highway State and County roads, BLM, and BIA). Very limited geotechnical design guidance exists specifically for low volume roads. One example is the TRB Compendiums 1 through 16 prepared in 1979 (see TGM Bibliography). On many of these low volume road projects, application of investigation standards for high volume roads such as set forth in FHWA-ED-88-053 may be impractical or insufficient and not in accord with Geotechnical Policies, or an acceptable level of contractual risk deemed suitable on that specific project.

When the Geotechnical Discipline determines that variance from existing geotechnical standards is desired, this determination is shared with the Project Manager for concurrence. The Geotechnical Professional writes to the Project Manager to explain the justification for the variance and how the issues of risk management, quality, and efficiency are addressed. Significant variances are first discussed with the Geotechnical Discipline Leader and/or Division Geotechnical Team Leaders for technical endorsement, and may require endorsement of FLH management.

6.2.4 TECHNICAL GUIDANCE

Through specific direction to the TGM and, in some cases, Primary Sources, this manual provides guidance for where standards do not exist and for when it is appropriate to deviate from an existing standard. The TGM presents institutional experience in the form of practices that have worked well in the past on FLH projects and commentary on guidance published elsewhere. The TGM presents considerably more "how to" discussion than this chapter, but does not simply reproduce most of the technical guidance that has been previously published. Rather, the TGM uses extensive links and commentary to technical references to direct the reader to additional published and on-line sources of technical guidance.

6.2.5 TECHNICAL REFERENCES

The guidance in the TGM is supported by published technical references. Primary Sources are the first information sources that the Geotechnical Professional refers to; they either present preferred guidance on how to accomplish a task or, when equal guidance is available through many sources, the Primary Source is most widely available. Secondary Sources are additional documents that are often relied on for FLH work; they present guidance to augment the Primary Source. Primary and Secondary Sources are not standards unless specifically identified as such in this chapter.

Although Primary and Secondary Sources follow the TGM in the succession of guidance, the sources are identified in each of the topical sections of this chapter for convenient reference, especially for the repeat user that knows the contents of the TGM. The complete listing of all Primary and Secondary Sources, which constitutes an excellent FLH geotechnical reference library, is listed in Section 6.6. The TGM includes these sources and has a bibliography that also includes tertiary sources of geotechnical guidance (TGM Bibliography).

6.2.6 STATE DOT REFERENCES

Geotechnical practice commonly includes regional bias related to regional geology, climate, resource availability, etc. State DOTs have often developed practices based on these regional factors and such experience and practice may be reflected in their published guidelines. On occasion, it is necessary to interface with the state DOT or to design according to their standards as a stakeholder and possibly a maintaining agency for the finished project. Published state DOT geotechnical guidance is listed in TGM Section 2.6. Unless specific project criteria direct otherwise, where state DOT guidance differs from FLH guidance presented in this chapter and the TGM, FLH guidance has precedence.

6.3 GEOTECHNICAL INVESTIGATIONS

This section presents FLH standards and links to FLH guidance on site and subsurface investigation. The standard practices, designs and specifications presented in this section have evolved from FLH experience and are used unless an exception is justified as described in Section 6.2.3.

Follow the established quality control and assurance procedures for investigation tasks. Procedures are unique to each Division and can be accessed through Division Supplements.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

6.3.1 PLANNING AND MANAGEMENT

The Geotechnical Discipline's standard practice is to perform and manage geotechnical investigations in accordance with a project-specific plan to characterize surface and subsurface conditions and address specific geotechnical issues, hazards, risks and uncertainties. The Geotechnical Discipline works within project constraints identified by FLH partners, the FLH Project Manager, and the multi-disciplinary Cross Functional Team, and within approved budgets. During project scoping (Exhibit 6.1–B) the scope of geotechnical investigations is developed to be commensurate with the geologic and project complexity, and project constraints.

The Geotechnical Discipline participates in scoping activities with the Cross Functional Team and, if this occurs through an on-site meeting, the Geotechnical Discipline prepares a brief geotechnical scoping report including an overview of project background information and requirements. Whether or not the Geotechnical Discipline attended a site visit, the Geotechnical Discipline prepares preliminary geotechnical recommendations and anticipated site investigation needs for discussion and concurrence with the Project Manager and Cross-Functional Team.

6.3.1.1 Project Requirements

Prior to commencing work and throughout the project, the Geotechnical Discipline seeks a clear understanding of project goals, objectives, requirements, constraints, values, criteria, and funding levels from the FLH Project Manger. The Geotechnical Discipline plans investigations with flexibility to evaluate evolving roadway designs, structure options, and locations.

A standard project investigation includes field reconnaissance, preliminary investigation, and supplemental investigation(s). Field reconnaissance is used to develop an overall scope of explorations. Preliminary investigation is conducted in support of early line and grade planning and project estimation, providing preliminary earthwork requirements, material source availability and suitability, identification of geotechnical hazards, determination of corrosive soil/rock/water conditions, location of substantial drainage issues, and identification of candidate structure foundation types and constructability issues. Supplemental investigations to improve site characterization are used to optimize design and to reduce risk carried into construction.

Supplemental site investigations (if necessary) are conducted in support of intermediate and final PS&E packages, providing the geotechnical information necessary to design structure foundations, mitigate geotechnical hazards related to landslides, rock slopes, etc., design cut and fill slopes, mitigate drainage issues, and support earthwork estimation and management.

For some projects, all investigation, preliminary and supplemental, is conducted at one time and there is essentially no distinction. Investigation plans follow the guidelines in *Subsurface Investigations – Geotechnical Site Characterization* NHI 132031 and include the following standard practices:

- Perform a desk review of available geotechnical information as the first step in planning an efficient geotechnical investigation.
- Plan the exploration program cost-effectively. Utilize the least-expensive method that is capable of obtaining the necessary subsurface information.
- Optimize the use of field reconnaissance, geologic mapping and simple test pits/ test holes to minimize the amount of higher-cost site explorations required (such as drilled borings and specialized in situ tests).
- Consider geophysical methods, selected to identify specific material contrasts, to augment subsurface explorations, possibly reducing the number of borings or other explorations below the standard criteria (Exhibit 6.3–C).
- Develop the exploration program using methods that minimize environmental impacts.
- Plan the investigation program within approved budgets.
- Plan a phased investigation approach with well-defined scopes to align with FLH Division and environmental compliance processes, thereby minimizing unnecessary costs and impacts and supporting the approved schedule. Use each phase of investigation to optimize the value and minimize the impact of subsequent phases. Consider reducing the number of phases when mobilization costs are high

The Geotechnical Discipline uses the investigation plan to manage the field work. The Geotechnical Professional coordinates explorations with the partner agencies, and exploration and traffic control subcontractors, and documents field activities, including:

- Crew participants;
- Equipment used;
- Explorations completed, with photographs;
- Site conditions encountered; and
- Individual logs (records) of surface and subsurface explorations, and samples recovered.

In addition to general roadway investigations, Geotechnical Discipline provides a wide variety of specialized investigations to fulfill the individual partner and specific project needs. Standard practices for roadway, material sources, structures, and landslide geotechnical investigations performed by FLH are provided in Section 6.3.2. Common boring types are presented in Exhibit 6.3–A, and other common types of explorations are presented in Exhibit 6.3–B. Standard practice is to use the exploration types in these exhibits whenever practical.

Standards for minimum boring and sampling frequency are provided in Exhibit 6.3–C and Exhibit 6.3–D, respectively.

Refer to TGM Section 3.1 for guidance on investigation tasks.

The primary source supporting investigation standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

6.3.1.2 Typical Project Practice

The primary purpose of site and subsurface geotechnical investigations is to provide design engineers with knowledge of the subsurface conditions, any geohazards, and available soil, aggregate and rock resources. The investigation also provides the construction project engineers and contractors with information concerning the materials and conditions that are expected to be encountered. A variety of standard investigations are performed to fulfill individual project needs, as described in the following subsections.

6.3.1.2.1 Roadway Alignment and Earthwork Investigations

Soil Cut and Fill Slopes – Conduct soil slope investigations, including surface and subsurface exploration, sufficient to support the development of stable slope designs for all soil cut and fill slopes. Assess material suitability for project needs. Investigation methods range from visual reconnaissance of existing surface conditions at shallow cuts to drilling, sampling, testing and instrumentation of critical slope designs. Use the methods and practices described throughout Section 6.3.2 and the minimum standards in Exhibit 6.3–C and Exhibit 6.3–D. Guidelines for cut slope investigations are in TGM Section 3.1.2.1. Pavement subgrade is addressed by the Pavement Discipline as described in Chapter 11.

Rock Slopes – Ascertain the relative performance of existing rock slopes on roadway projects, identifying hazard potentials and risks associated with slope failures, and incorporating the findings in recommended hazard mitigation methods for existing and planned rock slope excavations. Conduct rock mass investigations, including structure mapping and subsurface exploration, sufficient to support slope designs that mitigate significant rock mass failures and recurring rock fall hazards for rock cut slopes greater than 15 ft [5 m] high. Use the methods and practices described throughout Section 6.3.2 and the minimum standards in Exhibit 6.3–C and Exhibit 6.3–D. Guidelines for rock slope investigations are in TGM Section 3.1.2.1.

6.3.1.2.2 Material Sources

Government-Owned - Provide materials type, estimated quantity, and quality, and source accessibility, development, and reclamation information sufficient to support earthwork, construction materials, and paving materials planning and quantities estimation. If data are not available and investigation is required, FLH standard practice is defined throughout Section 6.3.2. Material source investigation guidelines are in TGM Section 3.1.2.2.

Commercial – In the absence of government-owned material sources, identify potential commercial sources and confirm quality and quantity availability for the various materials and aggregates required on the project.

Contractor Provided – Verify, through contractor submitted samples, that the proposed source meets the project rock quality requirements.

6.3.1.2.3 Structures

Conduct subsurface investigations for all significant structures (bridges, retaining walls, ground anchors, large culverts, etc.). Plan the investigation to include evaluation of all candidate foundation types and long-term performance requirements. Use the methods and practices described throughout Section 6.3.2 and the minimum standards in Exhibit 6.3–C and Exhibit 6.3–D. Guidelines for structure investigations are in TGM Section 3.1.2.3.

6.3.1.2.4 Landslides

Investigate surficial extent, depth, strength parameters, surface and ground water conditions, and seasonal movement of landslides with the potential to adversely impact roadway projects and monitor stability concerns throughout construction. Use the methods and practices described throughout Section 6.3.2 and the minimum standards in Exhibit 6.3–C and Exhibit 6.3–D. Guidelines for landslide investigations are in TGM Section 3.1.2.4.

6.3.1.2.5 Pavement Subgrade

The Pavements Discipline performs subgrade investigations, as described in Chapter 11. The Geotechnical Discipline coordinates with the Pavements Discipline when geotechnical investigations are also needed. For example, if the project includes constructing embankment and paving on the embankment section then the Geotechnical Discipline provides data on the material source, whether it is from cuts or an offsite location. The need for samples is discussed with the Pavements Discipline.

> Refer to TGM Section 3.1 for guidance on investigation tasks.
>
> The primary source supporting investigation standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

6.3.1.3 Safety

It is FLH standard practice to perform geotechnical work using safety practices that strive to minimize the risk of injury to the field crew and traveling public. The nature of the equipment used and climatic conditions often encountered present potential hazards that require site-specific safety evaluation. It is the responsibility of the Geotechnical Discipline and field crew members to adjust the investigation program and/or provide equipment, training, and other means to provide safe working conditions. These standard safety practices apply:

- Prepare a safety plan for use by field staff, including unique safety practices that apply to specific projects or are required by partner agencies, emergency contact information, and considerations for first aid in the event of an injury.
- Plan appropriate traffic control, consistent with road/traffic conditions, partner agency requirements, the MUTCD and local codes.
- Provide training and other means to provide safe working conditions. Drilling safety procedures can be found in the *National Drilling Association (NDA) Drilling Safety Guide.*
- Arrange for utility locates to identify probable locations of buried utilities that could potentially create hazards to subsurface explorations. Identify overhead power lines. Guidance on safety as related to utility location is in TGM Section 3.1.3.
- Follow applicable state and federal safety regulations pertaining to job site safety and management of hazardous materials. On-site safety requirements are defined in OSHA Section 29.

Refer to TGM Section 3.1.3 for guidance on safety.

The primary sources supporting safety standards and guidance are NDA for drilling and MUTCD for traffic. Secondary sources are BOR Drillers Safety, USACE EM 1110-1-1804, and FHWA-CFL/TD-05-00.

6.3.2 METHODS AND PRACTICE

FLH standard practice is to use appropriate methods for recovering physical samples of soil and rock strata for testing, and for characterizing subsurface materials and conditions in-situ. This means that multiple methods of investigation and sampling are generally needed for each project. This section presents standard methods and practices for:

- Surface and subsurface exploration;
- Logging and sampling;
- Laboratory and in-situ testing; and
- Instrumentation and monitoring.

6.3.2.1 Preliminary Study and Reconnaissance

After the preliminary planning described in Section 6.3.1, it is standard practice for the Geotechnical Discipline to perform a preliminary study and reconnaissance to identify and preliminarily address geotechnical issues, hazards, risks, and project constraints. Base the site study and reconnaissance on a clear understanding of project goals, objectives, constraints, values and criteria. Perform tasks to the extent necessary to disclose the probable materials and conditions to be encountered. Include an assessment of risk and uncertainty associated with each of the preliminarily recommended design options. Multiple design alternatives are often advanced at this stage.

Refer to TGM Section 3.2.1 for guidance on preliminary study and reconnaissance.

The primary supporting sources are NHI 132031 for office and field work, and FHWA-ED-88-053 for reporting. Secondary sources are AASHTO MSI-1 and USACE EM 1110-1-1804.

6.3.2.2 Surface Exploration Methods

Use appropriate surface exploration methods corresponding with project needs and goals. Standard surface exploration methods include field reconnaissance, wherein visual observations are recorded according to stationing, mile post or other location information such as GPS coordinates. Geologic mapping is standard where preliminary study indicates geologic features and rock units have direct bearing on project design or construction, and suitable geologic mapping does not already exist. Field-developed sketched cross sections or digital photographs are standard at locations of explorations and key features.

Refer to TGM Section 3.2.2 for guidance on surface exploration methods.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and NHI 132035.

6.3.2.3 Subsurface Exploration Methods

Subsurface investigation methods most commonly include drilled borings, and/or excavated test pits and trenches. Drilling is the standard and preferred method for subsurface exploration and sampling. Use the appropriate exploration methods for the anticipated ground conditions to optimize surface and subsurface characterization and sample recovery for roadway and structure design.

6.3.2.3.1 Geotechnical Equipment

FLH standard practice is to use equipment that is most advantageous to the project. This may be in-house drilling or geophysics equipment, or it may require rental of equipment or contract of equipment and services.

Guidance for selection of the applicable exploration methods is tabulated in Exhibit 6.3–A (borings) and Exhibit 6.3–B (probes, test pits, trenches and shafts). FLH standards on these methods and the steps of subsurface investigation are in the following subsections. Additional guidance on methods is in TGM Section 3.2.4.

6.3.2.3.2 Geophysical Methods

Evaluate the potential use of geophysical methods and the value they might add in terms of improved understanding of subsurface conditions, lower impact and/or cost, etc. Though geophysics may be used under other circumstances, standard practice is to incorporate geophysical methods where they are likely to lead to lower overall investigation, design and/or construction costs. Multi-channel seismic refraction with a sledge hammer source is the standard method used to help identify depth to bedrock and excavation requirements (e.g. rippability), and to extrapolate between borings. Other methods may be more appropriate for specific projects or other project needs.

Refer to TGM Section 3.2.3.2 for guidance on geophysical methods.

The primary source supporting the guidance is FHWA-Geophysical. Secondary sources are NHI 132031 and USACE EM 1110-1-1802.

Exhibit 6.3–A TEST BORINGS: TYPES AND APPLICATION

Boring Method	Procedure Utilized	Applicability
Auger Boring (AASHTO T203)	Hand or power operated augering with periodic removal of material. In some cases continuous auger may be used requiring only one withdrawal. Stratum changes indicated by examination of material removed.	Probe investigations to bedrock and shallow disturbed soil samples, typically less than 20 ft [6 m] in depth. <u>Typical Uses</u> Disturbed soil sampling. Determine overburden depth.
Hollow-Stem Auger (AASHTO T251)	Power operated augering. Hollow stem serves as casing.	General purpose drilling method for soil and very weak rock locations requiring a cased hole. <u>Typical Uses</u> Disturbed/undisturbed soil sampling. In situ testing. Foundation investigations.
Rotary Drilling (AASHTO T225)	Power rotation of drilling bit as circulating fluid removes cuttings from hole. Stratum changes indicated by rate of progress, action of drilling tools, and examination of cuttings in drilling fluid. Casing usually not required, except near surface.	Relatively fast and economical method to advance borings through wide variety of materials, including large boulders and broken rock. <u>Typical Uses</u> Obtaining rock cores. Probe drilling. Instrumentation installation. Foundation, landslide, and rock cut investigations.

Boring Method	Procedure Utilized	Applicability
Wire-Line Drilling	Rotary-type drilling method where coring device is integral part of drill rod string, which also serves as casing. Core samples obtained by removing inner barrel assembly from core barrel portion of drill rod. Inner barrel is released by retriever lowered by wire-line through the drilling rod.	Efficient method for recovering quality core samples of rock. <u>Typical Uses</u> General rock coring applications. Foundation, landslide, rock cut, and material source investigations.
Air Drilling	Uses compressed air to remove cuttings from the borehole as drilling advances. Both rotary and percussion techniques can be used with either open-hole (rotary reverse circulation) or under-reamed casing advancement (ODEX). SPT samples possible; however, materials between samples are highly disturbed.	This type of drilling is generally fast, but expensive. <u>Typical Uses</u> Deep holes in dense gravels and boulders where Hollow Stem Auger and Rotary methods cannot drill or sample effectively. Fast-moving landslides. Rock anchor drilling.

Exhibit 6.3–B USE OF PROBES, TEST PITS, TRENCHES AND SHAFTS

Exploration Method	General Use	Advantages and Capabilities	Limitations
Hand Auger Probes	Bulk sampling. Visual inspection. Depth of shallow soft deposits and top of shallow bedrock.	Useful in difficult access areas. Results in minor ground disturbance. Rapid, cost-effective exploration. Good for shallow deposits (< 15 ft [5 m] deep).	Difficult to advance in rocky or dense materials.

Exploration Method	General Use	Advantages and Capabilities	Limitations
Hand-Excavated Test Pits and Shafts	Bulk sampling. Visual inspection. In situ testing. Depth of shallow bedrock and groundwater.	Useful in difficult access areas. Results in less disturbance of surrounding ground.	Relatively time-consuming and expensive. Limited to depths above groundwater level.
Backhoe-Excavated Test Pits and Trenches	Bulk sampling. Visual inspection. In situ testing. Rapid excavation rates. Depth of shallow bedrock and groundwater.	Rapid, cost-effective exploration. Depths up to 20 ft [6 m] can be explored.	Limited equipment access. Generally limited to depths above groundwater level. Limited undisturbed sampling. Significant surrounding ground disturbance.
Drilled Shafts	Bulk sampling. Visual inspection. In situ testing. Depth of bedrock and groundwater. Pre-excavation for piles and shafts. Landslide investigations. Drainage wells.	Rapid, cost-effective exploration (compared to hand methods). Minimum 2.5 ft [0.75 m] to maximum 6 ft [2 m] diameter.	Limited equipment access. Costly mobilization. Visual inspection possibly obscured by casing. Limited undisturbed sampling. Significant surrounding ground disturbance.
Dozer Cuts	Bulk sampling. Visual inspection. In situ testing. Rapid excavation rates. Depth of shallow bedrock and groundwater. Rippability determinations. Increase backhoe depth capabilities. Provide access for other exploration equipment.	Rapid, cost-effective exploration (compared to hand methods). Provides exposures for geologic mapping.	Limited equipment access. Generally limited to depths above groundwater level. Limited undisturbed sampling. Significant surrounding ground disturbance.

6.3.2.3.3 Drilling and Soil Sampling

Drilling and sampling is the most common means of subsurface exploration. Standards are presented in Exhibit 6.3–C for boring layout and depth with respect to structure types, locations and sizes, and proposed earthwork. Standard drilling methods include hollow-stem auger in soils and wire-line core drilling in rock. Rotary-wash, casing advancer, solid-stem auger and other methods are also used to fulfill specific project needs.

Exhibit 6.3–C STANDARDS FOR BORING LAYOUT AND DEPTH

Geotechnical Feature	Minimum Boring Layout	Minimum Boring Depth
Structure Foundation	A minimum of two borings for piers or abutments over 100 ft [30 m] wide. A minimum of one boring for piers or abutments under 100 ft [30 m] wide. Provide additional borings in areas with erratic subsurface conditions.	All borings extend below estimated scour. Spread Footings (on soil) 2B where L < 2B; 4B where L > 5B; and Interpolate between 2B and 4B when 2B ≤ L ≤ 5B. (L is footing breadth and B is footing width.) Deep Foundations In soil, 20 ft [6 m] below tip elevation or twice maximum pile group dimension, whichever is greater. For piles on rock, 10 ft [3 m] into bedrock below tip elevation. For shafts on rock, extend borings below tip elevation 10 ft [3 m] into bedrock or 3D into bedrock for isolated shafts or twice the maximum shaft group dimension into bedrock, whichever is greater. (D is shaft diameter.)
Retaining Structures	A minimum of one boring for each retaining structure. Space borings every 100 ft [30 m] to 200 ft [60 m]. Characterize wall toe and anchorage zones with additional borings, as needed.	Extend borings 0.75 to 1.5 times the retaining structure height. When stratum indicates potential deep stability or settlement problem, extend borings to hard stratum. For deep foundations, use Structure Foundation criteria above.

Geotechnical Feature	Minimum Boring Layout	Minimum Boring Depth
Cuts and Embankments	A minimum of one boring per cut slope. Space borings every 200 ft [60 m] (erratic conditions) to 400 ft [120 m] (uniform conditions), with one boring per landform. Place borings in high cuts and fills perpendicular to the roadway to establish geologic cross-sections. Use additional shallow explorations to determine depth and extent of topsoil and/or unsuitable surface soils.	Cuts: In stable materials, 15 ft [5 m] below depth of cut at the ditch line. In weak materials, extend borings to firm materials or twice the cut depth, whichever is less. Embankments: Extend borings to a firm stratum or to a depth twice the embankment height, whichever is less.
Landslides	Place borings perpendicular to the roadway to establish geologic cross-sections for analysis. Locate at least one boring above the sliding area.	Extend borings below failure surface into firm stratum, or to a depth which failure is unlikely. Extend inclinometers below the base of the slide.
Culverts	A minimum of one boring per major culvert. Perform additional borings for long culverts or in areas of erratic subsurface conditions.	Use criteria presented above for embankments.
Material Sources	Space borings every 100 ft [30 m] to 200 ft [60 m].	Extend borings 5 ft [1.5 m] beyond the base of the deposit or depth required to provide needed quantity.

Note: Table is modified from FHWA Geotechnical Checklist and Guidelines (FHWA-ED-88-053) as discussed in TGM Section 3.2.3.3.

Select the most appropriate drilling technique to achieve the project specific information and sampling requirements. Do not use equipment design for other site conditions or purposes and expect to get adequate subsurface characterization and sample recovery. Sampling type and frequency is dependent upon both the type of material encountered and the purpose of the investigation. Disturbed and undisturbed samples can be obtained with a number of different sampling devices. The split barrel from the Standard Penetration Test (SPT) is the standard disturbed soil sampling method. Minimum disturbed and undisturbed soil and rock sampling standards are presented in Exhibit 6.3–D.

Exhibit 6.3–D MINIMUM STANDARDS FOR SAMPLING AND TESTING FROM BORINGS

Material	Sampling and Testing Criteria
Sand-Gravel Soils	• Obtain SPT (split-spoon) samples at 5 ft [1.5 m] intervals, or at significant changes in soil strata. • Continuous SPT samples are obtained in the top 15 ft [4.5 m] of borings at locations where spread footings may be placed in natural soils. • Submit representative SPT jar or bag samples to the lab for classification testing and verification of field visual soil identification.
Silt-Clay Soils	• Obtain SPT and undisturbed thin-wall tube samples at 5 ft [1.5 m] intervals or at significant changes in strata. Obtain a sufficient number of samples, suitable for the types of testing intended, within each soil layer. • Take alternate SPT and tube samples in the same boring, or take tube samples in separate undisturbed boring. • Submit representative SPT jar or bag samples to the lab for classification testing and verification of field visual soil identification. • Submit representative tube samples to the lab for consolidation testing (for settlement analyses) and strength testing (for slope stability and foundation bearing capacity analyses).
Rock	• Obtain continuous cores using double or triple tube core barrels. Photograph rock core as soon as possible after being taken from the boring and before shipping core boxes. • For structural foundation investigations, core a minimum of 10 ft [3 m] into rock to ensure it is bedrock and not a boulder. • Determine percent core recovery and Rock Quality Designation (RQD) in the field for each core run, and record on the boring log. • Submit representative core samples to the lab for unconfined compressive strength testing (foundation bearing capacity analyses, rock mass classification, and modulus estimation).
Groundwater	• Record water level encountered during drilling, at completion of boring, and (if boring remains open) 24 hours after completion of boring. • In low permeability soils, such as silts and clays, a false indication of the water level may be obtained when water is used as the drilling fluid and adequate time is not permitted after hole completion for the water level to stabilize (more than one week may be required). In such soils and where water level is critical to design, install a plastic standpipe observation well to allow monitoring of the water level over a period of time. • Determine seasonal fluctuation of the water table where such fluctuation will have a significant impact on design or construction (e.g., borrow sources, footing excavation, excavations at toe of landslide, etc.). • Measure and record zones of artesian water and seepage.

Material	Sampling and Testing Criteria
Soil Borrow Sources	• Use backhoes, dozers, or large diameter augers where possible for exploration above the water table. • Use borings for exploration extending below the water table. Obtain SPT (split-spoon) samples at 5 ft [1.5 m] intervals, or at significant changes in soil strata. • Submit representative SPT jar or bag samples to the lab for classification testing and verification of field visual soil identification. • Record groundwater levels. Install piezometers or observation wells to monitor water levels where significant seasonal fluctuation is anticipated.
Rock Quarry Sources	• Utilize rock coring to explore new quarry sites. Use double or triple tube core barrels to maximize core recovery. • For riprap source, measure rock mass fracture spacing to assess riprap sizes that can be produced by blasting. • For aggregate sources, note the amount and type of joint in-filling. • Base source assessment on exposed quarry face only if exposures are large relative to required quantities and quality is apparently very good with respect to requirements; otherwise augment with coring or geophysical techniques to verify that the nature of the rock does not change behind the face or at depth. • Submit representative core samples to the lab for rock quality tests to determine suitability for riprap or aggregates.

Note: Table is modified from FHWA Geotechnical Checklist and Guidelines (FHWA-ED-88-053) as discussed in TGM Section 3.2.3.3.

Refer to TGM Section 3.2.3.3 for guidance on drilling and sampling.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

6.3.2.3.4 Rock Coring

Use rock coring techniques to explore and sample bedrock, and to confirm bedrock locations beneath structures. Use double or triple tube core barrels to minimize disturbance. Measure and record percent recovery and Rock Quality Designation (RQD) as soon as the core is recovered, and classify the rock according to Exhibit 6.3–F. Log rock coring in accordance with the standards in Section 6.3.2.5.

Refer to TGM Section 3.2.3.4 for guidance on rock coring.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

6.3.2.3.5 Test Pits, Trenches, and Surface Exposures

Use surface exposures, test pits and trenches in lieu of drilling to quickly and cost-effectively investigate soils and highly weathered rock masses when shallow explorations (< 15 ft [5 m] deep) are planned. Use test pits and trenches only when the impact to the site is acceptable. Follow safety standards in Section 6.3.1.2.

Bulk disturbed soil samples are collected from distinct material types in test pits, trenches and exposures. Where practical obtain samples large enough to include representative gradation. Otherwise, note that this was not done and describe presence of larger particles. Tube samples and plastic bags of smaller samples are collected for in-situ water content and density when this information might be representative and useful.

Standard rock sampling includes "grab" samples obtained from outcrops or test pits. Obtain sample sizes small enough to carry, but large enough to be tested in a point load device or used as hand specimens. Label grab samples with the location where they were obtained and identify the location on a site map.

> Refer to TGM Section 3.2.3.5 for guidance on various explorations and sampling.
>
> The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and CalTrans 2001.

6.3.2.3.6 Boring and Test Pit Closure

Backfill and/or seal abandoned boreholes in consideration of guidelines for boring closure in TGM Section 3.2.3.6. Minimum standard practice is to backfill and compact all test pits to match original grade and replace conserved topsoil or revegetate with an owner-approved mulch/seed mix. Minimum standard practice for borings is use of cuttings, bentonite or grout in consideration of the guidelines in the TGM. Borings through asphalt pavement are covered with asphalt cold patch.

> Refer to TGM Section 3.2.3.6 for guidance on closing exploration sites.
>
> The primary source supporting the standards and guidance is NHI 132031. Secondary sources are NCHRP RR 378 and AASHTO R 22-97.

6.3.2.3.7 Care and Retention of Samples

Collect, transport, and store rock and soil samples in a manner suitable for maintaining sample integrity prior to testing, and for maintaining the character and integrity of the sample for review by engineers and contractors. Retain representative soil samples and all untested rock core samples until the construction contract is awarded, or longer if Division or project-specific requirements are set.

Refer to TGM Section 3.2.3.7 for guidance on care and retention of samples.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

6.3.2.4 Soil and Rock Classification

FLH standard practice is to classify soils in accordance with the ASTM Unified Soil Classification System (USCS) and/or the AASHTO Soil Classification System (NHI 132031). Field classification of soil and rock follow the standards presented in Exhibit 6.3–E and Exhibit 6.3–F, respectively. Rock and rock mass descriptions and classification follow the ISRM classification system presented in GEC-5.

Refer to TGM Section 3.2.4 for guidance on soil and rock classification.

The primary source supporting the standards and guidance is NHI 132031 and the secondary source is GEC-5.

6.3.2.5 Exploration Logs

FLH standard practice is to prepare exploration logs within the gINT™ boring/test pit log platform, though a variety of presentation formats may be used to best represent the field data. Use standardized logging and data collection forms for all field measurements to ensure accurate, concise, and consistent data management. Collect data during the field work on a field log and revise this log later to be a final log by including laboratory test data. The log is a record of factual data and observations, interpretations are generally not included and if they are they are explicitly identified as such.

Logs have a heading that identifies who did what, when, where and how. Otherwise they are a factual record of materials encountered versus depth using a consistent description format that is explained either on the log or on an attached legend sheet. Logs include sample types and locations, and also include other observations such as progress, water, and remarks by drillers. FLH does not have a standard format but uses the example in NHI 132031 for reference.

Refer to TGM Section 3.2.5 for guidance on exploration logging.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and GEC-5.

Exhibit 6.3–E FIELD CLASSIFICATIONS FOR SOIL

Particle Size Limits of Soils Constituents[1]		Cohesive Soils[2]			Granular Soils[2]	
Constituent	Sieve Size	Consistency	Field Identification	SPT Resistance	Relative Density	SPT Resistance
Boulder (BLDR)	12” [305 mm] +	Very Soft	Easily penetrated 4”-6” [100-150 mm] by fist.	0-1	Very Loose	0-4
Cobble (COBB)	3” to 12” [75 to 305 mm]	Soft	Easily penetrated 2”-3” [50-75 mm] by thumb.	2-4	Loose	5-10
Gravel (GR)	No.4 to 3” [4.75 to 75 mm]	Firm	Penetrated 2”-3” [50-75 mm] by thumb with moderate effort.	5-8	Medium Dense	11-30
Sand (SA)	No. 200 to No. 4 [0.075 to 4.75 mm]	Stiff	Readily indented by thumb, but penetrated only with great effort.	9-15	Dense	31-50
Silt (SL)	2 to 75 μm	Very Stiff	Readily indented by thumb.	16-30	Very Dense	50+
Clay (CL)	Less than 2 μm	Hard	Indented with difficulty by thumbnail.	31-60		
		Very Hard	Cannot be indented by thumbnail.	>60		

[1] *ASTM D653.*

[2] *N’ from Standard Penetration Test, AASHTO T-206-87(2000)*

6.3.2.6 In Situ Testing

The Standard Penetration Test (SPT) is the standard in situ test for FLH site investigations and is performed whenever subsurface conditions and drilling methods allow the use of this test. Automatic hammers are preferred to the “cathead” method. N-values and N-values corrected for energy ratio and overburden are used to evaluate soil variability and to estimate soil density and shear strength parameters.

Refer to TGM Section 3.2.6 for guidance on applying the SPT and other in-situ testing.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are FHWA-SA-91-043 and FHWA-SA-91-044.

Exhibit 6.3–F FIELD CLASSIFICATIONS FOR ROCK

Rock Strength			Rock Quality		Weathering	
Description (Grade)	Field Identification	Uniaxial Compressive Strength	Structural Quality	RQD[1]	Description (Grade)	Field Identification
Extremely Weak (R0)	Indented by thumbnail.	36-145 psi [0.25-1.0 MPa]	Very Poor	0-25%	Fresh (I)	No visible sign of weathering. Slight discoloration on major discontinuity surface possible.
Very Weak (R1)	Crumples under firm blows with point of geologist pick. Can be peeled by pocket knife.	145-725 psi [1.0-5.0 MPa]	Poor	25-50%	Slightly Weathered (II)	Rock discolored by weathering, and external surface somewhat weaker than in its fresh condition.
Weak (R2)	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow of point on geologists pick.	0.73-3.6 ksi [5.0-25 Mpa]	Fair	50-75%	Moderately Weathered (III)	Less than half of the rock is decom-posed and/or disintegrated to soil. Fresh or discolored rock present as discon-tinuous frame-work/corestones.
Medium Strong (R3)	Cannot be scrap-ed or peeled with a pocket knife. Specimen can be fractured with single firm blow of hammer end of geologist pick.	3.6-7.3 ksi [25-50 MPa]	Good	75-90%	Highly Weathered (IV)	More than half of rock is decompos-ed and / or disint-egrated to soil. Fresh or discolor-ed rock present as discontinuous framework / corestones.
Strong (R4)	Specimen requires more than one blow with hammer end of geologist pick to cause fractures.	7.3-14.5 ksi [50-100 Mpa]	Excellent	90-100%	Completely Weathered (V)	All rock is decomposed and / or disintegrated to soil. Original mass structure is still largely intact.

Rock Strength			Rock Quality		Weathering	
Description (Grade)	**Field Identification**	**Uniaxial Compressive Strength**	**Structural Quality**	**RQD[1]**	**Description (Grade)**	**Field Identification**
Very Strong (R5)	Specimen requires many blows of the hammer end of geologist pick to cause fractures.	14.5-36 ksi [100-250 MPa]			Residual Soil (VI)	All rock material is converted to soil. Mass structure and fabric are destroyed, but apparent structure remains intact. May be a in change in volume, but soil has not been significantly transported.
Extremely Strong (R6)	Specimen can only be chipped with geologist pick	> 36 ksi [250 Mpa]				

Note: Modified from Evaluation of Soil and Rock Properties, GEC-5.
[1] *"Rock Quality Designation"*

6.3.2.7 Laboratory Testing

FLH standard practice is to routinely perform laboratory and index property tests to verify field classifications and quantify material properties. Appropriate testing methods are dependent on materials encountered and on project requirements so they are not standardized. A laboratory testing plan is developed prior to exploration based on anticipated sample recovery and materials. The plan is finalized after exploration and sampling to best use the recovered materials to find the material properties and parameters needed for design and construction. Standard practice is to conduct relatively few complex tests, such as tests for shear strength or compressibility, and to use index tests to extrapolate their results to the extent practical.

Minimum testing standards are defined in Exhibit 6.3–D. Whenever possible, laboratory tests are performed according to standards of AASHTO. ASTM Standards are followed if AASHTO does not have an appropriate standard. Tests that are not standards of AASHTO and ASTM are seldom used and if they are specific laboratory procedures are included with laboratory reporting.

> Refer to TGM Section 3.2.7 for guidance on laboratory testing.
>
> The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and AASHTO Stds HM-25-M.

6.3.2.8 Instrumentation and Monitoring

Install and monitor instrumentation where necessary to answer specific critical questions relevant to project features and designs. Instrumentation is commonly used to measure water table depth and fluctuation, and/or slope movement. Standard instruments are standpipe piezometers, slope inclinometers and surface monuments. Prepare an instrumentation and monitoring plan to include: (1) the safety or economic justification for instruments and monitoring, (2) the timely monitoring of instrumentation to capture seasonal or other expected variations in ground conditions and displacements, (3) detailed and standardized data collection and record keeping processes, and (4) timely communication of findings to the design team members.

It is standard practice to install groundwater and ground deformation instrumentation at major landslides potentially impacting planned roadway construction. Locate deformation instrumentation within the slide in a manner supportive of slope and structure analyses, and install as early in the roadway design process as possible to maximize the monitoring period. Even though design and construction decisions will have been made, continue monitoring through design, and construction, if practicable. Convey results to Cross Functional Team and Project Manager with geotechnical interpretation of observations.

Refer to TGM Section 3.2.8 for guidance on instrumentation and monitoring.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are AASHTO MSI-1 and NHI 132012.

6.4 ANALYSIS AND DESIGN

This section presents FLH standards and links to FLH guidance for geotechnical analysis and design recommendations. Standards and standard practices presented in this section have evolved from FLH experience and are to be used unless an exception is justified (Section 6.2.3). In many cases, standards are not provided for many geotechnical analysis and design tasks because the needs are project-specific; consult TGM Section 4 for guidance if no standard exists and for further guidance where one does.

Standard practice for FLH is to do analysis and provide design recommendations for structures in accordance with *Standard Specifications for Highway Bridges*, AASHTO HB-17. There are many aspects of FLH geotechnical work not covered by AASHTO HB-17. Accordingly, standards presented in this section and the referenced guidance are to be used for design of earthwork, rock slopes, rockfall mitigation, landslide stabilization, dewatering, drainage and other geotechnical items not addressed by AASHTO HB-17. Referenced guidance is also for where AASHTO HB-17 requirements for foundations and retaining structures are deemed to be impractical or not inline with the project objectives or FLH technical policy (Section 6.2.1). Such determination is made by the Geotechnical Discipline following multi-disciplinary Cross Functional Team discussion of project objectives and geotechnical risks associated with alternate solutions either not addressed or not in accordance with AASHTO HB-17.

Follow the established quality control and assurance procedures for analysis and design tasks. Procedures are unique to each Division and can be accessed through Division Supplements.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

6.4.1 EVALUATION OF DATA, PROJECT REQUIREMENTS, AND DESIGN PARAMETERS

The first phase of the analysis and recommendations stage of project work is to evaluate the data present and the needs of the project. Evaluate if the data are suitable, the project needs are understood, and the appropriate scope of analysis is included in the budget. Evaluate if the data are suitable to support the analyses necessary to identify feasible design options, including assessments of cost, risk and uncertainty associated with each. Standard practices for data evaluation are as follows:

- Confirm understanding of project requirements and design criteria. Review preliminary plans and provide guidance and recommendations on geotechnical issues involving roadway alignment selection and the type, size, and location of roadway structures.
- Evaluate the accuracy and relevance of the available geotechnical data and whether they were collected according to standard or documented procedures. Section 6.3.2 provides standard site investigation methods and practices.
- Confirm suitability of data. Recommend supplemental explorations when additional geotechnical information is needed.

- Organize, tabulate, and format the field and laboratory data in order to extract suitable soil and rock properties and design parameters, and representative subsurface profiles and cross-sections supportive of required roadway and structure analyses.
- Document design parameters and design assumptions provided by others.
- Select values for geotechnical properties and design parameters with an understanding of uncertainty and variability. Refer to Section 6.2.2 for geotechnical discussion of risk management.

> Refer to TGM Section 4.1 for guidance on data evaluation.
>
> The primary source supporting the standards and guidance is GEC-5. Secondary sources are NHI 132031 and EPRI EL-6800.

6.4.2 SCOPE OF ANALYSIS

Perform analyses to address specific project requirements. FLH standard practice is to use simple, inexpensive methods when they suffice, such as simply inspecting and comparing with precedent on the project or in the vicinity. These methods usually suffice when there is abundant precedent and the consequence of failure is low. An example is new cut slopes of less than 15 feet [5 meters] height on a route that contains many such stable slopes already.

Use more rigorous methods where there is not ample precedent and where the consequence of failure is more significant. Most structures and some earthwork features (embankments and cuts) fall into this category. For unique conditions and uncertainties, project features, or project risk tolerance, use multiple methods to evaluate the same design criteria. For example, combine limit equilibrium and finite element analysis of slope stability, or use alternate methods of drilled shaft capacity or settlement.

Conduct analyses and provide recommendations to accommodate evolving roadway and structure options and locations by providing recommendations that can be used for a variety of configurations where possible (e.g. plots of bearing capacity versus depth and diameter for drilled shafts). Regardless of how simple or rigorous the analyses are, maintain analyses and calculations, including problem statements, given input, assumptions, reasoning, solution, and conclusions in a file.

> Refer to TGM Section 4.2 for general guidance on analysis.
>
> The primary source supporting the standards and guidance is FHWA-ED-88-053.

6.4.3 STRUCTURE FOUNDATIONS

FLH Geotechnical Discipline standard is to follow AASHTO HB-17 for design of foundations for structures wherever practical. Select and design foundations based on AASHTO requirements to meet minimum requirements for static and seismic loading and limiting settlement. Use AASHTO recommended minimum and typical ranges for factor of safety under static conditions, and design bridge foundations for a minimum service life of 75 years. Provide seismic analysis input based on the requirements of AASHTO Division I-A. Additional FLH standard practices are listed here for analysis and design of shallow and deep foundations.

Coordinate with the Structures Discipline, Design Discipline, and Hydrology and Hydraulics Discipline to select the most appropriate foundation type(s) for a given structure based on geotechnical subsurface investigations, material testing results, surface and groundwater issues, and design constraints. Specifically, select the foundation type based on an assessment of the magnitude and direction of loading, depth to suitable bearing materials, potential for liquefaction, undermining or scour, swelling potential, frost depth and ease and cost of construction. Provide effective peak firm ground acceleration and probability of exceedence based on AASHTO or USGS Hazmaps. Classify the site according to the AASHTO Standard Specifications for Highway Bridges seismic site soil profile "Type" classification and corresponding site coefficient factor, "S".

Guidelines for general foundation selection are presented in TGM Exhibit 4.3-A and *Soils and Foundations Workshop*, NHI 132012. The standard foundation selection process includes the following steps:

- Identify the type of superstructure and loads to be applied to the foundation.
- Define and summarize subsurface conditions.
- Assess the applicability of each type of foundation for their capability of carrying the required loads and estimate (qualitatively) the amount of settlement that is likely.
- Eliminate obviously unsuitable foundation types and prepare detailed studies and/or tentative designs for suitable foundation types.
- Select and recommend the foundation type that meets structure requirements, is best suited for site subsurface conditions, and is the most economical. Consider spread footings, driven piles, drilled shafts and micropiles first and, if these aren't well suited to the project, then consider alternative solutions (auger-cast piles, rammed aggregate piers, etc.).
- Document expected site and subsurface conditions that could significantly impact construction of the selected foundation type in a Geotechnical Advisory Statement for inclusion in the geotechnical report and contract documents.

Design all foundation elements per the AASHTO service load approach (SLD) unless the project specific design requirements specify use of the load and resistance factor design approach (LRFD). Use the safety factors for static loading conditions (interim ASD designs) presented in Exhibit 6.4–A. Consult TGM Section 4.3 for guidance on selecting values within given ranges.

Provide foundation recommendations for the range of candidate foundation types, anticipated site conditions, and anticipated foundation loads.

Refer to TGM Section 4.3 for general guidance on structure foundations.

The primary source supporting the standards and guidance is NHI 132012. Secondary sources are FHWA-ED-88-053 , AASHTO HB-17, USACE EM 1110-1-1905 and USACE EM 1110-1-1904.

Exhibit 6.4–A AASHTO FOUNDATION CRITERIA (FACTORS OF SAFETY)

Foundation Type	Analysis Condition	Minimum Factor of Safety (FOS)[1]
Shallow Foundations	Bearing capacity	3.0
	Slide along base	1.5
	Overturning (Rotational Failure)	2.0
Deep Foundations	Driven piles (Static Method)	2.0 to 3.0
	Drilled shafts	2.0 to 2.5
Slope Stability at Structure Foundation Locations	Global Stability	1.3 to 1.5

[1] *Factor of Safety based on AASHTO Standard Specification for Highway Bridges,* AASHTO HB-17.

6.4.3.1 Shallow Foundations

Shallow foundations are often used where they satisfy design criteria because they are generally less expensive to construct. The following is a list of standard shallow foundation analysis tasks for footings on soil. Footings on rock are presented with other rock engineering tasks and discussed in Section 6.4.8.4. Many projects have additional specific needs and require additional analysis tasks that are addressed in the cited TGM sections and guidance documents.

- Recommend minimum embedment depth or footing elevation (including frost and scour considerations), allowable bearing capacity, and estimated total and post-construction settlement. Estimate potential for post-construction differential settlement between foundation units.
- Discuss excavation requirements, dewatering expectations, and minimum footing size.
- Recommend limits on proximity to slopes and other project features based on global stability considerations or analysis.

Refer to TGM Section 4.3.1 for guidance on shallow foundation analysis and design.

The primary source supporting the standards and guidance is GEC-6. Secondary sources are AASHTO HB-17, NHI 132012, and FHWA-RD-86-185.

6.4.3.2 Driven Pile Foundations

Driven pile foundations are generally used when shallow foundations are not feasible. The choice of driven pile over drilled shaft foundations is based on many factors, but generally driven piles are found to be less expensive and are used where they satisfy project criteria. The following is a list of standard pile driving analysis tasks. Many projects have additional specific needs and require additional analysis tasks that are addressed in the cited TGM sections and guidance documents.

- Recommend pile type, estimated tip elevations and allowable axial capacity. Unless piles are to be end bearing on rock or a certain strata, present results as a plot of capacity versus depth.
- Provide graphs of ultimate and allowable axial capacity versus depth for various sizes of piles. Include separate graphs of both skin friction and end bearing (if appropriate). Standard practice does not use the driving formula in FP-XX Section 551 or any other such formula.
- Provide a tabulation of soil properties used in the foundation analysis, including unit weight and strength parameters, and recommended values of subgrade modulus (k) and soil strain parameters E^{50} for lateral load analysis using LPILE or COM624P.
- Provide analysis that discounts depth of scour susceptible material for capacity but includes it for driveability. Coordinate with the Hydrology and Hydraulics discipline to confirm anticipated scour depth as discussed in Chapter 7.
- Calculate anticipated pile group settlement.
- Use wave equation analysis to verify that the recommended driven pile type can be driven to the estimated tip elevation without damage. Recommend means for driving piles past obstructions, such as pile tips, pre-drilling, or blasting, as most appropriate.
- Recommend the means for evaluating installed pile capacity or drilled shaft integrity. For example, WEAP, Pile Driving Analyzer (PDA), and/or CAPWAP, dynamic or static tests.

Refer to TGM Section 4.3.2 for guidance on pile foundation analysis and design.

The primary source supporting the standards and guidance, including a step by step procedure, is NHI 132021. Secondary sources are AASHTO HB-17, NHI 132012 and WSDOT WA-M-46-03.

6.4.3.3 Drilled Shaft Foundations

Drilled shaft foundations are generally used when shallow foundations and driven piles are not feasible. The choice of drilled shaft foundations is based on many factors, but generally shafts are used where the site is not very suitable for driving because of hard layers or possible obstructions in the soil, or environmental restrictions exist to prohibit driving. The following is a list of standard drilled shaft analysis tasks. Many projects have additional specific needs and require additional analysis tasks that are addressed in the cited TGM sections and guidance documents.

- Recommend shaft diameter, estimated tip elevations, rock socket requirements, and allowable axial capacity. Unless piles are to be end bearing on rock or a certain strata, present results as a plot of capacity versus depth.
- Provide graphs of ultimate and allowable axial capacity versus penetration for various sizes of shafts. Include separate graphs of both skin friction and end bearing (if appropriate).
- Provide a tabulation of soil properties used in the foundation analysis, including unit weight and strength parameters, and recommended values of subgrade modulus (k) and soil strain parameters E^{50} for lateral load analysis using LPILE or COM624P.
- Provide analysis that discounts depth of scour susceptible material. Coordinate with the Hydrology and Hydraulics discipline to confirm anticipated scour depth as discussed in Chapter 7.
- Calculate anticipated shaft settlement and, if appropriate, group settlement.
- Provide a geotechnical advisory statement to document anticipated conditions and obstructions for construction.
- Recommend the means for evaluating installed shaft integrity.

> Refer to TGM Section 4.3.3 for guidance on drilled shaft foundation analysis and design.
>
> The primary source supporting the standards and guidance, including a step by step procedure, is GEC-10. Secondary sources are AASHTO HB-17, FHWA-RD-95-172, NHI 132012 and WSDOT WA-M-46-03.

6.4.3.4 Micropile Foundations

Micropile foundations are often more expensive than other alternatives and are therefore generally used when shallow foundations, driven piles and drilled shafts are not practical. The choice of micropile foundations is based on many factors, but generally micropiles are selected either because ground conditions are such that driving pile or drilling shafts is not practical, or access for the larger, pile and shaft equipment is not available. The following is a list of standard micropile analysis tasks. Projects may have additional specific needs and require additional analysis tasks that are addressed in the cited TGM sections and guidance documents.

- Recommend pile diameter, estimated tip elevations, rock socket requirements, and allowable axial capacity. Unless piles are to be end bearing on rock or a certain strata, present results as a plot of capacity versus depth. Recommend casing and plunge length, if applicable.
- Provide graphs of ultimate and allowable axial capacity versus penetration for various sizes of micropiles.
- Provide a tabulation of soil properties used in the foundation analysis, including unit weight and strength parameters, and recommended values of subgrade modulus (k) and soil strain parameters E^{50} for lateral load analysis using LPILE or COM624P.
- Provide analysis that discounts depth of scour susceptible material. Coordinate with the Hydrology and Hydraulics discipline to confirm anticipated scour depth as discussed in Chapter 7.
- Calculate anticipated settlement for pile groups.
- Recommend the means for evaluating installed pile capacity or drilled shaft integrity.

> Refer to TGM Section 4.3.4 for guidance on micropile foundation analysis and design.
>
> The primary source supporting the standards and guidance, including a step by step procedure, is FHWA-NHI-05-039. The secondary source is FHWA-SA-97-070.

6.4.4 EARTH RETENTION SYSTEMS

Earth retention systems are engineered systems to retain soil temporarily or permanently. Retaining walls are the most common example, but patterned ground anchors, rockeries, and temporary shoring of cuts are other systems common to FLH practice and are also included.

FLH Geotechnical Discipline standard practice is to follow AASHTO HB-17 for retaining walls wherever practical. Select and design retaining walls based on AASHTO requirements to meet minimum requirements for static and seismic loading and limiting settlement. Use AASHTO recommended minimum and typical ranges for factor of safety under static conditions, and design retaining walls for a minimum service life of 75 years. Perform seismic analyses based on the requirements of AASHTO Division I-A. FLH standard practices are listed in this section for analysis and design of earth retention systems. General standards are presented first, followed by subsections addressing specific earth retention systems.

Select the permanent earth retention system type based on an assessment of the magnitude and direction of loading, depth to suitable bearing materials, potential for liquefaction, undermining or scour, swelling potential, frost depth, ease and cost of construction, tolerable total and differential settlement, and facing durability and aesthetics. Select temporary cuts and shoring requirements to be as economical as possible.

Coordinate with the Structures Discipline, Design Discipline, and Hydrology and Hydraulics Discipline to select the most appropriate earth retention system for a given setting based on geotechnical subsurface investigations, material testing results, surface and groundwater issues, and design constraints. Provide soil/rock classification, density, lateral earth pressure, and strength parameters for design. Provide expectations of encountering water during construction and recommendations for managing it during construction, and for short- and long-term performance. Provide temporary excavation slope recommendations (including height restrictions and steepest slope ratio) and advise of the need for shoring, and specific geotechnical conditions that might impact shoring type selection, as in Section 6.4.4.7.

For seismic design, provide effective peak firm ground acceleration and probability of exceedence based on a literature review. Classify the site according to the AASHTO Standard Specifications for Highway Bridges seismic site soil profile “Type” classification and corresponding site coefficient factor, “S”.

Perform global stability and bearing capacity analysis for the selected earth retention systems. Use safety factors presented in Exhibit 6.4–B. For global stability analysis of walls on steep slopes consider the initial stability of the slope and the impact (or lack of) that the proposed construction has on the slope. This consideration may be more important than the theoretical minimum factor of safety for evaluating suitability of designs.

Exhibit 6.4–B AASHTO RETAINING STRUCTURES CRITERIA (FACTORS OF SAFETY)

Analysis Condition	Minimum Factor of Safety (FOS)[1,2]
Sliding (Static)	1.5
Sliding (Seismic)	1.125
Overturning (Static)	2.0 for footings on soil 1.5 for footings on rock
Overturning (Seismic)	1.5 for footings on soil 1.125 for footings on rock
Bearing capacity (Static)	3.0 (Shallow foundations)
Bearing Capacity (Seismic)	1.5 (Shallow foundations)

[1] *Based on AASHTO Standard Specification for Highway Bridges, AASHTO HB-17.*
[2] *Seismic factors of safety are applicable where the peak ground acceleration is greater than 0.09g.*

Refer to TGM Section 4.4 for guidance on wall selection and analysis tasks.

The primary source supporting the standards and guidance is GEC-2. Secondary sources are AASHTO HB-17, FHWA-FLP-94-006 and USACE EM 1110-2-2502.

6.4.4.1 Concrete Walls

The Structures Discipline designs concrete walls, usually and preferably according to FLH Standard Drawings. The Structures Discipline will use geotechnical recommendations to confirm the applicability of the standard plans. In addition to the standards listed in Section 6.4.4, provide soil, rock and groundwater design parameters for concrete gravity and cantilever walls. Include recommendations for the foundation and the retained soil, requirements for backfill, and the suitability of onsite material.

6.4.4.2 MSE Walls

In addition to the standards presented in Section 6.4.4, the following specific tasks are standard for MSE wall analysis and design. Include required minimum wall setback from a slope, embedment, and reinforcement length as a function of wall height. Final wall design including internal, sliding and overturning stability may be by FLH or by the construction contractor for FLH review, depending on the project; either way, MSE walls are designed or reviewed using MSEW and the procedures in GEC-11. Provide construction details and specifications using FP-XX Section 255 and Division specifications and Details (see Section 1.2.5) as appropriate

> Refer to TGM Section 4.4.2 for guidance on MSE wall analysis and design.
>
> The primary source supporting the standards and guidance is GEC-11. Secondary sources are WSDOT WA-M-46-03 and FHWA-NHI-09-087.

6.4.4.3 Soil Nail Walls

In addition to the general earth retention standards presented in Section 6.4.4, the following specific tasks are standard for soil nail analysis and design. Perform soil nail wall designs to evaluate nail lengths, spacing, layout, and global stability. Collaborate with the Structures Discipline to complete the least expensive satisfactory facing design. Evaluate corrosion and frost protection requirements and recommend how to address them. Use GoldNail or SNAIL to perform analyses for the final wall and at interim phases during construction, as in FHWA-SA-96-069R. Provide all details and specifications (using SCRs) necessary to construct the wall.

> Refer to TGM Section 4.4.3 for guidance on soil nail wall analysis and design.
>
> The primary source supporting the standards and guidance is GEC-7. Secondary sources are FHWA-SA-96-069R and FHWA-SA-93-068.

6.4.4.4 Pile Walls

Pile walls and other non-gravity, non-anchored cantilevered walls are used on FLH projects, but not frequently enough to have established analysis and design standards. Standard practice is, therefore, to follow the earth retention standards in Section 6.4.4 and the pile wall guidance in the TGM and GEC-2.

Refer to TGM Section 4.4.4 for guidance on pile wall analysis and design.

The primary source supporting the guidance is GEC-2. Secondary sources are AASHTO HB-17 and NAVFAC DM 7.2.

6.4.4.5 Ground Anchor Systems

In addition to the general earth retention standards presented in Section 6.4.4, the following specific standards for analysis and design of patterned ground anchors and ground anchor walls. Standard practice is also to follow the guidance in the TGM and GEC-4.

Perform preliminary ground-anchor designs for tieback walls and ground anchor systems to evaluate all modes of failure. Identify, with the project team, tolerable deformations and design accordingly. Provide requirements for factors of safety, allowable anchor capacity, unbonded length and hole diameter (if any), and minimum and maximum values for bond length. Use presumptive values of bond capacity and the results of field and laboratory exploration to estimate bond length for quantity estimation only. Do not design the anchor bond length or hole diameter, as these are contractor responsibilities based on their proposed installation method. Verify and prove the anchor capacity using the testing program presented in GEC-4.

Refer to TGM Section 4.4.5 for guidance on ground anchor systems and wall design.

The primary source supporting the standards and guidance is GEC-4. Secondary sources are PTI 2004 and FHWA-DP-68-1R.

6.4.4.6 Rockeries

A rockery is a retaining and slope protection structure that consists of stacked rocks without mortar, concrete or reinforcing steel. Rockeries are sometimes used where minimal earth retention is needed, the aesthetics of stacked rock is desired and there is cost savings over other retaining walls. In addition to the general standards presented in Section 6.4.4, standard practice is to follow the guidance in the TGM and FHWA-CFL/TD-06-006.

Refer to TGM Section 4.4.6 for guidance on rockery analysis and design.

The primary source supporting the standards and guidance is FHWA-CFL/TD-06-006. Secondary sources are ARC 2000 and WSDOT WA-M-46-03.

6.4.4.7 Temporary Cuts and Shoring

Maximum temporary un-shored slope heights and ratios are recommended based on observations, experience, and representative limit equilibrium slope stability analysis. Limit equilibrium slope stability analysis is used when observation and experience are not conclusive. Standard practice is to demonstrate a short-term factor of safety of 1.1 to 1.2 depending on uncertainty and consequences of failure. It is also standard to recommend in contract documents that the contractor evaluate the slope for safety during excavation and do what is required to maintain a safe working environment.

Shoring is recommended where the height and slope ratio limits cannot be met. Geotechnical based recommendations are provided on shoring types and on ground and water conditions to be expected. Shoring construction considerations and limits on types of shoring are developed based on-site conditions and project needs. Shoring design is the responsibility of the contractor, not FLH, is designed according to the appropriate general standards of Section 6.4.4 and must satisfy OSHA Section 29.

> Refer to TGM Section 4.4.7 for guidance on temporary cuts and shoring.
>
> The primary source supporting the standards and guidance is OSHA Section 29. Secondary sources are Ratay 1996 and CalTrans 2001.

6.4.5 OTHER STRUCTURES

6.4.5.1 Culverts and Pipes

Project specific geotechnical recommendations on culverts and pipes are not usually provided. FLH Standard Drawings address considerations such as bedding and minimum cover based on pipe diameter and material type. Standard practice is to provide foundation recommendations for box culverts in accordance with Section 6.4.3, and including backfill requirements and lateral earth pressure design parameters.

> Refer to TGM Section 4.5.1 for guidance on geotechnical recommendations for culverts and pipes.
>
> The primary source supporting the standards and guidance is USACE EM 1110-2-2902. Secondary sources are Spangler & Handy 1982 and FHWA-RD-98-191.

6.4.5.2 Building Foundations

Buildings are constructed on FLH projects, but not frequently enough to have established analysis and design standards. The same principles apply to building foundations as do to highway structure foundations so the investigation, analysis and design steps are the same. Standard practice is to design to local building code, the guidance in the TGM and NAVFAC DM 7.2.

Refer to TGM Section 4.5.2 for guidance on building foundations.

The primary source supporting the standards and guidance is NAVFAC DM 7.2 and the secondary source is NAVFAC DM-7.1.

6.4.5.3 Microtunnels and Trenchless Construction

Microtunnels and trenchless construction methods are used on FLH projects, but not frequently enough to have established analysis and design standards. Standard practice is, therefore, to follow the guidance in the TGM and FHWA-IF-02-064.

Refer to TGM Section 4.5.3 for guidance on geotechnical recommendations for mictrotunnels and trenchless construction.

The primary source supporting the standards and guidance is FHWA-IF-02-064 and the secondary source is CI/ASCE 36-01.

6.4.6 EARTHWORK

FLH standard practice is for the Geotechnical Discipline to provide the Design Discipline and Cross Functional Team specific materials and construction guidance for roadway earthwork. This guidance should include rippability, shrink/swell factors, usage of materials encountered on the project, embankment construction and stabilization requirements, embankment design, erosion and sediment control, and ground improvement alternatives. FLH standard practice for earthwork engineering is presented in this section through subsections directed towards specific aspects of earthwork.

Refer to TGM Section 4.6 for general guidance on earthwork.

The primary source supporting the standards and guidance is NHI 132012. Secondary sources are WSDOT WA-M-46-03, TRB SAR 8 and BOR Earth Manual.

6.4.6.1 Rippability

Bedrock rippability is based on bedrock characterizations from surface and subsurface exploration. Because rippability and seismic velocity are similarly influenced by intact rock strength, discontinuity frequency and strength, and discontinuity orientation, standard practice is to rely on published charts of seismic velocity versus rippability by standard excavating equipment as a first estimate of rippability. An example of such a plot is TGM Exhibit 4.6-D. Figures such as this are sometimes not consistent with experience, however, and it is standard practice to also consider and document other findings related to rippability, such as rock types, strengths and rock mass structure. Judgments on rippability are used during the design process to evaluate alternatives and costs, but it is standard practice to present only data in contract documents and to allow contractors to make the ultimate assessment of rippability based on their equipment and experience.

> Refer to TGM Section 4.6.1 for guidance on rippability.
>
> The primary source supporting the standards and guidance is FHWA-Geophysical, for seismic velocity, and the secondary source is NHI 132035.

6.4.6.2 Shrink/Swell Factors

FLH standard practice is to estimate shrink or swell of all excavation when placed as embankment in station-by-station, cut-by-cut, or material-by-material format (where the association of materials to cuts is also provided). Estimation is based on previous projects, published data, collected data, or in-situ density and lab measurement of density when compacted according to project specifications. Describe anticipated variances and complex soil/rock units, and note factors that impact earthwork quantities, such as topsoil stripping operations, clearing and grubbing requirements, survey accuracy, complex alignment, fill compaction and/or construction practices.

Shrink/swell factors provided by the Geotechnical Discipline account for only the difference in density between cut and embankment, and are noted as such in the Geotechnical Report. Unless otherwise specified, other factors that impact material balance such as survey, waste, or construction practices are not included. Estimates of shrink/swell factors for common materials are presented in TGM Exhibit 4.6-E. This source is usually tempered by other observations or experience.

> Refer to TGM Section 4.6.2 for guidance on geotechnical recommendations for shrink/swell.
>
> The primary source supporting the standards and guidance is Burch 2006 and the secondary source is Church 1981.

6.4.6.3 Material Sources and Excavation

FLH standard analysis and design tasks for material sources and excavated material consist of estimating locations and quantities of unsuitable materials, and identifying what could be done to make them suitable. Materials not identified as unsuitable or in need of processing are assumed to be suitable as is. Identify what type of processing is required to make materials suitable, if possible; for example, crushing, screening, blending, drying, or admixtures.

Identify if materials are suitable only for specific project features and uses. Refer to FP-XX *Section 703 – Aggregate, Section 704 – Soil, and Section 705 – Rock* for standard material designations, and use these where possible. Describe special required handling and placement requirements, or confirm that use of standard procedures in Division 200 of FP-XX is appropriate, and designate appropriate FP-03 Sections.

Because of the difficulty distinguishing between material types during construction, it is standard practice to not classify excavation as either rock or soil based on investigation results. See FP-XX *Section 204 – Excavation and Embankment*.

Refer to TGM Section 4.6.3 for guidance on analysis of materials and sources.

The primary source supporting the standards and guidance is FHWA-ED-88-053 and the secondary source is WSDOT WA-M-46-03.

6.4.6.4 Subgrade Stabilization

Subgrade stabilization within the roadway pavement prism is the responsibility of the Pavement Discipline and is covered in Section 11.3.1.3. It is standard practice for the geotechnical professional to coordinate with the Pavement Discipline and to provide geotechnical interpretation of subgrade conditions when requested. In addition to Chapter 11, geotechnical guidance is in the TGM and supporting documents.

Refer to TGM Section 4.6.4 for geotechnical guidance on subgrade stabilization.

The primary source supporting the guidance is FHWA-SA-93-004/5. Secondary sources are FHWA-HI-95-038 and FHWA-TS-80-236.

6.4.6.5 Embankments

Standard practice is to perform analyses and provide design recommendations with respect to embankment materials, special compaction requirements, foundation settlement, bearing capacity, and slope stability for embankments greater than 10 feet [3 meters] in height. Standards are presented in the following paragraphs.

Specify project materials suitable for embankment construction and recommended construction methods. Evaluate special embankment compaction requirements, if needed, and develop special contract requirements to address embankment compaction issues. Standard construction methods and specifications are shown in FP-XX *Section 204 – Excavation and Embankment*. Guidance is in the TGM and the primary source: *Soil Slopes and Embankments*, NHI 132033.

Evaluate settlement of large embankments using consolidation and elastic settlement methods, such as present in EMBANK or FoSSA. Evaluate ground improvement technologies where settlement predictions are not acceptable. Develop alternative embankment construction plans, as requested, to expedite settlement or improve embankment foundation conditions. Ground improvement guidelines are presented in Section 6.4.10.

Evaluate bearing capacity of the embankment foundation soils by inspection. If the possibility of bearing capacity failure cannot be ruled out by experience or precedent, complete a bearing capacity analysis (TGM Section 4.6.5). If necessary, make recommendations to modify the design using geosynthetics, staged construction or other means to prevent bearing capacity failure. Guidance on the use of geosynthetics is in TGM Section 4.10 and NHI 132034.

Evaluate embankment stability and provide maximum embankment slope ratios. It is FLH standard practice to design most small embankment fills using engineering judgment and precedents in the vicinity, and to not design slopes steeper than 1.5H to 1V. Perform limit equilibrium stability analyses for embankments where foundation conditions, material characteristics, and drainage conditions are poor. Evaluate slope stability of representative sections using limit equilibrium slope stability analysis procedures, automatic searches and/or specified surfaces. Distinguish between short-term (construction-phase) and long-term slope stability and consider the need for seismic stability analysis. The standard minimum short-term and long-term factors of safety are 1.1 to 1.2, and 1.3 to 1.5, respectively, depending on consequences of potential failure and uncertainty in how well the analysis model and its input parameters represent actual conditions; see the TGM section for further guidance.

Refer to TGM Section 4.6.5 for guidance on embankment analysis and design.

The primary source supporting the standards and guidance is NHI 132033. Secondary sources are WSDOT WA-M-46-03, and USACE EM 1110-1-1904 for settlement, and USACE EM 1110-2-1902 and FHWA-SA-94-005 for stability.

6.4.6.6 Reinforced Soil Slopes

Consider reinforced soil slopes (RSS) where design constraints require minimizing the footprint of a proposed embankment. FLH standard practice is to use ReSSA to evaluate RSS internal and external stability and design the type, length and spacing of the reinforcement elements. Evaluate global stability and subsurface drainage requirements. Provide slope treatment options that are compatible with project and partner agency goals. Guidelines for analysis and design of RSS are presented in the TGM and GEC-11.

Refer to TGM Section 4.6.6 for guidance on reinforced soil slopes.

The primary source supporting the standards and guidance is GEC-11 and the secondary source is GEC-1.

6.4.7 SLOPE STABILITY

FLH standard practice is to use precedence and limit equilibrium methods to analyze and design fill and cut slopes. It is standard practice to analyze landslides and design their mitigation using limit equilibrium methods. These standards are discussed in the following subsections for soil cut slopes and all landslides. Fill slopes and embankments are covered with other embankment design standards in Section 6.4.6.5 and rock slope stability is covered with other rock engineering tasks in Section 6.4.8.1.

6.4.7.1 Soil Cut Slopes

Evaluate the stability of planned and existing cut slopes along the roadway. Standard cut slope evaluation practice considers local precedence and engineering judgment. Slope design by local precedence applies where new soil cuts are less than 20 feet [6 meters] deep, slope height and/or slope ratio does not change appreciably, there is no prior evidence of instability, seepage is not evident or anticipated in the cut, and material types do not appear to change within the cut.

Limit equilibrium analysis is the standard method used to assess slope stability where local precedence does not apply. The standard minimum short-term and long-term factors of safety are 1.1 to 1.2, and 1.3 to 1.5, respectively, depending on consequences of potential failure and uncertainty in how well the analysis model and its input parameters represent actual conditions; see TGM section for further guidance.

> Refer to TGM Section 4.7.1 for guidance on cut slope stability.
>
> The primary source supporting the standards and guidance is USACE EM 1110-2-1902. Secondary sources are USFS EM 7170-13, Duncan & Wright 2005 and FHWA-SA-94-005.

6.4.7.2 Landslides

Use field mapping, survey, surficial geology reports, photography and monitoring to identify landslide extents and failure modes. FLH standard practice is to conduct landslide stability assessments based on soil/rock and groundwater profile information obtained during field exploration. Use measured soil/rock strength parameters and back-analysis of existing slide conditions. Analyze landslides on representative two-dimensional sections using limit equilibrium methods, with automatic searches and/or specified surfaces. Distinguish between short-term (construction-phase) and long-term slope stability and consider the need for seismic stability analysis (Section 6.4.11). The standard minimum long-term factor of safety is 1.25 to 1.5, depending on consequences of potential failure and uncertainty in how well the analysis model and its input parameters represent actual conditions. Guidance on safety factor ranges, including during construction, is presented in the TGM.

Recommend landslide mitigation measures based on cost, constructability, project constraints, and an understanding of risk and tolerance for ongoing movement. Include consideration of regrading/unloading of the slope, toe buttressing, enhanced slope drainage, ground conditioning, tieback retention, roadway realignment, etc.

> Refer to TGM Section 4.7.2 for guidance on landslide analysis and mitigation design.
>
> The primary source supporting the standards and guidance is TRB SR 247. Secondary sources are Cornforth 2005, FHWA-RT-88-040 and FHWA-ED-88-053.

6.4.8 ROCK ENGINEERING

This section addresses rock slopes, rockfall, foundations on rock, and rock tunneling. Standards are presented in the following sections for rock slopes, including rockfall evaluation and mitigation, and for rock foundations. Several FLH projects include rock tunnels, but tunnel analysis and design is relatively rare and FLH standards do not exist. The reader is directed to guidance in the TGM.

6.4.8.1 Rock Slopes

FLH standard practice is to make design recommendations for cut slopes in rock. The practice varies depending on the size of the cut.

- Design rock cuts less than 15 feet [5 meters] high or less than 10 feet [3 meters] deep (sliver cuts) by applying engineering judgment based on past performance of slopes in the project vicinity. Evaluate if changes in slope height or slope ratio are acceptable or desired based on past performance. Recommend maximum safe unreinforced slope ratios, slope heights and geometry based on observations and experience.
- For larger cuts and cuts where consequences of failure are especially critical, use geologic structure mapping and interpretation and/or kinematic and limit equilibrium analysis to augment observations and engineering judgment. For projects with complex geology, use stereonet-based kinematic analyses to determine the range of potential failure modes possible for a given slope, and then evaluate failure potential based on the shear strength of discontinuities and water conditions. The acceptable range of safety factors is 1.3 to 1.5, depending on consequence of failure and uncertainty in the data and how representative the analysis is of actual conditions. Additional guidance on analysis and factors of safety is provided in the TGM. If reinforcement can be used to considerably steepen a slope, reducing excavation and impact, recommend reinforcement requirements and maximum reinforced slope ratio.

> Refer to TGM Section 4.8.1 for guidance on rock slope analysis and design.
>
> The primary source supporting the standards and guidance is NHI 132035. Secondary sources are FHWA-TS-89-045 and FHWA-HI-92-001.

6.4.8.2 Rockfall Analysis

FLH standard practice is to provide rockfall hazard evaluation where rockfall hazards exist from previous highway work or will result from construction of the project. Hazard evaluation is the process of identifying the likelihood of rockfall occurring because of adverse geological (discontinuities, differential weathering, boulders, etc.) and environmental (water, ice, vegetation, slope angle and aspect, etc.) conditions. Hazard is evaluated by an experienced Geotechnical Professional with respect to other slopes on the project or similar projects. Hazard evaluation is based on site observations, boring logs and other explorations.

Key tasks are as follows:

- Conduct rock slope surveys that address the historic and potential future rockfall activity and hazard this activity presents to the proposed project.
- Assess rockfall risk for rock cuts on the project (new and/or existing). Rockfall risk is the potential for adverse consequence, such as maintenance cost, closure, injury or death. Standard practice is to do this in an efficient way for the project and to prioritize rockfall mitigation towards areas where hazard and risk are high. Use the Rockfall Catchment Area Design approach and/or numerical simulations such as the Colorado Rockfall Simulation Program (Section 6.4.8.3) to evaluate rockfall impact and runout.

> Refer to TGM Section 4.8.2 for guidance on rockfall hazard analysis.
>
> The primary source supporting the standards and guidance is FHWA-SA-93-057. Secondary sources are FHWA-OR-RD-01-04 and NHI 132035.

6.4.8.3 Rockfall Mitigation

Provide rockfall mitigation recommendations where rockfall hazards and risk exist from previous highway work or will result from construction of the project.

Key tasks are as follows:

- Recommend rockfall hazard mitigation methods, if needed, including proper excavation techniques, erosion control, rock reinforcement/conditioning, slope drainage, and failure management systems.
- Provide rockfall catchment ditch recommendations based on the Rockfall Catchment Area Design approach (FHWA-CFL/TD-05-008) and/or numerical simulations such as the Colorado Rockfall Simulation Program (CRSP). Discuss with the project team the rockfall hazard, the potential effectiveness of the ditch, and alternatives to modify both. Guidance for rockfall catchment ditch design is provided in the TGM.
- Convey long-term slope performance and maintenance expectations to the project team.

> Refer to TGM Section 4.8.3 for guidance on rockfall mitigation design.
>
> The primary source supporting the standards and guidance is FHWA-SA-93-085. Secondary sources are FHWA-CFL/TD-05-008, USACE EM 1110-1-2907, and NHI 132035.

6.4.8.4 Foundations on Rock

Foundations on rock are analyzed for bearing capacity and settlement. Standard practice for single span bridges and for walls is to recommend allowable bearing pressure based on published presumptive values for bearing capacity and 1 inch [25 mm] settlement (AASHTO HB-17 Table 1 in NAVFAC DM 7.2 or Figure 6-6 in USACE EM 1110-1-2908). Boring logs are used to characterize the foundation materials and conditions. Unconfined strength, if available, is used to refine classification of rock and optimize selection of bearing capacity.

For foundations of multi span bridges, structures with multiple foundation types, or structures that are particularly sensitive to settlement, and for foundations on intermediate geomaterials, FLH standard practice is to follow AASHTO HB-17 and the guidance in the TGM to develop design recommendations.

> Refer to TGM Section 4.8.4 for guidance on rock foundations.
>
> The primary source supporting the standards and guidance is AASHTO HB-17. Secondary sources are USACE EM 1110-1-2908, Wyllie 1992 and Canadian Foundation.

6.4.8.5 Tunnels

Rock tunnels exist on several FLH projects, but tunneling work is relatively rare and FLH analysis and design standards do not exist. For work on existing tunnels and for new tunnels, the Geotechnical Professional is directed to guidance through the TGM.

> Refer to TGM Section 4.8.5 for guidance on tunnel analysis and design.
>
> The primary source supporting the standards and guidance is FHWA-IF-05-023.

6.4.9 DRAINAGE, DEWATERING, AND EROSION CONTROL

FLH standard practice for the Geotechnical Discipline is to evaluate dewatering and drainage needs by observational methods except in locations where slope stability is analyzed. In analysis of slope stability dewatering is included in limit equilibrium analyses through use of a lower water table or water pressure. Assess site conditions, material types, drainage paths, hydrology, and planned geotechnical improvements. Assess drainage, dewatering and erosion control requirements associated with other geotechnical recommendations, such as slope stability, bearing capacity and settlement. Design and locate required surface and subsurface drainage including underdrains, horizontal drains, lateral trench drains, French drains, blanket drains, and cut-off drains. Coordinate with the Design Discipline and Hydraulics Discipline for the location and outlet of drains and ditches.

When geosynthetics are specified for drainage, dewatering and erosion control applications, identify the intended use of the geosynthetic (separation, filtration, drainage, strength, etc.), the general type of geotextile to be used (e.g. woven, non-woven), and specify soil and performance parameters for geotextile selection. Use standard drainage design details and construction specifications when practical. Standard specifications are in FP-XX *Section 602 – Culverts and Drains, Section 605 – Underdrains, Sheet Drains, and Pavement Edge Drains, Section 608 – Paved Waterways,* and *Section 610 – Horizontal Drains*. Standard designs are available through Chapter 9 and Chapter 7, and Geotechnical Discipline standards of practice are discussed in this section.

6.4.9.1 Surface Drainage

Provide design recommendations to control surface drainage when integral to the design or performance of specific geotechnical features, such as ditches on walls or integral to slopes. Surface drains include interceptor ditches, drainage channels and dry wells. Coordinate with the Hydrology and Hydraulics, and Design Disciplines. These Disciplines provide project-wide surface drainage design for the control of surface drainage as provided in Chapter 7 and Chapter 9.

Evaluate temporary construction erosion control requirements on cut and fill slopes when integral to geotechnical design or performance. For example, the requirement to provide bench drainage during top-down construction of slopes and walls might be required to assure construction phase stability. Incorporate appropriate design details or requirements in the geotechnical report and construction plans.

Refer to TGM Section 4.9.1 for Geotechnical Discipline guidance on surface drainage.

The primary source supporting the standards and guidance is FHWA-FLP-94-005. Secondary sources are FHWA-TS-80-218 and FHWA-RT-88-040.

6.4.9.2 Subsurface Drainage

Evaluate subsurface drainage needs, feasibility, and constructability, from a perspective of balancing risk and cost. Consider environmental and project design constraints, as defined by the Environmental Specialist, Hydraulics Engineer, and/or Designer, as well as specific geotechnical needs. Coordinate with the Hydraulics and Design disciplines, which provide project-wide surface drainage design.

Provide subsurface drainage design recommendations to reduce adverse effects of groundwater on the project. Subsurface drainage systems include pavement underdrains and edge drains, trench drains, horizontal drains, vertical relief drains, granular drainage blankets, chimney drains and interceptor drains.

Geotextiles and geocomposites are often used as part of subsurface drainage and standard practice is to provide recommendations including material requirements and construction methods. When geotextiles are specified for subsurface drainage applications, identify the intended use of the geotextile (separation, filtration, strength, or multiple uses, etc.), the general type of geotextile to be used (e.g. woven, non-woven), and specify soil and performance parameters for geotextile selection. Geotextile material specifications are in FP-XX *Section 714 – Geotextile and Geocomposite Drain Material*.

Refer to TGM Section 4.9.2 for Geotechnical Discipline guidance on subsurface drainage.

The primary source supporting the standards and guidance is FHWA-TS-80-224. Secondary sources are FHWA-RD-86-171, NHI 132013A, FHWA-SA-93-004/5 and FHWA-CA-TL-80-16.

6.4.9.3 Dewatering

Dewatering is the temporary removal of surface water or groundwater, either from within the ground or in excavations. Evaluate dewatering needs as they relate to slope stability and temporary construction requirements. If dewatering is potentially required, consider potential impacts dewatering may have to surrounding property, such as excessive settlement, and the environmental effects of the discharge water. Provide recommendations for geotechnical issues that may impact dewatering methods and requirements or may arise from dewatering.

Refer to TGM Section 4.9.3 for Geotechnical Discipline guidance on dewatering.

The primary source supporting the standards and guidance is Powers 1981. Secondary sources are USACE EM 1110-2-1914 and ASCE 1985.

6.4.9.4 Erosion Control

FLH standard Geotechnical Discipline practice is to evaluate surface erosion potential around structure foundations and unique geotechnical project features such as MSE walls, reinforced slopes, and ground anchors. Base evaluation on characterization of materials, potential water sources, roadway geometrics and slope design. Provide recommendations for erosion control needs.

Routine erosion control design is a function of design and is addressed in Chapter 7 and Chapter 9. Erosion control material specifications are in FP-XX *Section 713 - Roadside Improvement Materials and Section 714 – Geotextile and Geocomposite Drain Materials*. Standard construction specifications are *Section 629 – Rolled Erosion Control Products and Cellular Confinement Systems*.

Refer to TGM Section 4.9.4 for Geotechnical Discipline guidance on erosion control.

The primary source supporting the standards and guidance is FHWA-FLP-94-005 and the secondary source is NHI 142054.

6.4.10 GROUND IMPROVEMENT

FLH standard practice is to evaluate and use ground improvement methods where they can significantly impact a project by making construction feasible, faster, with less impact, or more economical. Where ground improvement may have significant value, assess site conditions, material types, and project needs, and follow the guidance in TGM Section 4.10. The primary source for guidance is *Ground Improvement Techniques*, NHI 132034. Exhibit 6.4–C shows method-specific sources.

When geotextiles are specified for geotechnical applications, identify the intended use of the geotextile (separation, filtration, strength, etc.), the general type of geotextile to be used (e.g. woven, non-woven), and specify soil and performance parameters for geotextile selection. Soil stabilization requirements specific to pavement structural sections are provided by the Pavement Discipline, as discussed in Chapter 11.

Exhibit 6.4–C REFERENCES FOR GROUND IMPROVEMENT ANALYSIS AND DESIGN

Subject	Secondary Sources
General	NCHRP Synthesis 147 FHWA-SA-98-086R FHWA-SA-92-041 FHWA-ED-88-053
Geosynthetics	Koerner 1994 WSDOT WA-M-46-03
Deep Soil Mixing	FHWA-RD-99-138
Dynamic Compaction	GEC-1
Blast Densification	WSDOT WA-M-46-03
Soil Stabilization	FHWA-SA-93-004/5
Stone Columns	FHWA-RD-83-026

6.4.11 GEOTECHNICAL EARTHQUAKE ENGINEERING

FLH standard practice is to evaluate geotechnical earthquake engineering needs for bridges by assessing site conditions, material types, and project needs, and by consulting AASHTO HB-17 Division 1-A. Provide AASHTO-derived seismic and site coefficients to the Structures group.

Standard practice is to perform seismic analysis for walls and anchored slopes when the peak ground acceleration (10 percent exceedance in 50 years) is estimated to be greater than 0.1g. Standard practice is that seismic analysis is not performed on slopes or landslides except where ground anchors or other structures are installed for stabilization, or the consequence of failure is exceptionally high. Pseudo static analysis is the standard analysis procedure in these cases.

Standard practice is to review available geologic maps and seismic hazard maps to augment AASHTO HB-17. The USGS Hazmaps is the standard source. Liquefaction potential is evaluated using published maps of susceptibility, where they exist, and SPT methods. Evaluate liquefaction impacts on projects such as drawdown on piles and embankment stability. Guidance on these standards and many other non-standardized issues related to earthquake engineering is available in TGM Section 4.11. Supporting sources, which are all identified and linked through the TGM section, are also listed in Exhibit 6.4–D.

Exhibit 6.4–D REFERENCES FOR GEOTECHNICAL EARTHQUAKE ENGINEERING AND DESIGN

Subject	Primary Source	Secondary Sources
Geotechnical Earthquake Design	GEC-3	AASHTO HB-17 NHI 132039A WSDOT WA-M-46-03 Kramer 1996
Liquefaction Potential and Mitigation	GEC-3	AASHTO HB-17 WSDOT WA-M-46-03

6.5 DOCUMENTATION AND SUPPORT

This section presents FLH standards and links to FLH guidance for geotechnical documentation and reporting, review of plans and specifications, construction support, post-construction (ongoing) monitoring, and emergency response. The standard practices presented in this section have evolved from FLH experience and are to be used unless an exception is justified (Section 6.2.3). These standards support the policies presented in Section 6.2.1 guiding FLH geotechnical practice. Standards are not written for many geotechnical documentation and support tasks because the needs are project-specific; consult TGM Section 5 for guidance.

Follow the established quality control and assurance procedures for reporting and documentation. Procedures are unique to each Division and can be accessed through Division Supplements.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

6.5.1 GEOTECHNICAL REPORTS AND DOCUMENTS

FLH standard practice is to prepare geotechnical memoranda and reports that clearly and succinctly document field investigation and laboratory data and design/construction recommendations. Develop the final geotechnical report to provide designers, construction project engineers and contractors with information concerning the materials and conditions that are expected to be encountered in the field. These standards are discussed in this section. Guidance on these standards and other non-standardized issues related to reporting and documentation is available in TGM Section 5.

6.5.1.1 General

Organize geotechnical memoranda and reports to be consistent and to follow the same general format to allow for familiarity by even the occasional reader. Ensure that factual data is presented separately from interpretation and opinion, and that all interpretations are clearly identified as such. Describe potential problems disclosed by analyses and recommend potential feasible solutions. Provide an assessment of relative cost and uncertainty associated with each of the recommended options. Include recommendations for design and considerations for construction.

Reports and memoranda are prepared at all stages of projects and they are to be clearly identified as “preliminary”, “interim”, or “final” to refer to the stage of the project, not the correspondence. When correspondence at any stage is going through development or review it is identified as “draft”.

6.5.1.2 Standard Reporting Organization and Content

The following list presents the standard reporting format for technical project. Each section might be a sentence, a paragraph or a chapter depending on the scope of work and the purpose of the correspondence. Omit sections when they are not relevant. Format reports so as to be suitable as hard copy and for electronic posting.

1. Executive Summary. Optionally included in larger reports with complicated scopes and content.
2. Introduction. Present the purpose of the correspondence/report.
3. Project Description. Describe the project only as needed to put recommendations in context.
4. Geology. Start regionally and end with site-specific observations and geohazards, including seismicity.
5. Site Conditions. Describe the physical setting based on above ground observations.
6. Subsurface Conditions. Describe subsurface investigation procedures and findings.
7. Analysis. Present analysis methods, assumptions, and input, and summarize results.
8. Design Recommendations. Present recommendations directed toward preferred alternatives, with a discussion on geotechnically-based risks, and in a station-by-station and/or feature-by-feature format.
9. Construction Considerations. Recommend construction specifications (FP-XX, SCR, or other) and present geotechnical observations that may impact construction methods and progress.
10. References. List of complete references (including previous work)specifically cited in the correspondence/report.

Refer to TGM Section 5.1 for Geotechnical Discipline guidance on reporting and documents.

The primary source supporting the standards and guidance is NHI 132031. Secondary sources are FHWA-ED-88-053 for geotechnical reports and ASCE GBR for baseline reports.

6.5.1.3 Review of Calculations and Reports

FLH standard practice is to review calculations and reports whether they are generated internally or by consultants. When reviewing internal calculations and reports the review is part of the Division QA/QC process, which is found through the Division Supplements link in Section 6.5. When reviewing external calculations and reports the review is part of the FLH oversight process that occurs after the consultant has conducted their own QA/QC process.

Refer to TGM Section 5.1.3 for Geotechnical Discipline guidance on work review.

The primary source supporting the standards and guidance is FHWA-ED-88-053. The secondary sources are ASFE Guidelines, for reports, and Division QA/QC plans for calculations.

6.5.2 FINAL DESIGN AND REVIEW OF PLANS AND SPECIFICATIONS

FLH standard practice is to review submittals of design plans and specifications with respect to the previous preliminary submittal and previous review comments. This is done for projects that include geotechnical aspects, such as walls, bridges, other structures with foundations, cuts or fills higher than 10 feet [3 meters], or any non-standard earthwork. Geotechnical recommendations will have been prepared for these projects. Geotechnical reports and memoranda will have been prepared for these projects and the Geotechnical Discipline checks that geotechnical recommendations are adequately included.

Review standards are discussed in this section. Guidance on these standards and many other non-standardized issues related to plan and specification review and finalization is available in TGM Section 5.2 and other sources listed in Exhibit 6.5–A. Specific standard practice tasks during submittal reviews are as follows:

- Ensure that the plans, specifications, and estimates of cost and/or quantity adequately reflect the geotechnical recommendations
- Assist the Project Manager with resolving inconsistencies between geotechnical recommendations and roadway/bridge preliminary designs
- Adapt or modify previous analyses and recommendations as necessary to evaluate changes made during final design and the preparation of plans and specifications
- Evaluate the reasonableness and acceptability of risks and consequences of design options. Ensure that the FP-XX is used where applicable and that project SCRs and design standards (including FLH Standard Drawings) are current and appropriate.
- Prepare addendum or revised geotechnical reports if conclusions and recommendations change during the design phase
- Where instrumentation exists, monitor using guidance in TGM Section 5.2 and Geotechnical Instrumentation, NHI 132041 and verify design recommendations based on new data.
- Confirm that if a Geotechnical Advisory was recommended it is included in the plans or specifications.

FLH standard practice is to compile comments on PS&E review forms as provided by the FLH Project Manager. Identify whether unique or complex construction would warrant geotechnical assistance or advice during the construction phase and communicate such needs in advance with construction personnel to help them plan for the construction phase. Where needed, the Geotechnical Discipline participates in pre-award support, pre-construction meetings, and during construction at key times.

Exhibit 6.5–A FINAL DESIGN AND REVIEW REFERENCES

Subject	Primary Source	Secondary Sources
Final Design	FHWA-ED-88-053	
Plans and Specifications	FP-XX	FLH Standard Drawings
Cost Estimates	FLH Engineer's Estimate Program	RS Means USACE ER 1110-2-1302
Instrumentation Monitoring	NHI 132041	TRB SR 247
Addendum Reports	FHWA-ED-88-053	
Planning Geotechnical Services for Construction Phase	NHI 132012	

6.5.3 CONSTRUCTION SUPPORT

The Geotechnical Discipline provides geotechnical support to construction management during bidding and construction. Inform the construction Project Engineer of any specialized geotechnical concerns or requirements and help provide related orientation or training for project inspectors. The Geotechnical Discipline participates in prebid and preconstruction meetings for projects that have major or complex geotechnical issues and designs.

FLH standard practice is to respond to calls from construction staff on geotechnical issues. Priority is given to construction needs so construction progress is not held up.

Review contractor submittals that include geotechnical items. Exhibit 6.5–B lists common work elements that require contractor submittals and Geotechnical Discipline involvement and support. In completing reviews, provide comments to seek clarification or correction of contractor designs, as necessary. Contractor submittal review should be in consideration of the standard design processes described in Section 6.4 and the guidance in TGM Section 5.3. In addition to FLH-specific guidance, the TGM provides links to primary industry construction inspection references and secondary sources. These links are repeated in Exhibit 6.5–B.

The Geotechnical Discipline visits the site as needed and requested to assist with special geotechnical inspection and to address unanticipated conditions, design changes or differing site condition claims. Coordinate monitoring of instrumentation that is required to evaluate the progress of construction and the performance of potentially impacted facilities. Perform prompt investigations of claimed or apparent “changed conditions” to assist in the resolution of issues and design or construction changes. Document the site visit observations and findings according to Division procedures.

Exhibit 6.5–B CONSTRUCTION SUPPORT REFERENCES

Subject	Primary Source	Secondary Sources
Contractor Submittals		
Footing Inspection		
Pile Inspection	NHI 132022	NHI 132021 NHI 132069
Drilled Shaft Inspection	NHI 132070	ADSC 1989
Micropile Inspection	FHWA-NHI-05-039	FHWA-SA-97-070
MSE Wall Inspection	GEC-11	
Soil Nail Inspection	FHWA-SA-93-068	
Anchor Inspection	GEC-4	FLH Anchor Inspection
Earthwork Inspection	TRB SAR 8	
Ground Improvement Inspection	NHI 132034	
Instrumentation Installation and Monitoring	NHI 132031	AASHTO MSI-1 NHI 132012 NHI 132041 NCHRP Synthesis 89 TRB SR 247
Geotechnical Documentation	NHI 132031	

6.5.4 POST-CONSTRUCTION MONITORING AND EMERGENCY RESPONSE

FLH standard practice is to monitor geotechnical instrumentation that is necessary to verify satisfactory performance of constructed facilities. Guidance on monitoring geotechnical performance is provided in TGM Section 5.4.

The Geotechnical Discipline provides emergency geotechnical support for evaluating geologic hazards and designing repairs to facilities harmed by natural disasters through the ERFO program. Guidance on ERFO repair is provided in TGM Section 5.4. The TGM guidance is supported by FHWA-RT-88-040 for highway slopes in general and FHWA-SA-93-085 for rock slopes in particular. Exhibit 6.5–C provides links to these and other sources of guidance.

Exhibit 6.5–C POST CONSTRUCTION MONITORING AND EMERGENCY RESPONSE REFERENCES

Subject	Primary Source	Secondary Sources
Monitoring Geotechnical Performance	NHI 132031 FHWA-SA-93-057	AASHTO MSI-1 NHI 132012 NHI 132041 NCHRP Synthesis 89 TRB SR 247
Repair of Geotechnical Features	FHWA-SA-93-085 FHWA-RT-88-040	FHWA-OR-RD-01-04 TRB SR 247
Responding to Emergencies	ERFO	OSHA Section 29 MUTCD

6.6 PRIMARY AND SECONDARY SOURCES

1.	AASHTO HB-17	AASHTO, Standard Specifications for Highway Bridges, 17th ed., HB-17, 2002
2.	AASHTO MSI-1	AASHTO, *Manual on Subsurface Investigation*, MSI-1, 1988.
3.	AASHTO R 22-97	AASHTO, Standard Recommended Practice for Decommissioning Geotechnical Exploratory Boreholes, AASHTO R 22-97, Standard Specifications, 2005.
4.	AASHTO Stds HM-25-M	AASHTO, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Part II: Tests, HM-25-M, 2005.
5.	ADSC 1989	ADSC, Drilled Shaft Inspector's Manual, 1989.
6.	ARC 2000	Associated Rockery Contractors, *Rock Wall Construction Guidelines*, Woodinville, WA, 2000 or current edition.
7.	ASCE 1985	ASCE, Dewatering: Avoiding Its Unwanted Side Effects, ISBN 0-87262-459-5, 1985.
8.	ASCE GBR	ASCE, Geotechnical Baseline Reports for Underground Construction - Guidelines and Practices, 1997.
9.	ASFE Guidelines	ASFE, The ASFE Guide to the In-House Review of Reports
10.	ASTM Standards	ASTM Standards
11.	BOR Drillers Safety	US Bureau of Reclamation, Driller's Safety Manual, US Department of the Interior, 1973.
12.	BOR Earth Manual	US Bureau of Reclamation, *Earth Manual, Third Edition*, US Department of the Interior, 1998.
13.	Burch 2006	Burch, Deryl, Estimating Excavation, Craftsman Book Company, 2006.
14.	CalTrans 2001	CalTrans, *Trenching and Shoring Manual*, 2011
15.	Canadian Foundation	Canadian Geotechnical Society, Canadian Foundation Engineering Manual, 3rd ed., 1992.
16.	Church 1981	Church, H.K., Excavation Handbook, McGraw-Hill, 1981.
17.	CI/ASCE 36-01	Standard Construction Guidelines for Microtunneling, 2001

18.	Cornforth 2005	Cornforth, D.H., Landslides in Practice: Investigation, Analysis, and Remedial/Preventative Options in Soil, Wiley & Sons, 2005.
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