Chapter 2 Project Geotechnical Planning

2.1 Overview

This chapter addresses geotechnical planning for projects that involve significant grading or foundations for structures, from the project definition or conceptual phase through the project design phase to preparation for the PS&E development phase. Final design for the PS&E development will be covered in other chapters of this manual specific to each project element.

The design objectives of the different phases of a project and guidance on the general level of geotechnical investigation for each phase were discussed in Chapter 1. The *Design Manual* M 22-01 Chapter 510 and Chapter 1 provide guidance concerning the roles and responsibilities of the Region Materials Engineer and the Geotechnical Office, as well as information on initiating geotechnical work, scheduling and site data and permits needed for each stage of a project. Geotechnical design for WSDOT projects is generally provided by the Region Materials Engineer and the Geotechnical Office or geotechnical consultants working either on behalf of these groups or as part of a consultant design team.

This chapter includes general guidelines for geotechnical investigations conducted for project definition and design phases (see Sections 1.1.1 and 1.1.2), and preparation of the subsurface exploration plan for the PS&E phase. Specific information on the number and types of explorations for PS&E level design is provided in the chapters for the specific design elements.

To assure success of a project, it is important for the geotechnical designer to become involved in the project at an early stage. The usual process starts with studying the preliminary project plans, gathering existing site data, determining the critical features of the project, and visiting the site, preferably with the project and structural engineer. Good communication throughout the project between the geotechnical designer, the structural designer, and the region project engineer is essential.

2.2 Preliminary Project Planning

2.2.1 Overview

The goal in the initial planning stages is to develop an efficient investigation plan and to identify any potential fatal flaws that could impact design or construction as soon in the project as possible. An effort should be made to maximize the amount of information obtained during each phase of the investigation process and minimize the number of site visits required to obtain information.

For larger projects, it may be beneficial to conduct the field exploration in a phased sequence, consisting of a reconnaissance investigation and a preliminary subsurface investigation during the project definition phase and more detailed exploration conducted during the project design and PS&E development phases. If the subsurface exploration can be conducted in phases, it allows information obtained in the preliminary phase to be used in planning the exploration program for the detailed design phase. This can be cost effective in maximizing the efficiency of the explorations in the subsequent phases. That is, the likely depths of the test borings are known, problem soil layers can be identified and sampled in subsequent phases, and the lab testing program can be planned with greater efficiency.

The location of the site will play a part in the way the investigation is planned. For projects where mobilization costs for drilling equipment are high, the number of subsurface investigation phases should be minimized, even on fairly large projects.

The studies and activities performed during the planning stage should be documented. A list of references should be developed, citing nearby explorations, notes from field visits and conversations with design engineers and construction engineers from nearby projects. Any critical issues that are identified during the planning stages should be documented, such as geohazards that are identified. At a minimum, enough documentation should be maintained so that another engineer picking up the project would not have to go through the same search for information.

2.2.2 Office Review

The geotechnical designer should become completely familiar with the proposed project elements by studying the preliminary plans provided by the region project design office. Location and size of structures, embankments and cuts should be determined. Discuss with the structural designers the amount of flexibility in the location of structures and determine the approximate magnitude of the loads to be transmitted.

Site exploration begins by identifying the major geologic processes that have affected the project site. Soils deposited by a particular geologic process assume characteristic topographic features or landforms that can be readily identified by the geotechnical designer. A landform contains soils with generally similar engineering properties and typically extends irregularly over wide areas of a project alignment. Early identification of landforms is used to optimize the subsurface exploration program.

Many of the soils in the state of Washington fall into geologic provinces with distinct soil types typical of the province. For example much of the Puget Sound lowland has been glaciated, and the soils are typically related to glacial processes. Eastern Washington geology generally consists of basalt flows capped by glacial flood and loess deposits.

The general geology of a project may also give indications of soil conditions that may or may not be encountered in test borings, for instance boulders and large cobbles in glacially deposited or glacial flood deposits, buried trees in debris flow deposits, or relatively fresh rock encountered in residual soils deposits in the coast range.

One of the objects of the office review is to plan site reconnaissance and prepare a conceptual plan for subsurface exploration.

2.2.2.1 Site Geology and Seismicity

Topographic Maps – Topographic maps are generally readily available at a scale of 1:24,000 (7.5 minute) for the all of Washington State. These maps are prepared by the U.S. Geological Survey (USGS). The maps provide information on the overall topography of the site including drainage patterns, slope inclinations, wetlands and general accessibility for field exploration. Used in conjunction with geologic maps and aerial photos, easily recognized geologic features can sometimes be identified. The headscarps and hummocky terrain of landslides can often be identified from topographic maps.

Geologic Maps – The Department of Natural Resources (DNR) Division of Geology and Earth Resource has geologic map coverage of most of the state at 1:100,000 scale. The maps show the distribution of the basic geologic units and provide a brief description of each deposit and rock type including depositional environment and relative age. The maps also include a list of references that may provide more information on a particular area.

The DNR also has published maps showing the extent of geohazards in selected areas of the state. These maps give an indication of the potential problem areas. The maps showing slope stability and liquefiable soils are particularly useful. The DNR has published liquefaction susceptibility maps for several areas in the Puget Sound Region. These maps give a general indication of the extent of liquefiable soils in the region.

Geologic maps are also available from the USGS. Coverage of Washington is not complete, but the maps are readily available from USGS and may be available from the DNR Library. Seismic acceleration maps are also available from the USGS and can be found on their website. The peak ground acceleration map provided in Chapter 6 has been adapted from the USGS maps.

Some local agencies have developed geohazard maps depicting flood plains or areas of steep slopes. These maps are available from the individual cities and counties.

Aerial Photos – Aerial photos along the state route alignments can generally be obtained from the WSDOT Geographic Services Office in Tumwater. Aerial photos can be one of the most useful sources of information for planning the subsurface exploration program. When used with a general understanding of the geology of the site and limited subsurface information, the extent of geologic deposits on the site can often be determined. Using stereo-pairs of photos can greatly enhance the interpretation of landforms.

The identification of a landform as a dune, terrace deposit, alluvial fan, esker, moraine, or other type of deposit often permits the general subsurface conditions to be established within given limits and thus yields the initial appraisal of the situation. Drainage patterns can also aid in the identification of soil type and in the structural characteristics of the underlying rock. The maximum amount of information will be obtained when aerial photos are used in conjunction with field investigations that can verify and correct interpretations.

Landslides are often recognizable in aerial photos by slide formed features or conditions, including hillside scars; disturbed or disrupted soil and vegetation patterns; distinctive changes in slope or drainage patterns; irregular, hummucky surfaces; small undrained depressions; step-like terraces; and steep hillside scarps.

Although one of the more difficult features to evaluate, vegetation is often indicative of subsurface conditions. The relationship between vegetation soil type, moisture content, topography and other pertinent factors may be important and any variations should be checked in the field.

Aerial photos may be available in both black and white or in color. Color photographs are generally preferred because objects are easier to identify when they appear in their natural color. Fine details and small objects can be identified more positively than on black and white photographs at the same scale and the cause of tonal variations is more readily established.

Aerial photos from different years can give an indication of the history and previous use of the site. A complete set of air photos from the oldest available to the most recent can give an indication of the previous site use, as well as significant changes in topography or landforms due to the more rapid geologic processes such as stream channel migration, beach erosion, landslides, or rockfall.

Remote Sensing – Satellite imagery such as Landsat can often be used for regional interpretations of geologic features and drainage patterns. The AASHTO Manual on Subsurface Investigations (1988) provides a more detailed discussion on the types and availability of satellite imagery. LiDAR (Light Detection And Ranging) mapping uses a laser to measure distances to specific points and is capable of rapidly generating digital elevation data similar to that obtained by traditional photogrammetry techniques. The equipment can be mounted in a small plane or helicopter and can produce accurate digital topographic maps of the terrain beneath the path of the aircraft. One of the advantages of LiDAR is that vegetation can be removed from the database to reveal a “bare earth” model. Landforms that are typically obscured by western Washington’s heavy vegetation are often apparent on the “bare earth” view. Similar technology using land based equipment is also becoming available. These techniques are being more widely used for mapping river morphology and flood plains, and geologic hazard such as landslides and may be available from local agencies

Soil Surveys – Agricultural soil surveys in the United States have been conducted by the Department of Agriculture (USDA) in conjunction with state agencies since the early 1900’s. The results of the surveys are presented in the form of reports and maps which commonly cover a complete county. The reports, in general, contain a description of the aerial extent, physiography, relief, drainage patterns, climate, and vegetation, as well as the soil deposits of the area covered. The maps show the extent and derivation of the various deposits. The surveys give some information on the slope inclination and erosion hazards that may be common. The reports also provide engineering classifications of the near surface soil and sometimes information on the suitability of the soils for various construction uses as well as an indication of the general drainage characteristics.

The surveys are regional in aspect and only provide information on the top several feet of soil. They should not be used for more than providing some preliminary soil information.

Other Sources – WSDOT's unstable slope data base should be reviewed for any historic problems with slope instability or rock fall problems.

Hydrogeologic surveys can provide regional information on the presence and depth of groundwater. Both the DNR and USGS have completed hydrogeologic surveys in parts of Washington.

Scientific articles and reports on geology in Washington may also be available, through the DNR and university libraries.

2.2.2.2 Previous Site Exploration Data

Most highway transportation projects are on or near existing alignments, and previous subsurface information might be available. For WSDOT projects the Geotechnical Office maintains files at the Materials Lab in Tumwater. Files are generally available for existing bridges, retaining walls, or significant cuts and embankments. Materials reports and source reports that were prepared for alignment studies might also be available either from the Geotechnical Office or the Region Materials Engineer.

Water well records are available from the Department of Ecology. Many logs can be obtained from their website. The soil descriptions are generally not very reliable; however, information on groundwater levels and presence of bedrock can be obtained from them.

The City of Seattle has developed an existing boring database in conjunction with the University of Washington. The database includes borings completed for local agency projects as well as data provided by consultants. The database is available on-line and includes a map showing exploration locations along with PDF images of the boring logs.

2.2.2.3 Previous Site Use

Environmental Impact Statements (EIS) will probably have been completed and will indicate the most recent land use of the area. Note that a review of land use records or reports that describe previous site uses, especially those that could identify the potential for hazardous waste will be contained in a separate report produced by the Environmental Affairs Office (EAO) or their consultant.

Note that identification of potential hazardous subsurface materials could affect the subsurface investigation approach for the geotechnical design. This issue may need to be considered, therefore, in the planning for the geotechnical subsurface investigation. The geotechnical investigation approach will also need to be adjusted during the subsurface investigation if potentially hazardous materials are retrieved during the subsurface investigation, both for crew safety purposes and to comply with environmental regulations.

If, during the office review or during subsequent subsurface investigation potentially hazardous materials are discovered, the EAO should be notified. The EAO will investigate the potential for hazardous waste, defining its nature and extent, and how to address it for the project.

Other site uses may also affect the site investigation approach and possibly the timing of the investigation. Especially important is whether or not the site is historically or archeologically significant, and whether or not there is potential for artifacts to be discovered at the site. The investigation for this type of previous site use should be conducted prior to beginning the geotechnical site investigation. In general, the region project office is responsible for making sure that this investigation is carried out.

While the geotechnical designer is not responsible to specifically carry out a detailed investigation regarding the potential to encounter hazardous subsurface materials or archeological artifacts, the geotechnical designer is responsible to know whether or not such investigations have taken place, to communicate this information to the Field Exploration Manager (FEM), and to adjust the geotechnical site exploration program accordingly.

2.2.2.4 Construction Records

Many WSDOT projects consist of improvement or replacement of existing alignments or facilities. Construction records and existing geotechnical or materials reports are often available from WSDOT files. Headquarters Final Records has the most complete collection of construction records.

Generally the Region Materials Engineer will be the primary contact to obtain any construction records from the Region Project offices. The Geotechnical Office also has some construction records. All three offices should be contacted for available construction records.

Consultation with WSDOT project engineers who may have completed work on similar structures in the same general area should be utilized to gain general information on the soil, foundation, and groundwater conditions. Previous experience may also reveal acceptable foundation conditions for the problems at hand.

Many of the county and city agencies also maintain records of investigations and construction, and these are generally available through each agency.

2.2.3 Site Reconnaissance

2.2.3.1 General

Before the site reconnaissance is performed, the geotechnical designer should have performed the office review as described in Section 2.2.2, as well as given some thought to the field exploration plan. The review of available data should be done prior to the field reconnaissance to establish what to look for at the site. The field reconnaissance should also be done with the preliminary plans in hand. Cross sections rovided with the preliminary plans should be field checked. The cross sections are often generated by photogrammetry and may not accurately represent the existing ground surface. If available, the project design engineer, structural engineer and field exploration supervisor should also participate in the site visit.

Note the location, type and depth of any existing structures or abandoned foundations that may infringe on the new structure. Inspect any nearby structures to determine their performance. If settlement or lateral movement is suspected, obtain the original structure plans and arrange to have the structure surveyed using the original benchmark, if possible.

For water crossings, inspect structure footings and the stream banks up and down stream for evidence of scour. Riprap present around the bridge foundation may indicate a past scour problem, could impact the location of test borings and will need to be dealt with during construction. Take note of the streambed material. Often large cobbles and boulders are exposed in the stream bed, but not encountered in the borings or noted on the boring logs. The boulders are an indication of unexpected subsurface obstructions to deep foundation installation.

Relate site conditions to proposed boring locations. Check access for exploration equipment and make an initial determination of what type of equipment might be best suited to the site conditions. If site preparation is necessary, note the type of equipment, such as a bulldozer, that may be needed for drilling equipment access. Note potential problems with utilities such as overhead and underground power, site access, private property or other obstructions. While utility clearances will need to be obtained before the subsurface exploration begins, the locations will influence where explorations can be located. Note any water sources that could be used during drilling. Also note traffic control needs to accomplish the field exploration program, considering the practical aspects of the proposed drilling plan with regard to impact to the public. If borings are to be located in a stream bed, the reconnaissance should note the size of the barge best suited for the job, details of anchoring, depth of water, locations for launching the barge, etc. Notes should be made as to which type of drilling is best suited to the site. Also note potential problems with borings such as shallow groundwater table, loose or heaving sands, cobbles and boulders, etc. Availability of water, if coring or mud rotary methods are anticipated, should be determined. Special sampling equipment needed, such as undisturbed sampling equipment, should be noted. This evaluation of field investigation logistics should be done with the assistance of the geotechnical field exploration manager or supervisors to take advantage of their expertise in working with geotechnical exploration equipment and in conducting a geotechnical field investigation (see Section 3.2).

Right of Entry on WSDOT projects is generally obtained through the project office. However, note proximity of residences and buildings for possible difficulties due to noise and other disturbances during the subsurface exploration. Local residents can often provide some information on the history of the site.

Compare the topography of the site with that shown on maps and try to confirm the assumptions made during the office review concerning the site geology. Observe and note natural occurring exposures such as river banks, natural escarpments, quarries, highway or railway cuts and rock outcrops. Measure the inclination of any existing steep slopes. Note and describe the type and amount of fill that has been placed on the site.

Note the extent of any existing unstable slopes or erosion features. For unstable slopes or landslides note the length and width of the area affected. Note any other indications of instability such as pistol butting of trees, hummocky terrain or springs. Note types of vegetation present. Full investigation of these issues will require review of the site conditions well above and below the facility alignment, and may extend on to private property. Right of entry may be needed in such cases to complete the site reconnaissance. If steep slopes must be accessed to fully investigate the site, safety issues will need to be addressed before attempting to access the area, or alternative means of getting into the position to make the necessary observations should be considered (e.g., a man-lift, or use of a helicopter).

Note the presence of any wetland or other surface water.

Hand holes or probes may be useful to obtain information on depth of soft soils.

Photographs are valuable records of the site visit and should be labeled with the approximate stationing, direction of view, date, and a brief title. Photos should be obtained of all the site features listed above and of the probable exploration locations.

A record of the field visit should be kept and included in the project file. Measures should be taken to permanently archive any photographs taken. The record should list and describe significant site features as discussed above along with approximate stationing. An example field reconnaissance report form is included in the FHWA Soil and Foundations Workshop Manual (Samtani and Nowatzki, 2006).

Special site reconnaissance requirements for investigation of rock slopes are provided, by reference, in Chapter 12.

2.3 Development of the Subsurface Exploration Plan

2.3.1 General Considerations for Preparation of the Exploration Plan

If the site reconnaissance is performed as part of a project definition phase investigation, the results will be used to develop the project definition conceptual level geotechnical report in accordance with Chapter 23. Otherwise, the site reconnaissance and office review results are used to develop the project design and/or PS&E phase field investigation.

A description of the site data needed for each type of project is provided in the Design Manual Chapters 510 and 1130. The sections that follow expand on the considerations required for the preparation of the subsurface exploration plan. Development of exploration plans for geotechnical baseline reports is covered in Chapter 22.

2.3.2 Criteria for Development

The goal of the geotechnical investigation program is to obtain the engineering properties of the soil or rock and to define the aerial extent, depth, and thickness of each identifiable soil/rock stratum, within a depth that could affect the design of the structure, fill, cut, landslide, or other project element, dependent on the size and nature of the element. Typical properties and conditions to be evaluated include permeability, compressibility, shear strength, the location of groundwater and the presence and magnitude of artesian pressures, if present. Regarding the determination of properties for design, the focus of the exploration and testing program should be on the geologic unit/stratum, and the number of measurements of each critical design property in each unit/stratum to have a reasonable degree of confidence in the property measured (see Chapter 5). The geotechnical investigation at the PS&E level should be adequate to fully define the subsurface conditions for design and construction purposes, and shall be consistent with the national standards of practice identified in this manual and as specifically augmented in this manual, subject to adjustment based on the variability of the site conditions and the potential impact of site condition variability as determined based on the judgment of an experienced geotechnical engineer or engineering geologist.

The type, location, size and depth of the explorations and testing are dependent upon the nature and size of the project and on the degree of complexity and critical nature of the subsurface conditions. In general, it is justifiable to spend additional money on explorations and related testing and engineering beyond the standards as identified in this manual as long as sufficient savings can be realized in the project construction costs. Consideration should be given to the small cost of a boring in relation to the foundation cost. A test boring will typically cost less than one driven pile. Yet the knowledge gained from the boring may permit a more efficient design that may allow elimination of one or more piles for that structure.

Consideration should be given to how sensitive the structure or embankment is to variations in subsurface conditions when planning the geotechnical investigation. Embankments can generally tolerate several inches of settlement while a structure may be limited to less than one inch. Embankment loads are spread over a wide area while structure loads are concentrated.

Some consideration should be given to the amount of risk that unknown soil conditions could bring to the project (e.g., what is the risk to the constructability and functioning of the facility if detailed subsurface information at a specific location is not obtained?). There are times when soil conditions may be understood fairly well for the geotechnical design, but that unknown soil conditions could affect the cost of the project. Generally if rock is encountered at the foundation grade in a boring at a pier location, the location and quality of the rock should be explored at the other side of the pier. If rock may fall off towards the river, make sure the borings explore the rock contact on the front side of the footing.

Specific requirements for boring spacing, depth, and sampling frequency are provided in Chapter 8 for foundations and hydraulic structures, Chapter 9 for embankments, Chapter 10 for cuts, Chapter 15 for walls, Chapter 17 for noise walls, signal and sign foundations, culverts, and buildings, and by reference to other documents/ manuals in Chapters 11, 12, 13, and 19 for ground improvement, rock cuts, landslides and infiltration facilities, respectively. While engineering judgment will need to be applied by a licensed and experienced geotechnical professional to adapt the exploration program to the foundation types and depths needed and to the variability in the subsurface conditions observed, the intent of specific requirements provided in the chapters identified above regarding the minimum level of exploration needed should be carried out.

The specific exploration requirements identified in the chapters identified above should be used only as a first step in estimating the number of borings for a particular design, as actual boring spacings will depend upon the project type and geologic environment. In areas underlain by heterogeneous soil deposits and/or rock formations, it will probably be necessary to drill more frequently and/or deeper than the minimum guidelines provided in these chapters to capture variations in soil and/or rock type and to assess consistency across the site area. Even the best and most detailed subsurface exploration programs may not identify every important subsurface problem condition if conditions are highly variable. The goal of the subsurface exploration program, however, is to reduce the risk of such problems to an acceptable minimum.

In a laterally homogeneous area, drilling or advancing a large number of borings may be redundant, since each sample tested would exhibit similar engineering properties. Furthermore, in areas where soil or rock conditions are known to be very favorable to the construction and performance of the foundation type likely to be used (e.g., footings on very dense soil, and groundwater is deep enough to not be a factor), obtaining fewer borings than specified in the chapters identified above may be justified.

Test borings are typically the primary means used to obtain the needed subsurface information and samples for laboratory testing. However, other means of obtaining subsurface data should be considered to provide a more complete picture of the subsurface conditions and to help reduce exploration costs.

Cone probes can be a rapid and cost effective means to reduce the number of conventional borings, yet provide additional data that cannot be obtained from conventional test hole drilling and sampling. Cone data can be especially effective in defining the finer stratigraphy of geologic units, to obtain pore pressure measurements and in-situ permeability and shear wave velocities, as well as obtain data that can be directly correlated to a variety of soil properties. However, the cone is not very useful in dense to very dense soils or soils with larger gravels and cobbles (due to inability to penetrate such soils). The cone can be especially useful in comparison to conventional borings when heaving sands are present. If cone probes are used to supplement a subsurface exploration program, some conventional test hole data are necessary to correlate readings from the probe to physical samples of the soil (since the cone is not capable of retrieving physical soil samples, as well as to obtain soil samples for laboratory measurement of soil properties.

Similarly, in-situ testing devices such as the pressuremeter and vane shear can be conducted to supplement conventional test hole drilling to obtain specific in-situ properties. For example, the pressuremeter is useful for obtaining in-situ soil stiffness properties that can be used to more accurately assess settlement or lateral load response of foundations. Shear vane testing can be useful to obtain in-situ undrained shear strength of soft cohesive soils. See FHWA Geotechnical Engineering Circular 5 (Sabatini, et al., 2002) for additional information on these types of in-situ tests and their use.

Geophysical techniques should also be considered to fill in the gaps between test holes and to potentially reduce the cost of the geotechnical subsurface investigation. Geophysical techniques are especially useful for defining geologic stratigraphy, and can be useful to identify buried erosion channels, detailed rock surface location, overall rock quality, buried obstructions or cavities, etc., as well as to define certain properties.

Geophysical testing should be used in combination with information from direct methods of exploration, such as SPT, CPT, etc. to establish stratification of the subsurface materials, the profile of the top of bedrock and bedrock quality, depth to groundwater, limits of types of soil deposits, the presence of voids, anomalous deposits, buried pipes, and depths of existing foundations. Geophysical tests shall be selected and conducted in accordance with available ASTM standards. For those cases where ASTM standards are not available, other widely accepted detailed guidelines, such as Sabatini, et al. (2002), AASHTO Manual on Subsurface

Investigations (1988), Arman, et al. (1997) and Campanella (1994), and Sirles (2006) should be used.

Geophysical testing offers some notable advantages and some disadvantages that should be considered before the technique is recommended for a specific application. The advantages are summarized as follows:

- Many geophysical tests are noninvasive and thus, offer, significant benefits in cases where conventional drilling, testing and sampling are difficult (e.g. deposits of gravel, talus deposits) or where potentially contaminated subsurface soils may occur.
- In general, geophysical testing covers a relatively large area, thus providing the opportunity to generally characterize large areas in order to optimize the locations and types of in-situ testing and sampling. Geophysical methods are particularly well suited to projects that have large longitudinal extent compared to lateral extent (such as for new highway construction).
- Geophysical measurement assesses the characteristics of soil and rock at very small strains, typically on the order of 0.001%, thus providing information on truly elastic properties, which are used to evaluate service limit states.
- For the purpose of obtaining subsurface information, geophysical methods are relatively inexpensive when considering cost relative to the large areas over which information can be obtained.

Some of the disadvantages of geophysical methods include:

- Most methods work best for situations in which there is a large difference in stiffness or conductivity between adjacent subsurface units.
- It is difficult to develop good stratigraphic profiling if the general stratigraphy consists of hard material over soft material or resistive material over conductive material.
- Results are generally interpreted qualitatively and, therefore, only an experienced engineer or geologist familiar with the particular testing method can obtain useful results.
- Specialized equipment is required (compared to more conventional subsurface exploration tools).
- Since evaluation is performed at very low strains (or no strain at all), information regarding ultimate strength for evaluation of strength limit states is only obtained by correlation.

There are a number of different geophysical in-situ tests that can be used for stratigraphic information and determination of engineering properties. These methods can be combined with each other and/or combined with the in-situ tests presented in Section 5.4 to provide additional resolution and accuracy. ASTM D 6429, "Standard Guide for Selecting Surface Geophysical Methods" provides additional guidance on selection of suitable methods.

Sampling requirements will depend on the type of soil or rock encountered and the nature of the project element to be designed and the properties necessary for the geotechnical design of that project element. Properties needed for design, and how those properties can best be obtained, should be identified as part of the geotechnical investigation planning process. For example, if soft to stiff cohesive soils are present, an adequate number of undisturbed samples will need to be obtained to perform the laboratory shear strength and consolidation testing to define the shear strength and compressibility properties needed for design, considering the potential variability of these properties in each geologic unit, as well as to account for problem samples that are discovered to not be usable for testing. The degree of sample disturbance acceptable should also be considered, as well as the ability of the specific sampling technique to retain the high quality undisturbed soils needed (see Chapter 3 regarding sampling techniques). The disturbed sampling technique selected to obtain representative samples for classification and characterization will depend on the size of the bigger particles anticipated. For example, SPT sampling is generally not suitable for soils that contain a large percentage of medium to coarse gravel – in such cases, a Becker hammer sampler may be more appropriate. If the gravelly soils of interest are close enough to the surface, it may be possible to obtain more representative bag samples through test pit techniques. For large projects where shaft foundations are anticipated, and if permits and access can be obtained far enough in advance of when the final design is due, larger diameter augers could be used to install test shafts to evaluate the soils and evaluate shaft constructability. If detailed stratigraphy is needed, for example, to identify potential unstable zones or surfaces, Shelby tube samples or triple tube coring techniques can be used to get a continuous soil or rock sample for visual assessment.

Field instrumentation planning is also crucial to the development of a complete field exploration program. Ground water measurement in terms of its location, pieziometric head, extent across the site, gradient, and connection to surface water features is typically important for most geotechnical designs, and its measurement should always be a part of any geotechnical investigation planning effort. Elimination of ground water measurement from the geotechnical investigation plan must be justified by strong evidence that there is no groundwater present within the depths of interest, or that the presence of ground water will have no effect on the geotechnical design of the project element or its construction. Note that measurement of ground water in the drilled hole at the time of drilling is generally not considered to be adequate for ground water measurement. In granular soil with medium to high permeability, reliable groundwater levels can sometimes be obtained in the drilled hole. At a minimum, groundwater levels should be obtained at completion of drilling after the water level has stabilized and 12 hours after drilling is completed. However, since the presence of drilling fluids and the time required for ground water levels to reach equilibrium after drilling can be significant, measurements of ground water at time of drilling can be misleading. It is generally necessary to install some type of piezometer to make such measurements. The extent of the ground water measurement program shall be capable of evaluating both design and constructability needs (note that this does not mean that the piezometers need to be available for use during construction of the project element, but only means that constructability issues can be assessed). Seasonal or tidal variations in the ground water levels should also be assessed to the extent feasible given the project design schedule. Continuous monitoring of groundwater can be achieved by using electrical piezometers such as vibrating wire type in conjunction with digital data loggers. Additional information on ground water monitoring as part of the field investigation is provided in Mayne, et al. (2002).

Other field instrumentation may be needed as part of a geotechnical investigation for certain situations. For example, where instability is anticipated, inclinometers placed at strategic locations to define the potential failure surface should be installed. The inclinometer should be installed deep enough to be firmly fixed in stable soil. For forensic analysis of existing structures, tilt meters and/or extensometers can be useful for determining the direction and location of structure movement. Setting up survey control of key points on the structure as part of the geotechnical investigation can also be of use in some cases.

2.3.3 Preparing the Exploration Plan

It is important to be confident of the accuracy of the site data provided by the office requesting the geotechnical services, and to clearly understand the scope of services being requested. The office requesting the geotechnical services should also clearly understand what affect approximations in the site data could have on the geotechnical design, and the need to go back later and redo some of the geotechnical work if the impact of such approximations on the geotechnical design is significant. Any geotechnical concerns that are likely to develop, or the need for contingencies, should also be communicated at this time. Communication between the geotechnical designer and the project office is essential throughout the geotechnical investigation. The geotechnical designer is defined as the geotechnical engineer or engineering geologist who has been given responsibility to coordinate and complete the geotechnical design activities for the project. Early communication of potential complications due to geotechnical concerns will result in more cost effective and constructible designs. Any impact to project schedule resulting from the geotechnical investigation as it progresses should also be communicated to the project office promptly. It is the geotechnical designer's responsibility to make sure that this communication takes place.

Once the geotechnical investigation plan has been developed and approved (see Chapter 1), a proposed budget for field exploration, laboratory testing and engineering should be developed and provided to the project office. The basis of this budget, including a description of the scope of work as the geotechnical designer understands it, the date and source of the site data upon which the geotechnical investigation plan was based, and the potential for changes to the plan that could occur once some of the geotechnical subsurface data becomes available must be clearly documented in the letter transmitting the geotechnical project budget.

The proposed locations of the borings should have been checked for accessibility during the site reconnaissance (normally, the drilling supervisor will check for this). It may be necessary to shift the locations of some explorations due to local conditions, such as utilities, encountering obstacles such as boulders during drilling, or changes in engineering plans. The revised locations of these holes should be carefully plotted on the layout by the drill inspector, and the reason for the shift should be noted on the field log. Some tolerance in location of the explorations should be expected and communicated to the drill crew. The amount of tolerance will depend on the topography at the site, the expected soil conditions, stage of exploration, and type of structure. For example, for explorations made during the project definition phase or for cut slope design, exact locations might not be critical. On the other hand, if the test boring is being made to define the rock contact beneath a spread footing, moving the boring 10 feet might be too much. If the location of the exploration is critical, it may be justified to mobilize a different type of drill rig. Costs incurred during construction because of differing site conditions are generally much greater than the cost of an additional mobilization.

Communication between the geotechnical designer and the drilling inspector during the field exploration is also crucial. The drilling inspector should be briefed as to what subsurface conditions to expect and should contact the geotechnical designer if any significant changes are encountered. It may be necessary to adjust the sampling intervals of depth of explorations or add explorations, if the subsurface conditions are different than expected. If it becomes apparent that such changes that will significantly impact the project budget or schedule, it is important to immediately contact the project office to discuss the situation with them, and come to an agreement on the best course of action, but without impacting the progress of the field crews in accomplishing the work.

The information needed on the drilling request form should be as complete as possible to make efficient use of the exploration crew's time. They need to know how to get to the site, where to drill, what equipment to take, and what difficulties to expect. The drill crew's time should be spent in drilling and sampling and not in sending back for more equipment.

A copy of the WSDOT Field Exploration Request Form is attached in Appendix 2-A. Other examples are available in the National Highway Institute (NHI) Course manuals.

Below is a partial list of information to be included on the field exploration request by the geotechnical designer. Other information should be included as appropriate.

Field Exploration Check List:

- Type of explorations required.
- Sequence of drilling to allow for adjustment in the plan. For example, explorations in areas where soil conditions are unknown or problem soils are expected to be present should be performed in the first stages of the program, to allow for adjustment in sampling intervals or additional explorations to be added.
- Expected soil conditions. Attach field logs from nearby explorations, if available.
- Sampling intervals and types of samples to be obtained.
- Instrumentation and procedures for installation.
- Criteria for ending borings - depth, refusal, thickness of bearing layer, etc. If at all possible, the depth of all explorations should be estimated prior to doing the fieldwork. However, that is not always practical in situations where no previous subsurface information is available and some criteria should be stated on the exploration plan. A criteria recommended for typical use is to have a minimum of 30 feet of material with blow counts of 30 blows per foot or greater, or a minimum of 10 feet into bedrock, and for deep foundations, the boring depth should be at least as deep as the estimated foundation depth plus 20 feet. Note that without communication between the geotechnical designer and drilling inspector, these criteria can sometimes result in borings that are drilled deeper than necessary.
- Coordination of drilling inspector and geotechnical designer regarding when and at what stages of the field exploration communication should take place.

The field exploration supervisor is responsible to obtain the following information, either through field review of the investigation plan, or with the help of the appropriate Region offices:

- Equipment required and access needs
- Known permits required and regulations
- Known utilities
- Special traffic control requirements
- Cost of field exploration services.

Coordination between the field exploration supervisor and the geotechnical designer is necessary to implement the field investigation program, to make sure that there are no logistical problems with the plan implementation.

2.4 Development of the Laboratory Testing Plan

The laboratory testing plan shall be developed in accordance with Section 5.6.2. The laboratory testing plan includes classification and index testing, and soil/rock property tests that can be used directly to assess design parameters. The development of the testing plan shall address the properties needed for geotechnical design, and shall consider the in-situ (field) test data available such that the results from both field and laboratory testing can complement one another to provide a consistent and complete assessment of the properties of the soil and rock strata encountered.

For soil classification/index testing, the plan shall consider the following:

- Enough samples shall be selected in each soil stratum to assess the consistency of each soil stratum,
- When samples are available from more than one test hole for a given soil stratum, samples from more than one test hole should be tested to verify spatial consistency of the soil properties,
- For soil samples with a significant fines content, Atterberg limits tests should at least be attempted to determine the plasticity of the fines.

For performance level laboratory tests, the plan shall consider the following:

- Availability of samples suitable for testing – note that the field exploration plan should address the laboratory sample needs,
- The number of performance tests for each property required for the geotechnical design needed to assess the potential variability in the property within a given geologic stratum, though it is recognized that it will generally not be possible to obtain enough test results to develop meaningful statistics for the property,
- The laboratory testing should be conducted in a way that best represents the in-situ conditions from which the tested samples were taken, and the stresses and moisture conditions to which the soil/rock being characterized through the tests will be subjected based on the geotechnical design anticipated,
- Minimization of sample disturbance, when testing is conducted on undisturbed samples,
- Classification/index testing to be conducted on the samples subjected to performance level tests.

The laboratory testing plan shall identify the following information and testing requirements:

- All tests shall be clearly identified as to the location within the borings from which samples to be tested will be taken.
- The specific test procedures to be used shall be identified, including any special sample preparation requirements and specific testing parameters, such as stress levels. If the test procedures have options, the specific options to be used shall be specified.
- The classification/index tests to be conducted on each sample subjected to performance level testing.

2.5 References

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Mayne, P. W., Christopher, B.R., and DeJong, J., 2002, *Subsurface Investigations – Geotechnical Site Characterization*, Publication No. FHWA NHI-01-031, National Highway Institute, Federal Highway Administration, Washington, DC, 300 pp.

Sabatini, P.J, Bachus, R.C, Mayne, P.W., Schneider, J.A., Zettler, T.E. (2002), Geotechnical Engineering Circular 5 (GEC5) - Evaluation of Soil and Rock Properties. Report No FHWA-IF-02-034. Federal Highway Administration, U.S. Department of Transportation.

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FIELD EXPLORATION REQUEST

DATE: **REVIEWED BY:** ____________________

REGION: **SR:** ________ **C.S.:** ________ **JOB No.:** ____________

PROJECT NAME:

PROJ. CONTACT: ____________________________ **PHONE:** ____________________

PROJECT TYPE:

☐ **CENTERLINE** ☐ **STRUCTURE** ☐ **LANDSLIDE** ☐ **PIT/QUARRY**

NUMBER OF TEST BORINGS: ____

ESTIMATED DRILL FOOTAGE: ____

TYPE OF TEST HOLE:

☐ **STANDARD TEST HOLE**
☐ **CPT**
☐ **STANDARD TEST HOLE AND CPT**
☐ **OTHER** ____

INSITU TESTING:	**FREQUENCY OF TESTING:**
☐ **VANE SHEAR**	________________
☐ **CPT PORE PRESSURE DISAPATION**	________________
☐ **CPT SEISMIC VELOCITY**	________________
☐ **OTHER**	________________

INSTRUMENTATION:

☐ **OPEN STANDPIPE PIEZO** ☐ **PNEUMATIC PIEZO**
☐ **SLOPE INCLINOMETER** ☐ **OTHER** ______________________

SAMPLING FREQUENCY:

☐ **STANDARD SPT AT 5 FOOT INTERVALS**
☐ **WSDOT UNDISTURBED SAMPLES**
☐ **SHELBY TUBE UNDISTURBED SAMPLES**
☐ **LONGYEAR UNDISTURBED SAMPLES**
☐ **PISTON SAMPLER UNDISTURBED SAMPLES**
☐ **CONTINUOUS SAMPLING**
☐ **OTHER** ____

Special Instructions