Chapter

3

# Field Investigation

## 3.1 Introduction

For any transportation project that has components supported on or in the earth, there is a need for subsurface information and geotechnical data during its planning, design, and construction phases. Any geologic feature that affects the design and construction phase of a project, or has a bearing on site or corridor selection in terms of hazards and/or economics must be investigated and analyzed. Of equal importance is the clear and accurate portrayal of these conditions in a format that is accessible and understandable by all users.

Consider the following during field investigation:

- **Subsurface investigation:** The objectives of a subsurface investigation are the provision of general information on the subsurface conditions of soil, rock, and water, and specific information concerning the soil and rock properties that are necessary for the project geotechnical design and construction.
- **Scale of investigation:** For transportation projects in Oregon, the appropriate scale of investigation must be carefully considered. Because of Oregon's geology and geography, subsurface conditions are complex and may vary widely over short distances. A more thorough investigation will provide additional information that will generally decrease the probability of encountering unforeseen conditions during construction, and increase the quality and economy of the geotechnical design of a project.
- **Balance of investigation:** Time and fiscal considerations will constrain the scale and resolution of the field investigation. Therefore, the geotechnical designer must balance the exploration costs with the information required and the acceptable risks.

The technical decisions and details required for site investigations require the input of trained and experienced professionals. Every site has its own particular circumstances, and diverse geologic conditions, professional experience, available equipment, and the previously described time and budgetary restraints all contribute to the most cost-effective site investigations. The implications of site-specific geologic conditions for the type of proposed facility must be investigated for each project. The remainder of this chapter describes established ODOT criteria to be used in field investigations as well as information on any areas where ODOT's criteria differs from the FHWA and AASHTO guidelines. More information can also be found in the Federal Highway Administration *Subsurface Investigations - Geotechnical Site Characterization Reference Manual* (*FHWA NHI-01-031*).

### 3.1.1 Established Investigation Criteria

Professional experience and judgment are the basis of any field investigation program. This chapter is not intended to provide a prescriptive approach to field investigation, however; there are some established base levels of investigation for transportation facilities that must be mandated to assure consistency and quality throughout the agency, and to address a common level of risk acceptance.

- These baselines were based on Federal guidance and the *AASHTO Manual on Subsurface Investigations*, 1988. ODOT has adopted the baseline requirements for subsurface investigations from the AASHTO Manual.
- However, due to the more variable conditions found in Oregon, ODOT's practice is slightly more rigorous with respect to exploration spacing and sampling. ODOT variance from AASHTO guidelines is outlined in Section 3.5 (Subsurface Exploration Requirements) and Section 3.6 (Subsurface Exploration Methods). *LRFD Bridge Design Specifications, Section 10* provides an additional resource for subsurface investigations, supplementary to the AASHTO guidelines.

The most important component of subsurface investigation is the personnel that direct the field activities, interpret the information, and present the results in a clear manner to those responsible for the final geotechnical design and construction of the project. The quality of information produced from a subsurface investigation can vary substantially depending on the experience and competence of the personnel charged with its conduct. Radically different interpretations and conclusions can result from substandard investigation programs. Subsurface investigation is an investment in the success of a project with returns that range from 10 to 15 times the cost of the investigation later realized during final design and construction.

## 3.2 General Subsurface Investigation

For most projects, the main purpose of a subsurface investigation program is to obtain the engineering properties of the soil and rock units and define their vertical and lateral extent with respect to thickness, position in the stratigraphic column – their depth, and aerial extent where they could affect the design and performance of a structural or earthwork feature.

The properties normally evaluated include Index Properties such as:

- natural moisture content,
- Atterberg Limits, and
- Electrochemical properties (pH and Resistivity)

Additional physical properties may be evaluated, such as

- shear strength,
- density,
- compressibility, and
- in some cases, permeability.

The location and nature of groundwater is evaluated in every subsurface investigation. In addition to material properties, subsurface investigations are carried out to explore and monitor geologic hazards that were identified in the office studies previously conducted.

For this later purpose, landslides are the most common hazard although caverns, compressible materials, high groundwater, faults, and obstructions may also form the basis or extension of a subsurface investigation program.

## 3.2.1 Subsurface Investigations – Phases

Subsurface investigations may be carried out with varying levels of intensity depending on the phase of the project for which they are conducted. The typical phases are described in the following sections.

### 3.2.1.1 Phase 1

For the Field Survey and/or Alternative Design phases (Usually described as “Phase 1”) of a project, the information gathered from the office study is usually sufficient for preliminary geologic/geotechnical input to the project team and for completion of the Soils and Geology chapter of the Environmental Impact Statement (EIS). In the case of a large and/or complex project, or if geologic conditions will have a major impact on the design and construction of a project, then some amount of subsurface investigation will be warranted to determine the exact location and extent of the problems and to devise some preliminary cost estimates and alternatives. Ideally, when performing a subsurface investigation during Phase 1, the exploration would be situated at the location of a major project feature that would be investigated later during project design. However, as this occurs early in the project, or certain other alternatives are under consideration, the precise locations of bridge bents and final alignments may not be known.

### 3.2.1.2 Phase 2

The project design phase (Field Survey up to Preliminary Plans, usually referred to as “Phase 2”) is where the most intense and focused subsurface investigation occurs for specific project features. Wherever possible, the project design or Phase 2 investigation should capitalize on any previous explorations in the project area. Personnel responsible for the field investigation and geotechnical design should determine the utility of this information.

The project design phase subsurface exploration and testing program provides the geotechnical data specifically required by the project’s geotechnical design team. The investigation provides the aforementioned informational needs for the foundation and earthworks design as well as:

- Additional information applicable to other related project elements such as the chemical properties of soil with respect to corrosion of structural elements, and issues associated with environmental protection and erosion control.
- The project geotechnical design analyses, decisions, and recommendations for construction will be based on the information gathered during the Phase 2 investigations.

For these reasons, the information gathered during this phase of investigation should achieve a degree of accuracy, thoroughness of coverage, and relevancy to support the project design decisions and to allow for realistically accurate estimates of geotechnical bid items.

### 3.2.1.3 Other Phases

There will be some instances where additional subsurface investigation is necessary during Advanced Plans, Final Plans, or even during the construction phase of a project. This is not necessarily due to an incomplete investigation during the project design phase, but rather the result of unforeseeable problems that arise during construction, or late design changes following the main investigational effort and/or geotechnical design. Subsurface investigation is conducted to provide design information and is usually adequate, in most cases, for contractor's estimates for construction and bidding. Explorations conducted during construction are uncommon, and are usually carried out to resolve problems or answer questions that arise while the project is being built.

Occasionally, explorations will occur as part of the construction activity to install and monitor needed instrumentation. When design changes occur late in a project, additional subsurface investigation can be necessary to confirm the geotechnical design assumptions or to develop additional information.

## 3.3 Exploration Plan Development

The Exploration Plan is a document that describes the subsurface investigation activities that will take place to obtain the engineering properties required for geotechnical design. The objective of the Exploration Plan is to:

- Assure that the sampling and testing carried out for the subsurface investigation thoroughly covers each of the geologic units applicable to the geotechnical design.
- Verify that the maximum amount of information can be obtained from the fewest number of borings or other higher-cost methods.

In order to achieve this, the plan must be updated and modified as exploration proceeds to make sure that the number of samples taken, and tests performed in each unit provides enough numeric measurements of each critical engineering property distributed throughout the geologic unit to provide enough confidence in the property to base the geotechnical design upon. In this regard, the properties of a material at one end of a long alignment may not hold true for the other end, and a geotechnical designer will not want to base all design parameters for that material on only one or a few samples.

Subsurface investigation conducted during the project design phase must fully define the subsurface conditions at a project site to meet the requirements of geotechnical design and construction. The proper execution of the Exploration Plan will assure that samples and tests are numerically adequate and distributed vertically and laterally throughout each geologic unit, and that every important geologic unit at the site is discovered and investigated to the maximum feasible extent. The Exploration Plan will also assure that the site investigation is conducted in accordance with the standards of practice outlined in the 1988 AASHTO *Manual on Subsurface Investigations* and augmented in this manual. These standards are further subject to modification due to the variability of the site geology, sensitivity to potential changes, and risk or potential impact.

**Note:**
*Exploration Plans should be created, reviewed, and executed by an experienced engineering geologist or geotechnical engineer.*

The geotechnical designer should comprehensively evaluate the various methods and procedures for subsurface exploration that are currently available to maximize the amount of information gathered while reducing costs to the extent possible. The most common method for achieving this is to gain the most information from the fewest number of borings.

Alternatively, various types of exploration methods may be used where practical in lieu of the more expensive borings to realize those cost savings without compromising the necessary acquisition of information.

## 3.3.1 Exploration Plan Considerations

One of the leading issues addressed when developing the Exploration Plan is the overall scale or intensity and level of effort for the subsurface investigation. To answer these questions, the expected complexity of the project site's geology must be considered with respect to nature of the proposed project, and the project's requirements from the subsurface investigation.

In effect, there are some primary factors that will necessitate increasing the Exploration Plan for a larger-scale subsurface investigation including:

- complex site geology
- complex site conditions
- scale of the project
- sensitivity of the facility to variations in site conditions

The subsurface investigation program should be scoped according to these issues rather than from some baseline requirement. Each exploration should be justifiable in terms of the information needed from it. Such informational requirements form the basis of the following criteria:

- the type of boring
- location
- depth
- types of sampling
- sampling interval

These questions can only be answered by the experience, knowledge, and application of engineering geologic principles by the geotechnical designer. Through careful examination of the results previously obtained by the office study, and previous experience working in the area are the essential elements for determining the objectives and requirements of the subsurface exploration program.

### 3.3.1.1 Minimum Requirements for Subsurface Investigations

The considerations of section 3.3.1 do not preclude the necessity of established minimum requirements for subsurface investigations. The base level of investigation has value as an initial approach to a subsurface investigation and for preliminary cost estimation of exploration activities as well as assuring that some uniform amount of exploration is accomplished for all geotechnical design. The minimum standards for subsurface investigations are well defined in the 1988 *AASHTO Manual on Subsurface Investigations* and are broadly accepted in the practice.

**Where ODOT Differs from the AASHTO Manual**

Where ODOT practice differs from the AASHTO Manual is in the divergence from the minimum amount of investigation. AASHTO allows for a reduction from the minimal amount of exploration in areas of predictable geologic conditions and the absence of any geologic hazards. Such conditions generally do not exist in Oregon and as a rule, prohibit any reduction of the exploration program. Rather, explorations are added to the program due to the unpredictable nature of the state's geology. Much of the work performed during the preliminary office studies will assist in determining the overall scale of the subsurface investigation program.

Such added expenditures are always justifiable when additional exploration, testing, and analyses result in correlative savings on the construction cost and in an overall better geotechnical design.

### 3.3.1.2 Risk Tolerance

Further consideration in the development of the Exploration Plan should be given to developing an assessment of the risk tolerance of the project to unforeseen subsurface conditions. In this regard, an assessment of the risks assumed by the constructability and function of the design feature without the benefit of site-specific subsurface information should be conducted with respect to the potential for cost overruns during construction and to potential for long-term maintenance or increased lifecycle costs. The cost of an over conservative design resulting from a hedge against unknown subsurface conditions is another aspect of risk that should also be evaluated. This is where a design is forced to be based on the worst possible condition known to be present or perceived at a site in order to prevent failure because the lack of information precludes the assessment of other alternatives. Generally, an evaluation of the potential risks at a project site occurs as exploration progresses and the variability of the subsurface is discovered.

### 3.3.1.3 Structure Sensitivity

The sensitivity of a structure or other facility in terms of performance to subsurface variability also influences the scale of the subsurface investigation. Consider the following in relation to structure sensitivity:

- Where settlement is concerned, structures are much more sensitive whereas embankments overall are able to tolerate more post-construction deflection not withstanding those sections adjacent to bridges.
- Existing structures adjacent to transportation projects also increase the sensitivity of projects in the built-up or urban environment. Where construction is to occur adjacent to existing structures or private buildings, the tolerance for settlement or deflection and even vibration is essentially eliminated, and correspondingly, the need for subsurface information increases.
- Such sensitivity can also extend to environmental, cultural, and archaeological sites where great efforts will be made to mitigate impacts during construction. For these circumstances, significant efforts in pre through post-construction monitoring are often required with instrumentation installed far in advance of contract letting.
- Certain types of construction may also be more sensitive to unanticipated subsurface conditions such as drilled shaft installation where relatively small changes can result in a sizeable cost increase.

Despite the best efforts and most detailed subsurface investigations, every significant subsurface condition may not be discovered or fully examined. The objective here is to reduce the risks accepted to the barest minimum, and to have some understanding of the risks that will remain.

### 3.3.1.4 Subsurface Investigation Strategy

An important strategy when conducting the subsurface investigation is to complete the most important explorations first with the idea that the project schedule may change, funding may be terminated, or some other decisions made that preclude the completion of all the planned borings. From this standpoint, the important borings are those that:

1. Provide information about geologic hazards affecting the project or that require monitoring for mitigation design,

2. Provide the information that the engineer needs to design the most critical structures, and
3. Again, those locations that provide the most amount of information for the lowest expenditure.

This approach to the subsurface investigation allows design to proceed in the event of the inevitable project schedule or other priority shifts that may have a more urgent need for geologic or geotechnical resources. It is quite common for a planned exploration to be interrupted by the needs of emergency repair work or other critical-path project, and having these explorations complete first allows engineers to continue work on a project rather than having to wait for the emergency to pass before getting the information they need to continue so that the interrupted project doesn't become an emergency itself.

**Note:**
*We recommend referring to Section 7.4.1 AASHTO that provides additional items to consider in determining the layout of a project subsurface investigation in addition to prioritization of the explorations. This bulleted list describes key issues in determining importance and priority of explorations from locations to structures that they are intended for as well as the use of less or even more expensive methods for investigation that may be required.*

## 3.3.1.5 Schedule of Subsurface Investigations

Subsurface investigations are ideally completed as early in the project as possible to allow sufficient time for geotechnical design, quantity estimation, and consideration of alternatives. Clearly, many of the project features must already be known to some degree before the Exploration Plan can be formulated. Right-of-way needs must be established to determine cut and fill slope angles and heights or the need for retaining structures. Plans that are even more detailed are needed to begin bridge foundation investigations. Typically, the bridge type, size, and location (commonly referred to as "TS&L) must be known in order to obtain ground-truth information at the precise bent locations.

### Completion of Exploration Plan

Because of these informational prerequisites, the Exploration Plan is usually completed soon after initiation of the structure TS&L phase with a goal for completion set at the 10% of TS&L completion with respect to its timeline. The target for completion of preliminary geotechnical recommendations is set at 2/3 TS&L.

In order to meet this date, there will be less than 50% of the TS&L timeline to complete the subsurface investigation and provide the needed information to the geotechnical designer charged with making the preliminary recommendations.

Subsurface investigation performed during preliminary phases may be called for at any time prior to Phase 2, particularly during the EIS phase depending on the size of the project or any other special requirements. These investigations are intended to develop project geotechnical constraints and/or to provide general information to assist in alternative route selection, and to address particular requirements of the EIS rather than to gain site-specific geotechnical design parameters. Preliminary subsurface investigation typically takes place on an existing state right-of-way readily accessible areas so there should not be additional time and money spent in acquiring permits of entry, building access roads and reclaiming sites.

### Instrument Monitoring Periods

An additional aspect of the subsurface investigation schedule that also needs to be determined is the requirement for instrument monitoring periods. These are particularly important as they commonly extend before and beyond typical project timelines.

- **Landslides:** Projects that involve landslide repair or evaluation are the usual reasons for broadening timelines as it is critical to monitor landslide movements over periods of time that include at least one wet season (usually November through April) to assess the nature of the slide evaluate the relationships between precipitation, groundwater, and slide movement, and determine the correct slide geometry for stability analysis.
- **Groundwater:** It is also important to monitor groundwater for other construction applications throughout seasonal fluctuations to help determine actual construction-time conditions. Grading operations or excavations that would be made "in-the-dry" during certain times of the year may occur below the groundwater surface during other months. Every effort must be made to collect this information regardless of the time of year that exploration is conducted.
- **Post-construction monitoring:** Where post-construction monitoring is necessary, it should also be identified as early in the Exploration Plan development as possible. Critical structures in addition to landslides may require such instrumentation for quality assurance in addition to providing an assessment of long-term performance.

#### 3.3.1.6 Exploration Sites

One of the primary factors affecting the schedule of the subsurface investigation program is providing access to drill sites. This includes acquiring the necessary permits as well as the actual physical occupation of the drill site.

**Note:**
*Preliminary borehole location should have taken place during the initial site reconnaissance and major requirements with respect to accessibility should have been identified at that time. Since access to certain drill sites requires a significant investment of time, it is necessary to start acquiring permits of entry, environmental clearances, and engaging contractors to build access roads or bring additional resources to move the drilling equipment.*

The geotechnical designer should clearly indicate the necessary borehole location tolerances to the field crews to assist in determining site access. When situating a borehole, consider the following:

- For some sites, a few extra feet of tolerance available will allow a borehole to be accessed with standard equipment or with minimal disturbance while at others, considerably greater efforts will be necessary to place the borehole at the precise location.
- Where the location of the exploration is crucial, it may be reasonable to mobilize specialty-drilling equipment.
- Several factors contribute to the amount of tolerance allowed for an exploration. Among these are the phase of the investigation for which the explorations are performed, in this case, the final design explorations would require the more precise location.
- The types of structure, expected subsurface conditions, and surrounding facilities also have more exacting standards for borehole placement.
- A spread footing on rock, or a tieback wall adjacent to and supporting an existing structure are examples of cases where relatively minor changes in the subsurface conditions have very serious consequences during construction and would therefore warrant the extra expenditure to precisely locate the explorations. In this case, the expenditure for mobilizing special equipment would be far exceeded by orders of magnitude from ensuing claims or even, litigation.

### 3.3.1.7 Right of Way and Permits of Entry

Determining the exact boundaries of the State's right of way during exploration planning is essential since this demarcation is very commonly not correlative to the highway centerline nor does it fall at a constant length perpendicular to it. Current right-of-way maps should be consulted to assure the correct property ownership at the exploration site or for any land that must be traversed by exploration equipment and personnel.

Permits of entry (also known as "Right of Entry Permits") are required for any site exploration outside of the highway right-of-way whether the site is on private property or on public lands outside the jurisdiction of ODOT. For simple cases, these permits can be obtained by the geotechnical designer in charge of the exploration or other staff. For most circumstances however; these permits should be obtained by the Region's Right of Way section. In either case, the region Right of Way section should be consulted prior to any entry onto private property. A sample Permit of Entry Form is included in Appendix 3-A.

Each permit of entry form should be accompanied by a site map showing the precise location of the exploration with respect to property lines and any structures or features on the private property.

Considerable delay in the exploration timeline can stem from the permit of entry process. In many cases, property owners are unaware of upcoming transportation projects until a geologist or geotechnical engineer asks them for a permit-of-entry for exploration. Even if unopposed or unaffected by the project, the owner may be reluctant to sign a permit of entry for a variety of reasons.

Often, further explanation of the activity and its purpose will be all that is necessary, or just allowing extra time for consideration is all that is required, but will affect the exploration schedule nevertheless.

**How to Handle Problems Obtaining Access to Property for Field Investigation**

In some cases, landowners are particularly slow in granting access to their property for whatever reason and may even respond to a request for a permit of entry with a letter from their legal counsel. In these instances, **the Region right of way office should be contacted immediately** to take a lead role in negotiations to resolve the issue. Although the Agency has the statutory authority to access any real property for the purpose of survey or exploration, it is an exceedingly rare case for ODOT to exercise this authority for subsurface investigation. The cause for performing a subsurface investigation on such a property must be well founded and without feasible alternatives.

**Note:**
*When a property owner refuses permission to enter their property, then all further communication and resolution becomes the responsibility of the Right of Way Section and the project management. Under no circumstances should field personnel mention or discuss the State's statutory authority to enter upon their property to complete the work, nor should they engage in any bargaining or make agreements other than those stated on the permit of entry form in exchange for access to their properties.*

**Obtaining Right of Way from other Real Property-owing Entities**

Other real property-owning entities will take more time in granting a permit of entry. Corporations, governmental agencies, mutually owned properties, and railroads all have different procedures and requirements for granting access. Corporations may sign permits of entry only from their main offices, governmental agencies may have lengthy policies and procedures for granting permissions, and mutually owned properties may have numerous non-resident owners that must all be contacted for their consent.

**Railway Right of Way**

Getting permission to access railroad right of way is a special case and can be a particularly time-consuming undertaking. For local operators and short lines, getting access may be relatively straightforward. Some larger carriers have a lengthy and rather Byzantine process for handling permit of entry requests that can severely affect a project timeline. If exploration or access is needed on railroad right of way, the project timeline should be adjusted accordingly and alternatives sought wherever possible. Permit of entry requests for railroad right-of-way should be forwarded through the headquarters Right of Way section.

In the event that the state-owned railroad right of way must be accessed, contact ODOT's Rail Section to obtain that permit.

**Limiting Site Impact**

When performing subsurface investigation on private property, all care must be taken to avoid and mitigate the site impact. Access to such sites should be planned with the smallest possible impact. Although some exploration sites will be completely removed during construction, there may be considerable time between then and the time of exploration. The responsibility for complete restoration of exploration sites is placed on ODOT by the same statute that provides legal access to those sites.

## 3.3.1.8 Utility Location/Notification

Underground and overhead utilities in the project area must be identified and approximately located early in the Exploration Plan development. The presence of utilities may dictate the location of, or access to exploration points.

**Warning:**
*Encountering underground utilities during site investigations can be detrimental to the exploration schedule and budget. Digging or drilling into underground utilities or contacting overhead power lines with drill rig masts or backhoe arms can be lethal. For these reasons, the exact location of all utilities must be determined before any equipment is mobilized to the project site.*

**Utility Notification Center**

In Oregon, the law requires that the Utility Notification Center is contacted no less than 48 business hours prior to any ground disturbing operations. This includes all test pit excavation, drilling, and even hand auguring or digging.

**Note:**
*The Utility Notification Center (or "One-Call" Center) can be reached at 1-800-332-2344.*

The Utility Notification Center contacts all of the utility services with facilities in the location(s) provided to them based on their records. The individual utilities then dispatch their personnel or contractors to the site to locate and mark the positions of their facilities according to the instructions provided. The following occurs in relation to utility marking:

- The utilities are also required by law to locate their facilities within 48 business hours. If the utility operator does not have facilities near the proposed location site, he or she will mark it as such to indicate that it is safe to proceed. Otherwise, they will mark the approximate location of their facility in the requested vicinity.
- If the utility is close to the proposed exploration, prudence would dictate that the exploration be moved slightly to allow for errors in the utility location, and to further prevent the accidental contact with the utility.

- If the utility has not marked the requested area in the required period, they should be contacted prior to commencement of exploration to confirm that the utilities have been contacted, and that they do not have facilities in that area.

The utility operators are often hard-pressed to comply with the 48-hour requirement due to the sheer volume of utility locations – particularly during the summer months when numerous contractors are requesting them. Additional time may be required, so utility location with respect to projected exploration starting times should be planned accordingly. It is also important to look for any other utilities that might be operating in the area in case they are not in the records of the Utility Notification Center. Indications of other utilities are marked riser boxes, manholes, valves, and obvious illuminated structures such as street lighting and advertising. It is the responsibility of the project geologist to notify any other utilities operating in the project area.

## Procedures to Perform Prior to calling the One-Call Center

The procedures for utility notification and location are relatively simple, but minor mistakes or overlooked information can result in unnecessary delay and risk to the utilities and the exploration personnel. The following steps should be completed and information gathered prior to calling the One-Call Center:

- All proposed exploration sites must be located and clearly marked in the field with a survey lath, painted target on the ground surface, or both. By convention, the survey lath and target should be painted white. Efforts should also be made to make the location as visible as possible for the utility locators such as using additional directional markers and survey flagging.
- Each exploration site should be numbered and labeled as either "proposed test boring" or "proposed test pit."
- The nearest physical address or milepost, and the closest cross street should be recorded.
- The Township, Range, and quarter Section should also be determined.

When contacting the One-Call Center, the following information will be asked by their operator:

- The caller's identification number (one will be assigned if not already registered)
- For whom the work is being performed
- Who will be doing the work
- Type of work
- Alternate contact
- Location of site (number of exploration points, county, nearest city, address, cross street, township range, section)
- Marking instructions (typically a 25' to 50' radius from each stake or target)
- Presence of any overhead utilities

The operator determines which utilities are known to have facilities in that area and provide the list verbally along with the ticket number, which will be used to identify that particular work order. The operator provides the date and time at which the work should be able to proceed. Once this call is complete, the operator will then notify those utilities that will then dispatch their locators. ODOT geotechnical designers use **Utility Notification Worksheet,** Appendix 3-B**,** to document utility location for future reference while on site.

### 3.3.1.9 Methods for Site Access

Exploration equipment selected for the subsurface investigation should be matched to the site conditions. Truck-mounted drills are the most commonly available and are capable of accessing most sites with or without additional work and equipment. However, for many sites, access to boring locations can be difficult and even very complex in some cases. Often, the cost for mobilizing special equipment to a project site is more than compensated for in reduced site impact, reclamation effort, time and materials costs, and the additional personnel and equipment that might be needed. Frequently, the method of site access is selected based on one or a combination of desired outcomes whether time and cost, minimizing impact, equipment availability, or equipment capability.

**Truck-Mounted Drill Rigs**

Truck-mounted drills that are road-legal generally have limited off-road capability even when equipped with 4-wheel or all-wheel drive due to their size and weight. These types of equipment are best suited to work on paved or surfaced areas although they are capable of reaching many off-road locations "in the dry." Because of their axle loading, they can rapidly become mired in wet or soft soils.

In order to use a truck-mounted drill in difficult conditions, access roads may need to be built using one or more additional pieces of equipment. In steep terrain, access roads may require substantial cuts and fills, and where soft ground is encountered, sizeable amounts of rock and geotextile will be needed to surface the road. Special mats or even plywood may be used to distribute the trucks weight over soft ground when accessing a boring location. In any case, such work can be expensive, time-consuming, laborious, and high-impact requiring significant reclamation work after exploration.

Truck-Mounted drills that are off-road capable may require lower-standard access roads, but still need these roads. If a significant amount of winching or vehicle towing is necessary, an alternative method of site access should be strongly considered, if only for safety reasons. The advantage of truck-mounted drill rigs is that they are usually the best-equipped and highest-powered pieces of equipment available, so if a particular type of drilling or deep hole is required, these may be the only option. For accessible sites, truck-mounted drills are usually the cheapest and fastest way to accomplish explorations since they can drive over a site, set up, complete the boring, and move on to the next location with relative ease and with fewer support vehicles.

**Track or ATV-Mounted Drill Rigs**

Many exploration drill manufacturer's product lines now include drill rigs mounted on a variety of track and rubber-tire ATV platforms with some of the same features and capabilities as their truck-mounted counterparts. In some cases, the drilling equipment is the same, and only the platform varies:

- **Track-mounted drill rigs:** Track-mounted drill rigs offer a much greater off-road capability and ability to access sites in rough terrain and soft ground. Although the track-mounted drill can reach difficult locations, some road building or at least clearing of trees and vegetation may be required, although to a much lesser degree, than their truck-mounted counterparts. A level pad upon which to set the drill may also need to be constructed. One of the drawbacks of track-mounted drills is that they require slightly more time for set up and moving between longer distances since they must be hauled to project sites on a flatbed truck or trailer. The presence of the trailer or large truck for hauling the drill may also prove to be another encumbrance when working in tight locations or those sites with limited parking or space for maneuvering a long truck and trailer combination. The types of tracks must also be appropriate for the site.

**Note:**
*Older-style steel caterpillar tracks are ideal for traversing steep slopes with a soil cover, but will be harmful to pavements or landscaped areas. Newer developments with rubber tracks offer better traction on bare rock surfaces, and are less harmful to pavements and landscaping but should still be used with caution as their treads can still damage or scar most surfaces.*

- **ATV Mounts:** Typical ATV-mounts consist of “balloon” or other oversized rubber tires for use in soft ground or swampy areas. The advantage that such vehicles have over tracks is the lighter load per unit area and correspondingly reduced impact to sensitive areas such as wetlands, landscaping, private properties, etc. Because of their distributed load, these vehicles are more suited to soft or uneven ground applications rather than for sites where traction on steep slopes is most needed. Several manufacturers now produce ATV platforms with tractor-style tires that offer many of the advantages of tracked and “balloon” tires with respect to traction, impact, and load distribution.

## Difficult Site Access

A variety of site conditions and subsurface information requirements create substantial difficulties in reaching exploration sites whether in remote, environmentally sensitive areas, or restricted space in the built-up environment. Such obstacles can range from high-angle slopes and physical barriers to restricted work areas such as confined spaces (as defined by OSHA), limited work space due to objects or environmentally sensitive areas, and over-water work. Diverse methods are available to assist with difficult site access as well as drilling contractors that specialize in this type of work.

Methods and equipment for difficult site access are as varied as the sites themselves. The common factor that limits what methods can be used for certain applications is the weight of the equipment with the volume of the machinery also being a limitation.

- **Winching or dragging:** Much of this work in the past has been performed by skid or trailer-mounted equipment with some man-portable also employed in some areas. This equipment has been winched, crane-lifted, or dragged into place by other tractors. With the advent of track and ATV-mounted drills, winching and skidding drilling equipment into place is no longer necessary or recommended due to the amount of ground disturbance involved.

- **Cranes:** Cranes are often employed to lift equipment into tight work areas although the weight of many of these drill rigs necessitated very large pieces of equipment to move them and had their own space issues.

- **Specialized equipment:** Until recently, most of the skid or trailer-mounted and man-portable drill rigs had restricted power and capabilities. However, drilling technology has advanced to the point where smaller and lighter equipment is capable of performing heavier drilling tasks. Specialized difficult-access drilling contractors generally use their own customized equipment that comes with a specific platform, or breaks down into lighter compartmentalized sections that are reassembled at the boring location. Much of this specialized equipment is light enough to be transported while slung beneath a helicopter.

Most modern drilling equipment not mounted on a truck chassis, with the exception of some man-portable equipment, is capable of completing almost all geotechnical exploration tasks in the same amount of time as their road-legal counterparts. However, these drills will always be restricted by allowable axle loads during transport, and so they will always have a disadvantage with respect to their overall horsepower versus a truck-mounted rig that does not require a truck and trailer combination for roadway transport. This disadvantage is typically only manifest in very deep and/or large-diameter boreholes.

## Barge/Over-Water Drilling

Foundation investigation for bridges commonly requires in-stream access to drill sites. To achieve this, barges or other platforms must be used to set the equipment over the foundation location. Over-water work will add extra details to a site investigation, and depending on the location, this can add extensive logistical complexity to a project.

- **Permitting:** Additional permits will be needed to conduct the over-water work from the US Army Corp of Engineers and/or the U.S. Coast Guard, and from the port authority or harbormaster with jurisdiction over the waters in which the investigation is being conducted. An additional staging and launch areas must be identified where equipment can be loaded onto the barge, and where the crew can access the work site for daily operations. The appropriate equipment must also be selected for the site with respect to the currents, depths, river traffic, obstructions, and other details.
- **Launch site:** The site for initially loading and launching the drill barge must be of sufficient size for the type of equipment being used. The launching ramp should have enough grades to provide enough draft for the barge. The facility will also need enough room to either drive or lift the drilling equipment onto the barge and to safely load and unload all other ancillary equipment and supplies. Scheduling the facility for loading and unloading may also be important at different times of the year. Some ports may only be available at certain times due to their ongoing cargo loading operations and public or commercial fishing ramps may be crowded during those seasons. A proximate and smaller location may be available for launching a skiff or other small craft to support the daily drilling operations and permit crew changes between shifts.
- **Drilling barge:** The barge and any other vessels used for the over-water drilling operations must also be selected and rigged for the conditions.
    - The drilling barge itself must be of sufficient size not only to support the weight of the drill and other equipment, but must also have enough deck space for whatever sampling and testing operations that will also be carried out.
    - The vessel used to transport the drilling barge should also be capable of moving the barge in all conditions of weather and current.
    - For work in very slow currents or standing bodies of water, the drill barge may be fixed in place by spud anchors or by lashing to a fixed object such as a driven pile or pier. Where stronger currents occur, whether stream or tidal, a larger vessel may be required to transport and anchor the drill barge during operations. Additional anchoring will be needed in such conditions.
    - Where water levels will fluctuate quickly during the conduct of drilling such as in tidal zones and downstream of large dams subject to rapid discharge, allowances must be made for the drill barge to move accordingly with respect to elevation. These operations will usually require the drill barge to use free-moving spud anchors that are also fixed to a more securely anchored vessel.
    - The access vessel or skiff must also be capable of operations in all conditions at the site.
    - Provision must be made for keeping track of elevation changes during tidal or current changes as this will profoundly affect the drilling operations.

**Note:**
*As a condition of the Corps of Engineers and/or the Coast Guard permit, a licensed Marine Surveyor must be engaged to examine the equipment and the site conditions. This professional will then make recommendations concerning the equipment, personnel, and safe conduct of operations. Whether or not a Marine Surveyor is required, their inclusion for over-water work planning is highly recommended for the particular skills and efficiencies that they bring to this rather hazardous aspect of subsurface investigation.*

## 3.4 Exploration Management and Oversight

The daily field exploration activities on a project should be based primarily on the execution of the Exploration Plan. The Exploration Plan provides a framework for scheduling and adjusting field operations as needed. It will necessarily allow for enough flexibility to modify the subsurface investigation program as information comes in from the field.

- The Project Geologist should maintain a base-level subsurface model from the subsurface information as it is received in order to make the needed modifications.
- The Field Geologist/Drill Inspector will need to provide regular updates on the field activities and information gathered so that changes to the schedule and routine can be made expediently. With the advent of cellular telephones and increasing areas of coverage, field crews should only be a few minutes away from contact with the senior geotechnical designers to inform them of unanticipated field conditions and in turn, receive direction on how to proceed with the modifications.

Because of the costs of subsurface exploration and the rapid use of the data, it is imperative that the subsurface investigation is directly supervised by qualified and experienced personnel. All on-site personnel including drillers, field geologists/engineers, and testing specialists should be instructed and familiarized with the project objectives and their role in achieving those objectives. Special geotechnical or other problems that may be anticipated during exploration including contingencies for addressing them should also be conveyed. All field personnel should be instructed in their role concerning project requirements for schedules, environmental protection, and especially, site safety and health procedures. Field personnel should communicate frequently with project supervisors or geotechnical designers.

Regular transmission of field data such as boring logs, test data, field conditions, and daily driller's reports will streamline and economize the site exploration.

**Note:**
*Any unforeseen site changes, complications, and geologic or geotechnical problems revealed during the investigation that will affect the project scope, schedule or budget should be communicated to the Project Leader without delay. The geotechnical designer charged with the exploration program is responsible for immediately and succinctly informing the Project Leader of the nature of the problem, the expected remediation, and the anticipated impact to the project. The geotechnical designer should then be prepared to offer alternatives and their respective outcomes for the resolution of the problem.*

# 3.5 Subsurface Exploration Requirements

## 3.5.1 General

The 1988 *AASHTO Manual on Subsurface Investigations* is the basis for subsurface investigations conducted by ODOT. This manual provides guidance on the minimum amount of investigation for the various structures and geotechnical features constructed for transportation projects. The manual states however, in numerous places, that there can never be a set of specifications and guidelines that will determine the amount of exploration that must take place for every project.

**Note:**
*The number of borings, their distribution, sampling interval, and depths of penetration will always be determined by the underlying geology and the size and complexity of the project.*

Planning for the subsurface exploration will be based on past knowledge of the site and on the published and unpublished literature that was consulted during the project reconnaissance phase. However, even the most thoroughly studied sites will still reveal previously unknown conditions, and each exploration provides new information about it. In a sense, the site conditions are truly unknown until the exploration begins, and knowledge of it increases as the investigation proceeds so adjustments must be made in the field to economize the investigation while assuring a full investigation of the important geotechnical design elements.

## 3.5.2 Exploration Spacing and Layout

The layout of explorations on a project is determined by many variables. As previously discussed, the assumed complexity of the underlying geology and the type of facility typically dictate the exploration spacing. Consider the following:

- Where conditions are uniform and a considerable amount of previous, reliable work has been accomplished in a project area, exploration spacing may be increased.
- If the geologic conditions are complex and change significantly over short distances, then explorations will necessarily be conducted on a shorter interval.
- Facilities that will impart a heavy load or are more sensitive to settlement or other movements will also require a more detailed exploration.

The 1988 *AASHTO Manual on Subsurface Investigations* provides a range of exploration spacing for the various structures and features that are typically the subject of subsurface exploration.

These guidelines are modified for use within the State of Oregon where subsurface conditions at the vast majority of sites warrant much tighter exploration spacing due to the highly changeable nature of the state's geology.

### 3.5.2.1 Spacing and Layout Strategies

Because transportation projects are typically linear, explorations tend to be channeled into a relatively straight and narrow corridor, and are often laid out only along the centerline of many features. This should be avoided as it most often results in poor development of the subsurface model. To avoid this, boreholes should be spread out to either side of the centerline to help determine the strike and dip of the underlying strata, the nature of the contacts (i.e. conformal or non-conformal), and other changes or irregularities across the subsurface profile. Exploration to reveal or characterize geologic hazards such as faults and landslides that affect the proposed project may necessarily be conducted outside of the proposed alignment(s). Material source or disposal site investigations normally take place far away from the project alignment and will have different exploration spacing criteria.

Take special care when conducting explorations in particular alignments and foundation locations. Certain geologic conditions, such as openwork cobbles and boulders, heaving sands, or highly fractured rock may bind exploration tools severely enough that the drill crew is unable to retrieve them from the hole where they subsequently form an obstruction during drilled shafts construction. In areas that experience high artesian pressures, improperly sealed boreholes may form an undesirable conduit for groundwater to enter footing excavations, cut slopes, or cofferdams.

**Note:**
*All borings should be abandoned in accordance to Oregon Water Resources Department Regulations to prevent vertical water migration. Provision should also be made to extract bound drilling tools from the boring with special equipment.*

The boring layout guidelines presented here are of a general nature and are intended for use in the preliminary location of site exploration points. The final exploration locations should be developed as the site investigation proceeds. Information must be incorporated into the Exploration Plan as it becomes available to assure the most complete, cost-effective outcome.

#### 3.5.2.2 Embankment and Cut Slope Explorations

The maximum exploration spacing for embankment fills over 10 feet (3.05m) in height is 200 feet (61m). Where changeable conditions or problem areas such as those with soft and/or compressible materials are present, then the exploration spacing should be decreased to 100 feet (30m). In many cases it will be necessary to conduct additional exploration using cone penetrometers, hand augers, or backhoe test pits to further define the properties and boundaries of problem foundation conditions. At least one boring should be located at the point of maximum fill height.

For cut slopes 10 feet (3m) and higher, the maximum boring spacing is 100 feet (30m). Borings should be staggered to each side of the cut line to help determine the strike and dip of the units in the cut slope, and one of the borings should be placed at the maximum depth of the cut. For “through-cuts” where a cut slope will be located on each side of the roadway, boring spacing may be increased to 200 feet (61m) for each cut slope, but the borings must be staggered so that the total 100 foot (30) spacing continues along the length of the cut.

Additional borings will be required in areas of faulted, sheared, tightly folded, highly weathered, or other potentially detrimental conditions exist.

Hand augers, direct push (i.e., GeoProbe), air-track drills, test pits, geophysical surveys, and other alternative exploration techniques can be used to supplement the test borings in proposed cut slopes to determine the elevations of variable bedrock surfaces and depths to bedrock. Air-track drills may also be used to penetrate the bedrock surface to determine and further resolve the location(s) of weathered rock zones and other features within the proposed cut slope.

#### 3.5.2.3 Subgrade Borings

Where relatively unvarying subsurface conditions are predicted and no other foundations or earthworks are expected, the maximum subgrade boring spacing should be 200 feet (61m). In areas where highly variably geology is predicted, the boring spacing should be decreased to 100 feet (30m) and further decreased to 50 feet (15m) in highly erratic conditions. Where critical subgrade conditions exist, the boring spacing may be decreased to 25 feet (8m).

Alternate exploration methods may be used in variable geologic conditions to supplement the borings and further resolve the characteristics and distribution of problematic materials and conditions. Such methods may include hand augers, push-probes, geophones, and test pits.

**Test pits**

Test pits on short intervals (25 feet/8meters) are not recommended due to the potential introduction of soft areas in the subgrade where the pits were located. If necessary, this problem may be alleviated by the use of compacted granular backfill materials to abandon the test pits after exploration. The test pit spoils would then need to be disposed of off-site. Several geophysical survey methods may also be appropriate for subgrade investigations to supplement the test boring information. Seismic reflection and electro-magnetic methods are commonly the best suited for determining material property boundaries and saturated or water-bearing zones.

#### 3.5.2.4 Tunnel and Trenchless Pipe Installation Borings

Tunnel construction for highway projects in Oregon is rare; however, trenchless pipe installation is common. Tunnels and trenchless pipe installations share many common construction and design issues and are thus treated in a similar manner with respect to subsurface characterization and exploration. Borehole spacing requirements for tunneling and trenchless pipe installation are highly dependent on the site geologic conditions and topography. The soil, rock, or mixed-face conditions predicted will determine the borehole spacing as well as the type of exploration and testing conducted. The depth of the tunnel/trenchless pipe alignment will greatly influence the total amount of drilling required.

The actual borehole spacing selected for tunnel or trenchless pipe installation should be determined by the actual site conditions. These conditions should be identified in advance by preliminary site review, and in the case of larger projects, preliminary site investigations conducted during the Phase I field survey. The recommended general borehole spacing for selected conditions is shown in the following table:

**Table 3-1. Tunneling and Trenchless Pipe Installation Recommendations**

| Recommendations | |
|---|---|
| Soft Ground Tunneling | |
| Adverse Conditions | 50-100 feet (15-30m) |
| Favorable Conditions | 200-300 feet (61-91m) |
| Mixed-Face Tunneling | |
| Adverse Conditions | 25-50 feet (8-15m) |
| Favorable Conditions | 50-75 feet (15-23m) |
| Hard Rock Tunneling | |
| Adverse Conditions | 50-100 feet (15-30m) |
| Favorable Conditions | 200-500 feet (61-152m) |
| Trenchless Pipe Installation | |
| Adverse Conditions | 15-30 feet (5-9m) |
| Favorable Conditions | 30-50 feet (9-15m) |

In addition to the geologic conditions, other site constraints will equally determine the number and spacing of borings for tunnels and trenchless pipe installations. The location of existing structures with respect to the proposed depths and alignments will necessitate a more detailed investigation at those locations.

Geophysical surveys may also be used in conjunction with the borings to further define the geologic conditions and to help determine the final boring layouts as defined below.

- Wherever possible, horizontal borings should be taken along the proposed tunnel alignment. Current technology and contractor capabilities allow longer and more accurate horizontal borings that provide essential information regarding the expected tunnel face conditions.
- Trenchless pipe installations through existing embankments can and should be fully penetrated by horizontal borings to determine the conditions along the full length of the trenchless installation. Because the horizontal borings do not reveal the conditions above and below the tunnel/trenchless pipe installation horizons, vertical borings are still required.

Clearly, tunnels with horizontal and vertical curves will be difficult to investigate with horizontal borings, but as technology advances, methods may soon be available to steer borings along these alignments.

### 3.5.2.5 Structure-Specific Borings

The actual number and spacing for borings for specific structures varies greatly depending on the predicted geologic conditions and the complexity of the site. In this regard, nearby features such as streams and environmentally sensitive areas, geologic hazards, and nearby structures will further prescribe the actual amount of exploration required.

**Bridges**

For all bridges on ODOT projects, at least one boring will be placed at each bent location. Borings should be placed at opposite sides of adjacent bent locations when practical as defined below.

- For bridges that are 100 feet (30m) wide and larger, at least two borings will be placed at each bent.
- When spread footings are proposed, two borings at opposing corners of the footing are advisable. Spread footings located on the banks of rivers and streams should be investigated with at least two borings – one on the down-slope and one on the upslope side of the proposed footing.
- If wing walls greater than 20 feet long are to be constructed, then a boring should be placed at the end of each wing wall and at 50-foot (15m) intervals from the end of the wing wall to the bridge abutment.
- Trestle-type bridges (usually for detours) should also be investigated at every bent. Preferably, the borings should be staggered from opposite ends of adjacent bents.
- Where highly variable conditions are anticipated, then a boring should be advanced at both ends of each bent.
- For drilled shaft foundations, 1 boring should be placed at the location of each proposed shaft of 6 feet (1.8m) in diameter and larger. Federal Highway Publication FHWA-NHI-10-016 should be consulted for exploration spacing at drilled shaft foundation locations using smaller diameter shafts.

## Culverts

All proposed new and replacement culverts require some level of subsurface investigation as defined below:

- Typically, culverts with a diameter of 6 feet (1.8m) and larger are investigated with test borings while smaller culverts are investigated with hand-dug test pits or hand auger holes. However, judgments should be made regarding the actual site conditions and the facility in question to determine the number and spacing of borings.
- Complex geologic conditions merit a more intense investigation, while larger embankments, adjacent facilities, and proximate unstable slopes may result in a more detailed investigation for smaller-diameter culverts.
- At least two borings should be completed for each culvert up to 100 feet (30m) long.
- For culverts longer than 100 feet (30m), borings should have a maximum spacing of 50 feet (15m).
- In complex geologic conditions, boring spacing may be decreased to 20 feet (6m). Borings will typically be located along the axis of the proposed culvert.
- For culvert replacements, the borings should be located immediately outside or partially within the excavation limits of the original culvert installation with particular care to not locate a boring where it will penetrate the existing pipe.
- Borings will typically be located along the axis of any proposed culvert location.
- Box culverts 100 feet (30m) and longer require two borings at each end and at the prescribed interval between the ends. Refer to Section 3.5.3.4 (Tunnel and Trenchless Pipe Installation) for exploration spacing on culverts installed using trenchless technology.

## Retaining Walls

Retaining walls higher than 4 feet (1.2m) and any wall with a foreslope and/or backslope angle steeper than horizontal require a subsurface investigation. At least two borings are required for every retaining wall regardless of length with the exception of retaining walls less than 25 feet (8m) long. The maximum borehole spacing along any retaining wall is 100 feet (30m). The preponderance of retaining walls for ODOT projects will require closer spacing due to the typically variable conditions encountered. One boring is required at each end of the proposed wall. Where the proposed wall is longer than 100 feet (30m) long, and less than 200 feet (61m), the third boring may be placed at either the midpoint of the wall, or at the location of the maximum wall height. Embankments supported by retaining walls on each side should be investigated as two separate walls.

Borings are typically located on the wall alignment at the proposed location of the wall face however; they may be staggered to either side of the wall line but should remain within the wall footprint to evaluate the wall foundation conditions. Consider the following:

- For soil nail, tieback, and similarly reinforced walls, additional borings should be completed in the wall reinforcement zones.
- Borings should be located behind the wall in the predicted bond/anchorage zones for tieback walls, or horizontally 1 to 1.5 times the wall height back from the wall face.

- Borings for tiebacks/anchors should be interspersed with the borings along the wall face. Thus, a 200 foot (61m)-long wall would have (at a minimum) 5 borings – 3 along the wall centerline at the ends and the midpoint and 2 in the prescribed locations behind the wall at the 50 foot (15m) and 150 foot (46m) points along the wall centerline.

The preceding recommended borehole spacing should be halved for walls that will be constructed to retain landslides. Landslide retaining walls should have a minimum of 2 borings along the wall line regardless of length. The maximum borehole spacing along such walls is 50 feet (15m) with corresponding holes interspersed between located in the bond/anchorage zone. These boreholes are specifically for characterizing the subsurface conditions at the location of the proposed retaining wall, and are in addition to any borings advanced to characterize the landslide. Landslide investigation borings may suffice for the retaining wall investigation only where they fall within the prescribed locations.

## Sound walls, Traffic Structures and Buildings

Sound walls and traffic structures, such as mast arm signal poles, strain poles, monotone cantilever sign supports, sign and VMS truss bridges, luminaire poles, high mast luminaire poles, and camera poles are common features on highway transportation projects. Buildings such as maintenance facilities, rest areas, pump stations, water tanks and other unique structures are also sometimes required for ODOT projects.

Standard drawings have been developed for sound walls and most of the traffic structures and these standard drawings contain standard foundation designs for each of these structures. Each foundation design shown on a standard drawing is based on a certain set of foundation soil properties, groundwater conditions and other factors that are described on the drawings. These soil properties and conditions must be met in order to use the foundation design shown on the standard drawing.

**Note:**
*The subsurface investigation for these structures (with standard foundation designs) should be sufficient to determine whether or not the subsurface and site conditions meet the requirements shown on the standard drawings. If the foundation conditions at the site are determined not to meet the subsurface and site conditions described on the standard drawings (e.g., "poor" soil conditions or steep slope), then the standard drawings cannot be used, and a site-specific foundation investigation and design is required.*

For buildings and traffic structures without standard foundation designs, the foundation conditions must be investigated sufficiently to determine the soil properties and groundwater conditions required for a site-specific foundation design.

All new sound walls, traffic structures, or buildings require some level of subsurface investigation. Considerable judgment is needed to determine which structures will need site-specific field investigations. If the available geotechnical data and information gathered from the site reconnaissance and/or office review is not adequate to make an accurate determination of subsurface conditions, then site-specific subsurface data should be obtained through a proper investigation. In these cases, explorations consisting of geotechnical borings, test pits and hand auger holes, or a combination, shall be performed to meet the investigation requirements provided. The extent of the investigation will be largely dependent on the predicted site conditions. At unfavorable locations, drilling and sampling may need to be conducted more frequently while sites with favorable conditions may allow for less frequent and/or less expensive investigation methods such as hand augers holes and test pits.

As a minimum, develop the subsurface exploration and laboratory test program to obtain information to analyze foundation bearing capacity, lateral capacity, stability, and settlement.

The following information is generally obtained:

- Geological formation(s)
- Location and thickness of soil and rock units
- Engineering properties of soil and rock units such as unit weight, shear strength and compressibility
- Groundwater conditions (seasonal variations and maximum level over the design life of the structure)
- Ground surface topography
- Local considerations, (e.g., slope instability potential, expansive or dispersive soil deposits, utilities or underground voids from solution weathering or mining activity)

Specific field investigation requirements for sound walls, traffic structures, and buildings are summarized in Table 3-2. Note that the term “borings” in the table refers to conventional geotechnical boreholes while the term “exploration points” may consist of any combination of borings, test pits, hand augers, probes, or other subsurface exploration device as required to adequately determine foundation conditions.

**Table 3-2. Specific field investigation requirements**

| Structure Type | Field Investigation Requirements |
|---|---|
| Mast Arm Signal Poles,<br>Strain Poles,<br>Sign, and VMS Truss Bridges,<br>Monotube Cantilever Sign Supports, Luminaire Poles,<br>High Mast Luminaire Supports, and Camera poles. | Only a site review is required if the new structures are founded in new or existing embankments that are stable and known to be constructed of granular materials or general borrow and compacted in accordance with Section 00330.43 of the ODOT Standard Specifications. Otherwise, subsurface conditions should be verified using geotechnical borings and the Standard Penetration Test (SPT).<br>• For mast arm signal pole or strain pole foundations within approximately 75 ft. of each other or less, such as at small to moderate sized intersections, one geotechnical boring for the foundation group is adequate if conditions are relatively uniform. For more widely spaced foundation locations, or for more variable site conditions, one boring near each foundation should be obtained.<br>• Investigate sign and VMS truss bridges with one boring at each footing location unless uniform subsurface conditions are sufficient to justify only a single boring. Where highly variable conditions occur or where the sign bridge footing is proposed on a slope, additional borings, or exploration points may be necessary.<br>• For single, isolated monotone cantilever signs; one geotechnical boring at each footing location.<br>• Luminaires, High Mast Luminaire Supports and Camera Poles; one exploration point each footing location.<br>• The depth of the explorations should be equal to the maximum expected depth of the foundation plus 2 to 5 ft. |
| Sound Walls | For sound walls less than 100 ft. in length, a geotechnical boring approximately midpoint along the alignment and should be completed on the alignment of the wall. For sound walls more than 100 ft. in length at least 2 borings are required. Borings or exploration points should be spaced every 100 to 400 feet, depending on the uniformity of subsurface conditions. Where adverse conditions are encountered, the exploration spacing can be decreased to 50 feet. Locate at least one exploration point near the most critical location for stability. Exploration points should be completed as close to the alignment of the wall face as possible. For sound walls placed on slopes, an additional boring off the wall alignment to investigate overall stability of the wall-slope combination should be obtained. |
| Building<br>Foundations | The wide variability of these projects often makes the approach to the investigation of their subsurface conditions a case-by-case endeavor. The following minimum guidelines for frequency of explorations should be used. More detailed guidance can be found in the International Building Code (IBC) International Building Code (IBC). Borings should be located to allow the site subsurface stratigraphy to be adequately defined beneath the structure. Additional explorations may be required depending on the variability in site conditions, building geometry and expected loading conditions. Water tanks constructed on slopes may require at least two borings to develop a geologic cross-section for stability analysis. |

**Table 3-2 (Cont.)**

| Structure Type | Field Investigation Requirements |
|---|---|
| | Building surface area ($ft^2$) — No. of Borings (minimum):<br><200 — 1<br>200 - 1000 — 2<br>1000 - 3,000 — 3<br>>3,000 — 3 – 4 |
| | The depth of the borings will vary depending on the expected loads being applied to the foundation and/or site soil conditions. All borings should be extended to a depth below the bottom elevation of the building foundation a minimum of 2.5 times the width of the spread footing foundation or 1.5 times the length of a deep foundation (i.e., piles or shafts). Exploration depth should be great enough to fully penetrate soft highly compressible soils (e.g., peat, organic silt, soft fine-grained soils) into competent material suitable for bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesion less soil or bedrock). |

| Building surface area ($ft^2$) | No. of Borings (minimum) |
|---|---|
| <200 | 1 |
| 200 - 1000 | 2 |
| 1000 - 3,000 | 3 |
| >3,000 | 3 – 4 |

In addition to the exploration requirements in Table 3-2 (Specific Field Investigation Requirements), groundwater measurements, conducted in accordance with Chapter 3, should be obtained if groundwater is anticipated within the minimum required depths of the borings as described herein.

### 3.5.2.6 Critical-Area Investigations

In areas where critical geologic conditions or hazards such as highly irregular bedrock surfaces, extremely weathered or altered rock, compressible materials, and caverns or abandoned underground facilities are predicted from detailed background study or preliminary exploration, it may be necessary to further investigate the area with additional explorations. Such investigations normally involve drilling on a grid pattern over the area in question. An initial, wider grid pattern may be selected to locate the area of most concern with a closer grid pattern used later to further characterize the area of concern. Grid pattern investigations may consist of hand auger holes, direct push holes, or cone penetrometers in addition to the more conventional test borings. Geophysical surveys may also be used to establish or refine the boundaries of the grid pattern investigation.

### 3.5.2.7 Landslides

The number and layout of test borings for landslide investigation depends upon the size and nature of the landslide itself and on the results of detailed site mapping and initial subsurface models based on the mapping. Since information about the subsurface is unknown initially, landslide investigation largely becomes an iterative process as new data obtained provides information that is used to further develop enough knowledge of the landslide to begin stability analysis.

The approach to landslide investigation is very complex and involves numerous techniques and procedures, and is discussed in greater detail in Chapter 13. This chapter is intended to convey a general sense of the layout of the borings needed for a “typical” landslide investigation.

Enough borings must be made initially to fully develop at least one geologic cross-section through the axis of the slide. Consider the following:

- As a minimum, there should be borings near the top, middle, and bottom of a known or potential landslide area. Ideally, the borings would be placed in the toe or passive wedge area (if applicable), at the head or active slide zone, the area of transition between the active and passive zones, and in the areas behind the headscarp and in front of the toe outside of the slide zone.
- For longer slides, space additional borings in the active and/or passive slide zones on 50-foot (15m) intervals.
- Place additional borings on a 50 foot (15m) interval in a line perpendicular to the direction of slide movement at the deepest zone of slide movement.

For investigation of areas of potential slide movement, a grid pattern of explorations are usually selected for preliminary identification and delineation of the affected area. The grid spacing is dependent on several factors. Usually, the predicted size of the landslide, results of remote sensing, availability of previous data, and site access will primarily determine the spacing between borings. Where large areas would potentially be affected by landslide movement, a 200 foot (61m) square or staggered grid spacing is sufficient for preliminary identification.

## Subsurface Investigations on Unstable Rock Slopes

Subsurface investigations for unstable rock slopes are necessary when a significant amount of rock excavation is needed to accommodate highway realignment or an increased fallout area.

- Typically, the amount of information available at a large, accessible rock exposure is sufficient for minor slope modification, and of generally greater value than core drilling with respect to information concerning rock conditions.
- However, when significant modification of the slope is considered for realignment and/or rock fall mitigation, subsurface investigation is frequently needed to determine the rock character within the proposed cut, overburden thicknesses, groundwater conditions, three-dimensional character of the units (if unknown), and other important design and construction information.
- Drilling is recommended to assure continuous subsurface conditions throughout the excavated rock material.

The skilled geologist's interpretation of the outcrop generally provides enough information for rock slope design, but the changeable nature of the state's geology, and the need to assure subsurface conditions to prevent construction delays and claims is usually reason enough to gain the additional assurance of further subsurface data. This is not to state that drilling for a rock cut slope modification is automatic. The geotechnical designer must determine the cost-benefit of additional subsurface investigation based on the local geology and the risks involved.

**Note:**
*For the assessment of large block or wedge failures, subsurface investigation should proceed in a similar manner to the approach to landslide investigations as described above. Some of the borings, or additional borings may be needed at prescribed orientations other than vertical to assess the projected failure planes.*

For projects where realignment or slope modification to increase the fallout area is needed the investigation should carry on according to the procedures for cut slope investigation described in Section 3.5.3.2 Embankment and Cut Slope Explorations.

## 3.5.3 Exploration Depths

Determining the required depths of subsurface explorations requires the consideration of many variables such as the size, type, and importance of the structure, and most of all, the underlying geology. Consider the following:

- The borings should penetrate any unsuitable or questionable materials and deep enough into strata of adequate bearing capacity where significant settlement or consolidation from the increased loads from the proposed structure is reduced to a negligible amount. The stress at depth added by the structure is usually taken from the appropriate tables and charts or determined using the **Boussingesq** or **Westergaard** solutions.
- All soft, unsuitable, or questionable strata should be fully penetrated by the borings even where they occur below an upper layer of high bearing capacity.
- Test borings should not be terminated in low-strength or questionable materials such as soft silt and clay, organic silt or peat, or any fill materials unless special circumstances arise while drilling.

### 3.5.3.1 Termination Depths

When competent bedrock is encountered, test borings may generally be terminated after penetrating 15 feet (4.5m) into it. Where very heavy loads are anticipated, test borings may be extended to a considerable depth into the bedrock depending on its characteristics and verification that it is underlain by materials of equal or greater strength. For most structures, it is advisable to extend at least one boring into the underlying bedrock even when the remaining borings are terminated in soils of adequate bearing capacity.

As with all other aspects of subsurface investigation, considerable professional judgment is needed to determine the final depths of planned explorations. Generally, previous subsurface information is needed to determine the approximate depth of the proposed borings on the Exploration Plan. Where this information is unavailable, general guidelines can be used to establish the preliminary exploration depths and quantities. These guidelines are outlined for specific geotechnical features in the following sections.

### 3.5.3.2 Embankment and Cut Slope Exploration Depths

For embankments of 10 feet (3m) or greater in height, the test borings should penetrate from 2 to 4 times the proposed fill height or more depending on the final width of the roadway and the actual materials encountered. If suitable foundation materials are encountered such as dense granular soils or bedrock, the depth may be decreased up to a minimum depth equaling the height of the embankment. Where confined aquifers with artesian pressures or liquefiable soils are present, the exploration depth should be extended to fully penetrate these units.

Cut slopes with a depth of 10 feet (3m) or more should be explored to a depth that is two times the height of the proposed cut. When bedrock is encountered in a cut slope boring, the boring should extend at least 15 feet below the finish grade of the cut. Cut slope borings should be extended if sheared surfaces or other evidence of landslide susceptibility are encountered that could affect the performance or constructability of the finished slope.

### 3.5.3.3 Subgrade Borings

Where minor amounts of earthwork (cut slopes less than 10 feet (3m) deep) for the alignment profile are expected, test borings and test pits should extend 15 feet (4.5m) below the proposed final grade elevation. Where bedrock or other hard materials are encountered, coring should be extended 15 feet (4.5m) into the hard stratum to evaluate their conditions. For fill areas less than 10 feet (3m) high, explorations should extend to 15 feet (4.5m) below the original ground surface unless questionable materials are encountered. If soft, organic, or other deleterious materials are encountered in subgrade borings, the depth of exploration should be increased as necessary to fully evaluate those materials.

### 3.5.3.4 Tunnel and Trenchless Pipe Installation Borings

A "rule-of-thumb" for tunnel exploration is the amount of exploration drilling should be 1.5 times the length of the tunnel. This should be considered as a bare minimum for exploration cost estimating for tunnel/trenchless installation projects will shallow alignments in very favorable conditions, and does not include horizontal drilling along the tunnel/pipe profile. Clearly, the amount of drilling for any given length of tunnel/trenchless installation alignment is dependent on several factors that include, among others, the depth of the invert, diameter of the tunnel/pipe, geologic conditions, and contingencies. Typically, tunnel/trenchless installation borings should be extended at least 1.5 tunnel/pipe diameters below the proposed grade of the invert. It may be beneficial to further extend the borings to as much as 3 times the tunnel/pipe diameter as a contingency if the final tunnel alignment has not been determined. The depth of the borings should be increased further to evaluate any unforeseen or unfavorable geologic conditions encountered that may affect the tunnel or pipe design and construction. Wherever practical, horizontal borings should be taken along the tunnel profile because of the advantages of having a full-length representation of the actual tunnel/pipe horizon conditions.

### 3.5.3.5 Structure-Specific Borings

The guidelines for boring depths presented in Section 3.5.3 stem from structure-specific boring guidelines developed by AASHTO and other agencies. Follow these guidelines:

- It is highly desirable for all structure-specific borings to penetrate at least 15 feet (4.5m) into bedrock.
- For drilled shaft installations, the test borings should be advanced 1.25 times the total projected shaft length beyond the predicted shaft base elevation.
- If the shaft base is to be founded in soil or rock with an RQD of 50% or less, then the test borings should be extended an additional depth below the proposed bottom of the shaft equal to the larger of 20 feet (6m) or 3 times the shaft base diameter. Shafts are most commonly designed to bear on competent bedrock, thus, where the RQD is greater than 50%, the test boring should also be advanced to the greater of 20 feet (6m) or 3 times the shaft base diameter below the estimated shaft base elevation.

**Note:**
*The geotechnical designer must exercise judgment concerning the nature of the facility with respect to the total and economical amount of drilling needed for the specific structure. Borings for sound walls, small traffic structures, or culverts may not be required to obtain core samples in bedrock, but for bridge foundations, bedrock drilling would certainly be needed.*

#### 3.5.3.6 Critical-Area Investigations

In those areas where unfavorable or critical geologic conditions are expected to have an adverse effect on the project design and construction, the explorations should be extended to a depth where those conditions may be fully evaluated. All problematic strata and areas of concern should be fully penetrated by the borings. It is advisable to extend the borings beyond the depths that are strictly necessary rather than terminate them before the desired information is obtained. Borings should never be terminated in soft, organic, or any other deleterious materials that will adversely affect the project design, construction, or performance. Extra drilling in some borings is less expensive than drilling additional borings or even remobilizing equipment to the site to obtain sufficient data for design.

#### 3.5.3.7 Landslides

Considerable flexibility must be built into the Exploration Plan for any landslide, and particularly with respect to the depth of the explorations. Follow these guidelines:

- Typically, the cross-section drawn along the centerline of the landslide is used to develop the preliminary exploration depths.
- Circular, elliptical, or composite curves drawn from the headscarp to the toe bulge are projected onto the cross-section to show the possible depths of slide movement. These curves are commonly exaggerated to conservatively estimate the slide depth.
- The preliminary boring depths should extend 20 feet (6m) or more below the projected slide plane to assure that the zone of movement is fully penetrated, and to secure instruments below the slide plane for the best results.
- Firm, resistant strata, bedrock projections, and irregular surfaces will also affect the geometry of the slide plane, and subsequently, the final depths of individual borings.
- Landslide borings should always be extended to a depth that clearly identifies which materials are involved in the current slope movement, which underlying materials are presently stable, and the location of the slide surface(s). This is not only important to the development of a stability analysis, but will become important once again during construction when the precise locations of mitigation efforts will be determined. There is often a possibility that the observed landslide activity is an accelerated portion of a slower, deeper-moving landslide that may only be detected by instrumentation. For this reason, at least one boring should be extended far below the predicted slide surface to divulge such activity. Any Exploration Plan for landslide investigations should contain the flexibility to extend borings to considerable depth during the site exploration.

### 3.5.4 Sampling Requirements

Since the primary purpose of the subsurface exploration program is the collection of samples that are as closely representative of actual site conditions, the sampling requirements are typically the most stringent in the Exploration Plan. Particular care must be taken in their method of collection, measurement, handling, and preservation since field and laboratory testing results are so greatly dependent on the quality of the sampling. Sampling requirements are also subject to the same variables that affect exploration layout and depth.

- **Sampling interval:** Most Exploration Plans will have a set maximum sampling interval. For most ODOT projects, Standard Penetration Tests (SPTs) are taken, and samples retained, on 2.5-foot (0.76m) intervals in the first 20 feet (6m) of the boring, and on 5-foot (1.5m) intervals thereafter to the bottom of the hole or until rock coring begins. In addition to this minimum interval, samples should also be taken at each noted change in material or subsurface condition. Where thick, uniform strata exist, a wider sampling interval may be warranted however, this greatly depends on the extent of previous site knowledge and project requirements. Where complex conditions and/or numerous strata exist, the sampling interval may be increased to a shorter sampling interval.
- **Sample collection:** Samples should be collected from each identified stratum, preferably from more than one boring to fully characterize each unit. In addition, undisturbed samples should be obtained from all cohesive soil units encountered. It is frequently warranted to drill additional borings to obtain undisturbed samples in particular units that may have been missed by previous sampling intervals or to further characterize those units. Where a larger volume sample is needed, a variety of sampling methods and techniques can be utilized including oversized split-spoons, various coring methods, and Becker-hammer drills. Sampling techniques are discussed in the next section.
- **Continuous sampling:** Continuous sampling is beneficial in areas of changeable site conditions and underlying geology as well as critical zones for project design. The zones immediately below proposed foundation elevations should be sampled continuously in addition to the zones immediately above, through, and below projected landslide zones of movement. For tunnel/trenchless pipe installations, continuous sampling should be conducted for 1 tunnel diameter above and below the tunnel horizon as well as the tunnel horizon itself. Soil and rock coring is by its nature, a continuous sample, and is the most common method to obtain a continuous representation of the subsurface materials. However, continuous SPTs, Shelby Tubes, or a combination of these and other methods can be used.
- **Observation:** Careful observation and evaluation during drilling and logging of the recovered samples is essential to the entire exploration program. Much information can be recovered even when sample recovery itself is minimal.

#### 3.5.4.1 Soil Sampling for Corrosion Assessment

The corrosion potential of buried or exposed metal structures depends primarily on the electro-chemical nature of the soil and the presence of oxygen and moisture. An assessment of these properties and conditions is necessary to properly determine the corrosion potential of culverts and structure foundation materials. Electro-chemical tests provide quantitative information related to the aggressiveness of the subsurface materials and surface water environments. Electro-chemical soil testing typically includes testing for pH and resistivity and sometimes sulfate, and chloride contents. Surface water should also be tested in coastal regions where the potential intrusion of brackish (salt-water) water may occur in tidal streams.

Corrosion of culverts, steel piling and other buried structural elements is most likely to occur at or above the water table and in disturbed stratified soils such as man-made fills, especially those containing cinders, slag or ash. Guidance on the amount and extent of soil and groundwater sampling and testing for corrosion assessment is provided in the later chapters of this manual that are dedicated to specific structures.

**Steel Culverts**

The electrochemical properties of the soil in which a culvert is placed are an important aspect of culvert design Steel culverts are often subject to corrosion due to either the chemical nature of the soils surrounding the pipe or due to the acidity of the water flowing through the pipe. The ODOT Hydraulics Manual (Section 5.8.2) provides guidance on the soil sampling and testing necessary for metal pipe design. Bulk sampling of surficial soils in the immediate vicinity of the culvert, sufficient in quantity for testing, is standard practice. If subsurface explorations were conducted, with samples obtained for the culvert, additional electrochemical testing may be warranted.

Soil sampling and testing recommendations for steel piling corrosion assessment are described in Chapter 8.

## 3.5.5 Sampling Methods

Various sampling methods are described in this section. Many of the sampling methods are based on ASTM International standards located at www.astm.org (the "ASTM Site").

### 3.5.5.1 Standard Penetration Testing

All Standard Penetration Tests must be performed according to ASTM D 1586-99. The Standard Penetration Test (SPT) is the most common method for field testing and sampling of soils. Some variations with respect to standard intervals and refusal criteria occur throughout the industry however the fundamental procedure still adheres to the ASTM standard. The SPT uses the following methods:

- This sampling method uses the standard configuration 2-inch (5cm) outside diameter split spoon sampler at the end of a solid string of drill rods. The split spoon is driven for a 1.5-foot (0.45m) interval using a 140 Lb. (63.5 Kg) hammer dropped through a 30-inch (76cm) free fall.
- The number of hammer blows needed to advance the sampler for each 6-inch (15cm) interval is recorded on the boring log and sample container.
- The Standard Penetration Resistance or uncorrected "N"-value is the sum of the blows required for the last two 6-inch (15cm) drives. Refusal is defined as 50 blows in 6 inches (15cm) of penetration and recorded on the log as 50 blows and the distance driven in that number of blows.
- The hole is advanced and cleaned out between sampling intervals for at least the full depth of the previous sample.

This general procedure can be used with larger diameter samplers and heavier hammers for the purpose of obtaining additional sample volumes, but the blow counts do not provide standard resistance values. Prior to the commencement of drilling operations, the hammer energy must be measured to determine the actual hammer efficiency. This information can usually be obtained by the drill manufacturer. If it is not available, a competent technician must be engaged to measure the hammer energy for each drill rig.

### 3.5.5.2 Thin-Walled Undisturbed Tube Sampling

Undisturbed samples of cohesive soils should be taken with 3-inch (7.6cm) diameter Shelby Tubes according to the standard practice for thin-walled tube sampling of soils in ASTM D 1587-00. This method obtains relatively undisturbed samples by pressing the thin-walled tube into the subject strata at the bottom of the boring. Thin-walled sampling is simply a method for retrieving a sample for laboratory testing. There is no actual field-testing involved with thin-walled sampling unless a Torvane or Pocket Penetrometer test is performed on the end of the sample. Pressures exerted by the drill rig while pushing Shelby tubes are frequently recorded for general reference but do not provide repeatable test results. After the unfavorable effects of the sampling procedure, transport, handling, and storage, a truly undisturbed sample cannot be realistically tested in the laboratory. However, with appropriate care, valid samples can be taken for shear strength, density, consolidation, and permeability testing.

Shelby tubes do not utilize a sample retention system to hold the sample in place during retrieval from the borehole, so sample recovery can be unreliable. Thin-walled sampling in general is successful only in soft to stiff cohesive soils. Soils that are very soft are difficult to recover with standard Shelby tube while the upper range of stiff and very stiff soils are difficult to penetrate or bend the tube resulting in a disturbed sample. Oversized clasts and organic fragments in the softer soil matrix can also be detrimental to thin-walled sampling.

Various samplers that use retractable pistons to create a vacuum in the top of the tube can achieve greater success in obtaining undisturbed samples of soft cohesive soils as well as granular materials.

## 3.5.5.3 Rock Coring

Rock core drilling should be carried out according to ASTM-D 2113-99. Successful core drilling is as much a skill as it is a test procedure. Experienced, conscientious personnel are necessary not only to run the equipment, but also to interpret the results of the drill action as well as the samples recovered. Material recovered may not actually represent the subsurface conditions present if not correctly sampled. Observation and interpretation of the drill action, fluid return, and other characteristics provide indications of the actual validity of the core sample as well as other information concerning the actual conditions in the subsurface.

**Note:**
*ASTM states that the instructions given in D 2113-99 cannot replace education and experience and should be used in conjunction with professional judgment. Qualified professional drillers should be given the flexibility to exercise their judgment on every alternative that can be used within the appropriate economic and environmental limitations.*

### Triple-tube Core Barrel Systems

Because of the close-jointed, highly fractured nature of many rock formations in Oregon, and the detailed observations desired, rock coring should be performed with triple-tube core barrel systems that are best suited to such material. These systems provide the best recovery in difficult, highly fractured, and/or weathered rock, which is extremely important since discontinuity spacing, and weathering characteristics usually limit the strength of a rock mass with respect to foundation loading, or the performance of rock excavations. Triple-tube barrels provide direct observation of the rock core specimen in the split-half of the innermost tube as it is extracted from the inner core barrel. This allows accurate measurement of RQD and recovery and discontinuity attitudes prior to further specimen handling. Partial isolation of the sample in the inner split-barrel from the drilling fluids also preserves much of the discontinuity texture and infilling material that is also very important to rock mass characterization.

Most rock coring is performed with “H”-sized systems that provide core specimens with a diameter of $2^{13/32}$ inches (61.1mm).

**Note:**
*Considerable penalties occur with respect to sample quality when using smaller diameter coring systems due primarily to drill action, particularly at greater boring depths; thus, H-sized core should be considered the minimum size for explorations.*

Larger diameter cores also provide a better assessment of discontinuity properties. There may be situations where smaller diameter coring is necessary such as difficult access sites where small equipment is needed that may not have the torque required to turn larger diameter casing. Core runs are typically made in 5-foot sections since this is the approximate length of most commonly available core barrels. Runs may be shortened when difficult drilling conditions are encountered. Longer barrels may also be used in highly favorable conditions such as quarry site investigations or other areas with uncommonly massive rock.

Rock core specimens should be preserved and transported according to the standard practice in ASTM D 5079-02. Core specimens should always be extruded from the inner core barrel using the hydraulic piston system. The inner split barrel should not be manually rammed out of the inner barrel as this will result in sample disturbance. The core should not be dumped out of the end of the barrel either since this will also disturb the sample as well as invalidate some of the information.

### 3.5.5.4 Bulk Sampling

Bulk sampling should be carried out at all pipe/culvert locations from the actual invert elevation when test borings are not required. The samples collected are submitted for the appropriate chemical testing. Typically, bulk samples of 25 lbs. (11Kg) if impermeable bags are used, or 2 gallons (7.5 liters) for jar/bucket samples are collected from each discrete sampling site. Sample receptacles must be sealed to preserve natural moisture conditions. Bulk sampling may also be conducted for material source investigations and other surficial applications. All samples collected should be preserved and transported according to ASTM D 4220-95.

## 3.5.6 Sample Disposition

Soil and rock samples collected during subsurface exploration should be transported to the appropriate ODOT region storage facility upon completion of the investigation. Soil samples are usually retained for only a short period of time after project construction since physical and chemical changes occur that, over time, invalidate the results of further testing regardless of any effort to preserve them. Rock core specimens are typically retained for 3 years after the final acceptance of

the project or when the contractors and other concerned parties have been settled with provided that there are no problems with the performance of the facility. Specimens related to future construction activities should be retained. Under no circumstance will soil samples and rock core specimens that may have a bearing on an unsettled claim be disposed of until such claims are finally resolved.

## 3.5.7 Exploration Survey Requirements

The actual location and elevation of all exploration sites should be surveyed and plotted on the project base map. Once exploration is complete, the actual exploration site should be marked with a survey lath or painted target so that the survey crew can readily measure the intended location. The exploration number should also be marked in the field for accurate reference by the surveyors. Surveys should be completed based on the project coordinates in addition to the WSG-84 datum. Elevations should be referenced to Mean Sea Level (MSL).

# 3.6 Subsurface Exploration Methods

## 3.6.1 General

Many factors influence the applicability and selection of subsurface exploration equipment and methodology for any selected project site investigation. Selection of equipment and methods are usually based entirely on geotechnical data needs and geologic conditions but may also be based on site access, equipment availability, project budget, environmental restrictions, or a combination of any of these.

In many cases, trade-offs between expected results and the exploration method chosen must be evaluated to achieve the needed results within defined time limits and project budget constraints.

Geotechnical designers should be familiar with the exploration methods applied on their projects, and their results and potential limitations or effects on the data they receive from the field.

Most test borings conducted for transportation projects in Oregon are standard diameter vertical borings using rotary or auger drilling methods. Sampling within the boring is typically done by Standard Penetration Tests (SPTs), 3-inch (7.62cm) Undisturbed Shelby Tube samples, HQ3-sized rock coring, and auger coring. Additional, supplementary explorations are conducted using hand augers, direct push (i.e. GeoProbe) rigs, cone penetrometers, and test pits dug either by hand or more commonly with hydraulic excavators. ODOT is currently evaluating and using newer exploration technologies as they are developed or become increasingly available. The use of sonic drilling and geophysical methods are examples.

## 3.6.2 Test Boring Methods

The most commonly used drilling methods on ODOT projects are auger boring and rotary drilling. Continuous sampling core drilling is employed with both methods. Most modern drill rigs are capable of employing both of these techniques with only minor adjustments to the tooling in the field. Other techniques that are less commonly used are displacement borings using rotosonic or percussion methods. Each drilling method should be selected based on the quality of information obtained in the materials for which the drilling method is best suited for, thus, selection of drilling technique should be carefully considered. Since most test borings penetrate many types of materials, several techniques are commonly employed in any single test boring. Various institutions or individuals have strong preferences for certain types of drilling methods and will tend to use them as a “default” for almost any condition encountered. This behavior should be corrected or avoided. Almost every technique is capable of penetrating the subsurface or “making a hole.” The quality of the results is the purpose of subsurface investigation, and different drilling techniques are better suited to certain materials and conditions. Achieving quality results from a drilling program are more important than convenience.

### 3.6.2.1 Methods Generally Not Used

Cable-tool, wash, jet, and air-rotary methods are generally not used on ODOT projects for many reasons. Cable-tool drilling may be useful for some environmental applications and well installations, but is generally antiquated and not productive for geotechnical investigation. Wash and jet borings cause down-hole disturbance well past the bottom of the boring, and the fluids are difficult to recover making them more of a liability than a source of data. Air-rotary drilling usually causes too much down-hole disturbance to provide reliable SPT data, and difficult to advance in soft soils. Groundwater typically stops further advancement of air-rotary drills, forms large voids, and casts sediment-laden water about the site. Air-rotary drilling may be suited to specific applications where known materials at a site are delineated based on the drill advance rate and obvious changes in the drill cuttings as they are flushed from the hole. In these applications, the air-rotary borings should be supplemental to standard geotechnical exploration borings conducted at the site.

### 3.6.2.2 Auger Borings

Rotary auger drilling is one of the more rapid and economical methods of advancing exploration borings. Most modern drilling equipment has enough power to turn augers of considerable diameter to a substantial depth. Currently, most auguring uses a hollow-stem auger that allows the hole to remain cased while the various sampling or drilling tools are used and withdrawn from the hole with drill rods or wireline retrievers. A central "stinger" bit or plug is placed at the bottom of the auger while the boring is advanced. Solid stem auger use has largely been discontinued due largely to the advent of hollow stem augers and the more powerful equipment that is capable of turning their larger diameter drill string. The standard practice for using hollow-stem augers is described by ASTM D 6151-97. Auger boring has many advantages and disadvantages for various materials encountered as described below.

**Auger Boring Advantages**

Auger boring has many advantages and disadvantages for various materials encountered. The primary advantages of augers are the preservation of the natural moisture content of the soil and the rapid advancement of the drill through soft to stiff soils. Augers are also useful where drill fluids are difficult to obtain or are an environmental concern, and in freezing conditions where the use of water is problematic. An additional advantage of augers is that they create a large enough hole to install larger-diameter standpipe piezometers or nested piezometers in conformance with Water Resources Department regulations. In addition, the natural piezometric surface is more readily monitored during drilling. Coring tools are also available for auger systems that provide continuous sampling in soils and even weak rock materials. These tools can be placed by either rods or wireline into special auger bits that feed a continuous soil sample into a split barrel that is then retrieved in 2.5 or 5-foot (0.76-1.52m) sampling intervals. Plastic liners that fit in the auger core barrel can also be used to preserve soil cores in their natural moisture conditions.

**Auger Boring Advantages and Disadvantages**

The disadvantages of auguring are the power needed to turn long strings of auger in dense formations, the volume of the hole and the cuttings created, and the disturbance of the natural materials in certain conditions. When hollow-stem augers are used in granular soils below the water table, the hydrostatic pressure differential between the inside and outside of the auger casing will force saturated sands, silts, and fine gravels up into the casing effectively loosening the materials below the auger bit. This can be caused by either the natural differential, or by the pressure induced during retraction of the "stinger" bit or plug. The augers themselves can also affect the conditions of loose granular materials and silts ahead of the bit. In both cases, SPT values obtained will be different than what is true for the natural conditions. To counter this effect, a head of water, or other drilling fluid can maintained in the auger casing to counteract these effects. Adding fluids to the auger generally negates their advantages and if such action is necessary, a different drilling technique should be employed. Hollow stem auguring should not be employed when assessing liquefaction potential.

A common complaint about auguring is the volume of cuttings generated. Where disposal is a concern, this is probably a disadvantage. However, when drilling in an environmentally sensitive area, auguring is often preferable because the cuttings are easily contained on site when drilling above the water table. A past complaint has also been the weight of the augers themselves although this has largely been negated by the more powerful equipment and the available wire line systems to assist with moving them around the site.

### 3.6.2.3 Rotary Drilling

Rotary drilling is the most common, and usually the most versatile drilling method available. Various tools and products available for rotary drilling allow it to be adaptable to most drilling conditions and geologic materials. Rotary boreholes can be uncased holes advanced with a drill bit on rods or cased holes made with a casing, casing advancer and casing shoe. The casing advancer is a driver assembly with latches that fit in the bottom of the casing where it holds the center bit at the bottom of the hole and is subsequently retrieved with a wireline system. This method of drilling involves a relatively fast rotation speed, fluid circulation, and variable pressure on the drill bit to penetrate the formation, pulverize the formation particles at the bottom of the borehole. The circulating fluids carry these cuttings away from the bit, up the borehole annulus, and out of the hole.

When the desired sampling depth is reached, the drill rods or casing advancer are retracted from the hole and replaced with the desired sampling tool. The sampling/testing is conducted while the hole is filled with fluid, retrieved from the hole, and then replaced once again with the drilling tool and borehole advancement continues to the next sampling depth. For uncased holes, the drilling fluid is relied upon to stabilize the borehole and prevent it from caving or heaving. In particularly weak or porous formations where drilling fluids are rapidly lost, cased holes are generally used. In uncased holes, the drilling fluid is usually recirculated from a mud tank or pit at the ground surface. Borings that use casing advancers typically use pure water that is not recirculated.

**Rotary Drilling Advantages**

The advantage of rotary drilling is the relative speed of advancement in deep borings while maintaining borehole stability that best preserves in-situ soil conditions by counteracting soil and pore-water pressures in partially or fully saturated conditions. It is of particular advantage in very soft materials that are very sensitive to disturbance by the drilling equipment. Because of its ability to maintain natural conditions, rotary drilling is usually the best choice when conducting in-situ analysis such as vane shear and pressure meter testing. The trade-offs for rotary drilling is the introduction of moisture and other minerals that will influence the natural moisture conditions, and the difficulties with installing groundwater monitoring instruments although this later can in some cases be rectified by the use of special drilling fluids and by purging the borehole prior to installation. Special care is needed to contain drilling fluids during exploration, and for ultimate disposal that may involve transport off-site.

**Drill Rods**

A variety of drilling rods, casings, and drill bits are available for various tasks. Most drilling tools come in standard sizes that are generally adaptable to one another. However, complexities arise when changing from one size to another when various thread sizes and configurations are used. Use the following information relating to drill rods and casing sizing:

- Drill rod and casing sizes are designated from smaller to larger by the letters R, E, A, B, N, and H. Drill rod outside diameters range from $1^{3/32}$ inches (27.8mm) for R-sized rods to 3.5 inches (88.9mm) for H-sized rods.

- Drill casing outside diameter sizes range from $1^{7/16}$ inches (36.5mm) for R-sized casing to 4.5 inches (114.3mm) for H-sized casing. Additional letters such as HW or NWJ designate different thread or coupling configurations.

  Complete tables of drilling tool types, sizes, weights, and volumes are available from the drilling suppliers and manufacturers.

- The important aspects of tool size is that the larger diameter, heavier drill sizes generally provide a more stable hole and allow a greater variety of testing and sampling tools to be used. These larger sizes also help control the eccentric movement of longer drill strings, reduce vibration at the drill bit, and help the driller maintain a straight and plumb boring.

The Diamond Core Drill Manufacturers Association (DCDMA) has standardized the drill rod and casing sizes although any number of other sizes and types remain on the market or are frequently introduced.

## Drill Bits

The choice of drill bit greatly influences the test boring quality and speed of completion. Rotary drill bits come in a variety of different types, each suited to a particular soil and/or rock composition. Driller preference is usually what determines what type of bit is used. Experienced drillers can and should normally be relied upon to select the appropriated bit. Certain drill bits are intended for specific geologic materials, but many drillers, through their experience and specific equipment, are able to achieve superb results with bits that are not usually used for that type of material. Follow these guidelines when using drill bits:

- **Soft or loose soils:** Soft or loose soils are usually drilled with drag bits. These bits have two or more wings of either tempered steel or carbide inserts that act as cutting teeth.
- **Hard soils and rock:** Roller bits are used to penetrate hard soils and rock. Roller bits may consist of hardened steel teeth or carbide “buttons.” Typically, steel teeth are sufficient for hard soil drilling while carbide button bits are used for bedrock drilling or for drilling in formations with numerous boulders and potential obstructions.

## Rotary Drilling Fluids

Various admixtures are available for mixing with the drilling fluids in different applications. Usually, the drilling fluid or “mud” is a mineral solution (usually bentonite and water, thus, a colloidal fluid) with a viscosity and specific gravity that is greater than water. These properties allow the fluid to better stabilize the borehole, cool and lubricate the bit, lift the cuttings out of the hole, and can also increase sample recovery. Various chemical and mineral additives may also be added to the mud mixture for the site-specific conditions. Certain chemical additives, such as pH stabilizers and flocculants, are introduced for common groundwater or mineral conditions that are the source of particular drilling difficulties. Mineral additives, such as barite, may be used to further increase the specific gravity of

the mud for unstable boreholes and zones of high artesian pressures. Other additives inhibit corrosion of tools; seal off highly fractured or porous formations to prevent fluid loss, increase the suspension, and entrainment of sediments to flush the borehole, and numerous other applications.

Fluids or “mud mixtures” can greatly enhance rotary drilling, and in some very difficult drilling situations, is the only way to complete borings. Mud mixing should be treated with care as improper materials and quantities can actually be detrimental. Volumes and weights should be carefully measured and fluid density and viscosity should be monitored during borehole advancement as these properties will be affected by the formation materials. Several batches may be needed for individual borings depending on the depth of the borehole and other conditions.

The U.S. Bureau of Reclamation and the U.S. Natural Resources Conservation Service have established general guidelines for drilling mud mixtures including amounts of dry materials, volume of water, and fluid densities. ASTM D 4380-84 describes the procedures for determining the density of bentonitic slurries that can be used in rotary drilling.

### 3.6.2.4 Rock Coring

Rock core sampling is used to obtain a continuous, relatively undisturbed sample of the intact rock mass for evaluation of its geologic and engineering characteristics. When performed appropriately, core drilling produces invaluable subsurface information. Rock coring procedures have generally remained the same since the advent of the technology: a steel tube with a diamond bit rotated into the rock. Advancements in the bits, core barrels for retrieving the samples, and improvements to mechanized equipment overall have greatly enhanced this method.

**Note:**
*Rock core drilling procedures and equipment has largely been standardized by ASTM D2113-99. The Diamond Core Drill Manufacturers Association (DCDMA) has also standardized bit, core barrel, reaming shell, and casing sizes similar to drill rods.*

Rock coring almost exclusively involves the use of diamond bits, thus the terms “rock coring” and “diamond drilling” are used interchangeably. Selecting the proper drill bit for the rock coring conditions is essential. Sample recovery and drill production is dependent upon it. The ultimate responsibility for bit selection is the driller’s, however, it is important to be familiar with bit types to help determine recovery problems in the field since they may actually be unrelated to the drilling method. The actual configuration of the drill bit is selected based on the actual site conditions. The cross-sectional configuration, kerf, crown, and number of water ports are all determined by the anticipated conditions and characteristics of the rock mass. Consider the following:

- Incorrect bit selection can be extremely detrimental to core recovery, production, and project budget.
- Typically, a surface-set bit consisting of industrial diamonds set in a hardened matrix is used for massive rock bodies.
- Larger and fewer diamonds in the set are used for soft rocks while smaller and more numerous diamonds are used in hard rock. Hard rock bits commonly have a rounded or steeply angled crown.
- Flat-headed bits are usually for very soft rock. Impregnated bits consist of very fine diamonds in the matrix and are generally used for soft, severely weathered, and highly fractured formations. Some carbide blade and button bits are used for soft, sedimentary rocks. These are ideally suited for soft rocks with voluminous cuttings that require a considerable amount bit flushing and cutting extraction.

**<u>Core Barrel</u>**

The core barrel is the section of the drill string that retains the core specimens and allows them to be retrieved as a whole section. Core barrels may be of different types and sizes, and may consist of numerous components that may be changed depending on the rock mass condition. Core barrels have evolved greatly over time. Single-tube barrels were originally used and required the entire drill string to be retracted to withdraw the sample. These have evolved through double-tube systems of either rigid-types where the inner tube rotates with the outer barrel, or swivel-types where the inner tube remains stationary. Most core barrels used today are triple-tube systems that employ another non-rotating liner to a swivel-mounted double core barrel. This split metal liner retains the sample during extraction that allows minimal sample handling and disturbance prior to measurement and observation. Where desired, a solid, clear plastic tube can be used in place of the split metal tube. Single and even double-tube coring system often require a considerable amount of effort to extract the cores from the barrel that can result in detrimental sample disturbance.

Consider the following:

- Available triple-tube coring systems usually provide specimens that range in diameter from $1^{5/16}$ inches (33.5mm) for "B"-sized core to $3^{9/32}$ inches (83mm) for "P"-sized core.
- Larger core sizes are also available from rather specialized systems.
- A substantial penalty on the quality of rock structural information results from smaller diameter cores. Most rock core taken is "H"-sized ($2^{13/32}$ inches, 61.1mm) in diameter.
- The use of smaller N-sized cores may be necessary in difficult access, or very deep drilling applications.
- The difference in RQD measurements between single, double, and triple tube systems are substantial.

**Specialized Methods**

These specialized methods are also used:

- **Oriented core barrels:** Orienting core barrels can be used to determine the true attitudes of discontinuities in the rock mass. These specialized core barrels usually scribe a reference mark on the core as it is drilled. Recording devices within the core barrel relate the known azimuth to the reference mark so that the exact orientation of the discontinuities can be determined after the sample has been retrieved.
- **Borehole camera surveys:** Borehole camera surveys are used to determine discontinuity orientations. Several methods for both oriented coring and down-hole surveying have evolved, and highly trained personnel are typically needed to operate them successfully. The 1988 AASHTO Manual is a good source of information on the older core orientation systems while vendors such as the Baker-Hughes Corporation have technical information on the newer magnetic/electronic core alignment systems.

### 3.6.2.5 Vibratory or Sonic Drilling

Sonic drilling may be called vibratory or rotosonic drilling. This type of drilling is used for continuous sampling in unconsolidated sediments and soft, weathered bedrock. It is best suited for use in oversized unconsolidated deposits enriched with cobbles and boulders such as talus slopes, colluvium, and debris flows or any other formation containing large clasts.

**Benefits**

- The primary benefit of this method is recovery of oversized materials in a continuous sample, rapid drilling rate, reduced volume of cuttings, and fast monitoring well installation.
- This drilling technique is 8 to 10 times faster than hollow stem auguring and produces about 10% of the volume of cuttings.

**Drawbacks**

- The drawbacks to this method are that it is typically more expensive, and cannot penetrate very far into bedrock.

- The vibration of the drill stem during borehole advancement may disturb the subsurface materials for an unknown distance ahead of the bit, and soft, loose materials can be liquefied during sampling.
- The sample size and speed of extraction will require additional personnel to process, log, and classify in the field.

Sonic drill rigs use hydraulic motors that drive eccentric weights to oscillate the drill head. The oscillation generates a standing sinusoidal wave in the drill stem with a frequency that can be varied depending on the materials encountered. The drill head also rotates the drill stem. An inner and outer casing is advanced so that the hole can be cased at the same time that samples are collected. During drill advancement, the sample is forced into the inner casing from which it is retrieved on a set interval. SPTs and Shelby tube samples can be taken between runs of rotosonic coring.

### 3.6.2.6 Becker Hammer Drilling

Becker hammer drills are specifically for use in sand, gravel, and boulders. Some Becker hammer drill operators may also have a scoring system that can also be run for limited applications. Becker hammer drills use a small diesel-powered pile hammer to drive a special double-walled casing. The casing can be fitted with an array of toothed bits depending on the application. An air compressor forces air through the annulus between the casings to the bottom of the hole where it extracts the materials up through the center of the innermost casing, through a cyclone, and into the sampling bucket. The materials can be extracted on a set interval as the driller engages the air compressor. The Becker drill casings range in size from 5.5-inch (14cm) to 9 inches (23cm) for the outer casing, and 3.3-inch (8.4cm) to 6 inches (15.2cm) respectively for the inner casing. This size of casing allows retrieval of relatively large, unbroken clasts. As the drill is advanced, blow counts are taken along with measurements of the hammer’s bounce chamber pressure. Becker hammer drill data can be correlated to the soil density and strength in coarse-grained soils similarly to the SPT test. In addition, SPTs can be taken through the inner casing of the Becker hammer string.

### 3.6.2.7 Supplemental Drilling/Exploration Applications

A wide assortment of exploration techniques are available to supplement the subsurface information gathered from test borings at a project site. Typically, any method that can be employed to properly evaluate the subsurface conditions in a supplementary capacity is acceptable on an ODOT project if not constrained by environmental considerations. These methods are usually the most simple and economic to quickly gather subsurface information with minimal cost. In some cases, more extensive and costly methods are required to obtain critical design information. Generally, supplemental investigations consist of simple hand auger borings or backhoe test pits to gather more detailed information and collect additional samples in near-surface or overburden materials.

**Hand Tools**

Hand augers are available in many forms that allow rapid penetration of near-surface soils and collection of representative samples. Various bits can be used that are suited to general soil conditions that help penetrate and retain samples from certain materials. Extra sections of rods can be added to extend the depth range of these tools. Small engine-powered augers can also be used to increase the depth of penetration and to reduce the physical workload. Most hand augers are of sufficient diameter to permit undisturbed Shelby-tube sampling in the boring where soft soils are encountered. Additional tools such as jacks, cribbing, and extra weights may be needed to retract the tube after sampling. Most field vehicles are equipped with shovels that geotechnical designers can apply to subsurface investigations. Hand-excavated pits can provide essential, detailed information on the near-surface environment.

Various hand probes and penetrometers can be used to make soundings of soft material depths and delineate underground facilities in soft ground conditions. Hand auger borings and hand-excavated test pits are often required for collection of bulk samples.

## Cone Penetrometers

Cone penetrometers can be operated from most drill rigs, or they may come as a separate vehicle specially rigged for cone penetration testing. The cone penetration test (CPT) is conducted by pushing an instrumented cylindrical steel probe at a constant rate into the subsurface with some type of hydraulic ram. The cone penetration test is very advantageous in certain (usually soft) soil conditions as it provides a continuous log of stress, pressures, and other measurements without actually drilling a hole. CPTs can be conducted with a transducer to measure penetration pore pressure. Additional instrumentation can be used to measure the propagation of shear waves generated at the surface. Standard cone penetration test procedures are described in ASTM D 3441-98. Electronic CPT testing must be done in accordance with ASTM D 5778.

## Percussion or Direct push (i.e. GeoProbe®) Borings

Direct push drills are hydraulically powered, percussion/probing machines originally intended for use in environmental investigations. The direct push method uses the weight of the vehicle combined with percussion to advance the drill string. Drive tools are used to obtain continuous, small-diameter soil cores or discrete samples from specific locations. Direct push drills can obtain continuous samples through the soil column and are capable of penetrating most soils up to about 100 feet (30m). Small-diameter piezometers can also be installed through the direct push tools. Direct push rigs are quick and economical to mobilize and sample the soil column very quickly. Their small diameter and method of penetration produce few if any cuttings that must be disposed of. The percussion advance of the direct push method produces a considerable amount of sample disturbance.

**Note:**
*Direct push advancement rates may provide a relative determination of soil density with respect to material encountered by that particular machine but it is not correlative to SPT data. Direct push rigs are lighter and less powerful than most conventional drill rigs. Thus, they do not have the ability to penetrate certain formations, and because of the effort in doing so, may give a false, overestimation of the formation density.*

## Test Pits

Backhoe-excavated test pits or trenches are commonly used to provide detailed examination of near surface geologic conditions and to collect bulk samples. Test pits allow examination of larger-scale features that would not be visible in standard borehole samples. Features such as faulting, seepage zones, material contact geometry and others are readily measured in test pit walls. In addition, Torvane and pocket penetrometer tests can be performed in the walls and floor of the test pit. In-place percolation testing can also be carried out in test pits. Test pits have the advantage of the shear bulk of materials that can be observed. In this regard, the overall composition of the materials in a unit are better assessed by the many cubic feet of material excavated and observed opposed to the relatively minute amount of material contained in a split spoon sampler.

**Warning:**
*Under no circumstances will personnel enter a test pit deeper than 4 feet (1.2m) below the ground surface unless the appropriate shoring and bracing is used. If any evidence of instability or seepage is evident in the test pit walls, no entry will be permitted until shoring is complete. Test pits must be filled in as soon as they are completed to prevent passersby from entering or falling in. When a test pit is used for percolation tests or for assessment of trench stability, appropriate barricades and signs must be placed around the site to prevent accidental entry.*

**ODEX or Air-Track Drilling**

Percussive air drilling is typically used in a similar manner to other probing systems with the exception that air-drill holes are used to probe harder materials. A relative rate of advancement coupled with the cuttings retrieved in certain intervals allows basic interpretation of subsurface conditions. ODEX systems using an outer casing allow installation of instruments below the water table that would otherwise be impossible to install with other air-driven equipment. The advantage of this method is the speed of installation and borehole advancement. As previously described, air drilling system are not suited for standard testing methods due to the unknown amount of down-hole disturbance.

### 3.6.3 Alternative Exploration Methods and Geophysical Surveys

Alternatives to drilling and test pit excavations characteristically involve the use of geophysical methods. For ODOT projects, geophysical survey results are always supplemental to direct observation of subsurface conditions by borings and test pits and should never be considered as a replacement.

Geophysical surveys play an important role in engineering geology and geotechnical engineering however they do not provide all of the information needed for the development of geotechnical design parameters.

**Note:**
*From a liability and construction claims standpoint, direct observation, sampling, and testing are critical. Direct observation and measurement will assure that subsurface conditions not measured by geophysical survey methods are revealed and further support or refute the results of geophysical surveys.*

Most of the data obtained from a geophysical survey require an experienced and highly trained geophysicist to interpret and process before it is of any use to an engineering geologist or geotechnical engineer. Geophysicists can base their interpretation on direct calculations, tabulations, or regression analyses, or they may base it wholly upon their own experience. Any geophysical method used has its own aspects that can result in serious misinterpretation or inappropriate use of the results. Prior knowledge of the actual site conditions and the possible errors of the survey technique are needed to calibrate, or fit the data to the known baseline data.

Geophysical survey results and resolution of the data is dependent upon the density of measurement points, and frequency of measurements. These variables may be set according to the overall project needs and level of detail required. Modern geophysical instruments are sensitive enough to produce measurements at the levels needed for geotechnical investigations. Methods most frequently used are:

- Seismic methods are the most commonly conducted techniques for engineering geologic investigations.
- Seismic refraction provides the most basic geologic data by using the simplest procedures, and commonly available equipment. The data provided is the most readily interpreted and correlated to other known material properties.

# 3.7 Geotechnical Instrumentation

## 3.7.1 General – Instrumentation and Monitoring

Of equal importance to site characterization and exploration as sampling and testing data is the information provided by geotechnical instrumentation and monitoring. Sampling and testing of materials provides needed design information concerning the existing site conditions at the time of investigation. Information regarding certain site conditions as they change through time due to the effects of natural variations in the earth's surface and atmosphere or the effects of human activities, such as construction, can be provided by the appropriate selection, installation, and monitoring of geotechnical instruments. Most geotechnical instruments are used to monitor the performance of structures and earthworks during construction and operation of the facility. Some instrumentation programs are planned to provide actual design criteria such as landslide depths of movement and piezometric surfaces. Other programs are intended to verify design assumptions. In any case, considerable design and planning efforts are needed to derive the needed results. Geotechnical instrumentation has become much more "user-friendly" as technologies have developed, but an all-inclusive process beginning with a determination of the instrumentation project objectives that are carried through to completion and use of the data.

## 3.7.2 Purposes of Geotechnical Instrumentation

A rule of thumb for geotechnical instrumentation programs is: "every instrument installed should be selected and placed to assist in answering a specific question." The point of this rule is to start a geotechnical instrumentation program on the correct course of study to acquire the necessary results with the greatest efficiency. Instruments can have an initially high installation cost, but the time and effort for reading them and making sense of the results where the most costly inefficiencies occur. Any instrument installed will provide some information; whether or not it is relevant to the immediate project requirements is the issue. Therefore, efforts must be concentrated on the primary questions to gather the most important data from the instrumentation program without time lost to the analysis of extraneous data.

### 3.7.2.1 Site Investigation and Exploration

Instruments are regularly used to characterize the initial site conditions during the design phase of a project. Landslide remediation projects rely on instruments to determine depths and rates of movement as well as pore water pressures to provide basic information for stability analysis and mitigation design.

Most project sites require some information concerning the actual depth and seasonal fluctuation of groundwater that not only affects the project design, but also its constructability.

### 3.7.2.2 Design Verification

Instruments are frequently used to verify design assumptions and to check that facility performance is as expected. Instrument data gathered early in a project can be used to modify the design in later phases. Geotechnical instruments are also an inherent part of proof testing to verify design adequacy.

#### 3.7.2.3 Construction and Quality Control

Geotechnical instruments are commonly used to monitor the effects of construction. Construction procedures and schedules can be modified based on actual behavior of the project features for ensuring safety as well as gaining efficiency in the actual construction as determinations can be made regarding how fast construction can proceed without the risk of failure or unacceptable deflections. Instruments can be used to monitor contractor performance to assure that contract requirements and specifications are being met.

#### 3.7.2.4 Safety and Legal Protection

Instruments can be used to provide early warning of impending failures allowing time to isolate the problems and begin implementation of remedial actions. Instrument data provides crucial evidence for legal defense of the agency should owners of adjacent properties claim that construction or operations have caused damage.

#### 3.7.2.5 Performance

Instruments are used for the short and long-term service performance of various facilities. Deformation, slope movement, and piezometric surface measurements in landslides can be used to evaluate the performance of drainage systems installed to stabilize the landslide. Loads on rock bolts and tiebacks may be monitored to assess their long-term performance or evaluate the need for additional supports.

### 3.7.3 Criteria for Selecting Instruments

For each project, the critical parameters must be identified by the designer that will require instrumentation to determine. The appropriate instruments should then be selected to measure them based on the required range, resolution, and precision of measurements. The ground conditions are another consideration in the choice of instruments. Use the following to help select instruments:

- **Landslides:** Relatively fast-moving landslides may require a larger-diameter inclinometer pipe or TDR cable to determine the zone of slide movement, or Vibrating Wire piezometers may be selected to measure groundwater in low permeability soils where a standpipe would require a large volume of water to flow into it before even small changes in pore-water pressure can be detected.
- **Temperature and humidity:** Temperature and humidity also affect the choice of instruments. Certain instruments may be difficult to use in freezing conditions while warm and humid environments may affect the reliability of electronic instruments unless particular care is taken to isolate their environment.
- **Number of parameters:** The number of parameters to measure is also important for instrument selection since soil and rock masses typically have more than one property that dictates their behavior. Some parameters correlate with one another, and instruments that obtain complementary measurements provide an efficiency gain. In areas with complex problems, several parameters can be measured, and a number of correlations can be found from instrumentation data leading to a better understanding of the site conditions. Strain gages and load cells on a retaining wall and inclinometers behind it are examples where complementary data can be obtained. When relationships can be developed with the data, further data can be obtained even when one set of instruments fail.

- **Instrument performance and reliability:** Instrument performance and reliability are also important considerations. The cost of an instrument generally increases with higher resolution, accuracy, and precision in the instrument. In addition, the range of measurements obtained can be reduced by higher-functioning instruments, so the geotechnical designer should have a clear understanding of the scale and level of measurements to be taken.

  **Example:** An example is the placement of a vibrating wire transducer in a borehole to measure an unknown piezometric surface. The instrument selected would have a wide range of testing, but a lower resolution of values that could be read. Where the piezometric surface is known within a narrower range and small changes are of significance to the design, an instrument capable of reading a smaller range of values but at a higher resolution within the known range.

- **Quality of the instrument:** There are some instances where the use of lower-quality instruments is warranted, but in general, choosing a lower-quality instrument to save on initial costs is a false economy. The difference in cost between a high-quality instrument and a lower-quality instrument is low with respect to the overall cost of installing and monitoring an instrument.

- **Cost:** The cost of drilling a hole and the labor of installing the instrument is usually an order of magnitude higher than the cost of the instrument. The less easily quantifiable loss of data from a failed instrument in terms of monetary cost should also be considered. It is expensive and often impossible to replace failed instruments. Furthermore, essential baseline data is also lost that cannot be replaced.

#### 3.7.3.1 Automatic Data Acquisition Systems (ADAS)

Automatic Data Acquisition Systems (ADAS) can provide significant advantages to a geotechnical instrumentation program. They can provide numerous readings at set and reliable intervals, and they can store and transmit data from remote or difficult access locations. ADAS are necessary for real-time instrument monitoring and relay. They are beneficial at sites where many sensors are present that would require copious staff time to read manually or for large-scale proof tests with many concurrently read instruments to be monitored throughout the test.

Automatic Data Acquisition Systems come in many forms ranging from the very simple, user-friendly devices to systems requiring significant programming and electronics to install and run. Project requirements usually dictate what system is selected, but the simplest, most inexpensive, and easiest to connect to the chosen instruments are best. Follow these guidelines:

- Simple data loggers connected to individual instruments that are retrieved and downloaded periodically are sufficient for most projects.
- Large, complex problems may require a more intelligent system that can be programmed to change monitoring routines in response to site or environmental changes.
- Most instrumentation companies also have companion data loggers to go with their products while several independent companies also manufacture easy-to-use data loggers. Other companies, such as Campbell Scientific Incorporated, produce more complex systems that can read multiple installations of different types of instruments as well as store and transmit data.

- In addition to the data collection devices, these firms also produce software for processing and displaying the data. The software is another consideration if export to other systems is desired. Compatibility between programs can create problems and errors in the end product of an instrumentation project.

### 3.7.3.2 Instrument Use and Installation

Instruments have been developed to monitor many specific geologic conditions and engineering parameters. In many cases, a single instrument can be used or adapted for use on other applications. For this, the manufacturer and other professionals should be consulted to assure that the results obtained are valid, or, they may have insights and case histories that are of use for the situation. The manufacturer's literature, installation procedures, and other guidance documents should be followed for proper installation of their products as procedures can vary for different manufacturers same instrument products. Detailed discussions of instrument installation and initialization procedures, function, and operation can be found in manufacturer's documents such as Slope Indicator Company (SINCO) Applications Guide or in published literature such as Dunnicliff (1988).

### 3.7.3.3 Inclinometers

Inclinometers are used on transportation projects mainly to detect and monitor lateral earth movements in landslides and embankments. They are also used to monitor deflections in laterally loaded piles and retaining walls. Horizontally installed inclinometers can also be used to monitor settlement. Inclinometer systems are composed of:

- grooved casing installed in a borehole, embedded in a fill or concrete, or attached to structures,
- probe and cable for taking measurements at set intervals in the casing, and
- a digital readout unit and/or data storage device.

The installed casing is for single installation use, and the probe, cable and data storage unit are used for almost all installations.

**Note:**
*It is important to use the same probe for each reading in any particular installation since each probe must be independently calibrated.*

Inclinometers are manually read by a trained technician on a set schedule or in response to environmental changes such as increased rainfall in the area or observation of surficial signs of slope movement. In-place inclinometers spanning known or highly suspected zones of movement can be installed for continuous, automatic monitoring. These usually remain in the hole permanently if significant slope movement occurs.

- Inclinometer casing installation is essential to successful performance of the instrument. Shortcuts taken during installation will frequently result in poor performance of the instrument or render it useless.
- Inclinometers should be installed according to the procedures described in the SINCO Applications guide with the exception of the grout valve.
- Borings should be initially drilled or later reamed to a sufficient diameter that will accommodate the inclinometer casing and an attached tremie tube.

- The tremie tube should be attached to the inclinometer casing approximately 6 inches above the bottom and along the casing at a close enough interval to prevent it from being tangled or constricted in the borehole.
- One of the four grooves in the inclinometer casing should be aligned to the direction of slide movement as the casing is assembled and lowered into the hole to prevent spiraling.
- If the borehole walls are unstable, the drill casing may need to remain in the borehole, and withdrawn as the grout level rises. Generally, the grout should be maintained at a visible level in the casing as the drill string is withdrawn.

Initial readings should be taken as soon as the grout has sufficiently set up. This is usually 3 to 5 days after grouting. During installation, some grout is naturally lost to fractures and voids in the formation. This may occur to the extent that additional grouting is required. Usually, this only entails topping off the hole with a small batch of grout to stabilize the uppermost portion of the casing. In more severe cases, the grout pump may be reconnected to the tremie tube to re-grout the remaining voids.

#### 3.7.3.4 Piezometers

Piezometers used to measure pore-water pressure and groundwater levels can range from simple standpipes to complex electronic devices or pneumatic systems. Piezometers are typically installed in selected layers to measure the piezometric pressures in that layer. The layout and target depths of piezometer installation are determined by actual site conditions and project requirements.

**Note:**
*All piezometers must be installed according to Oregon Water Resources Department regulations defined by OAR 690.240 and ORS 537.880 through 537.895. Specifications for properly operating instruments are usually more stringent than these rules apart from the requirements for abandonment.*

The various types of piezometers are generally used for different applications as described below.

- Standpipe piezometers are general-purpose instrument for monitoring piezometric water levels and are best suited for granular materials. Standpipe piezometers require a water level indicator to obtain readings.
- Vibrating Wire piezometers utilize a pressure transducer to convert water pressure to a frequency signal that is read by an electronic device. Vibrating Wire piezometers can be automated by electronic systems.
- Pneumatic piezometers are typically used to measure pore water pressure in saturated conditions. Both Pneumatic and vibrating wire piezometers are used for all soil types and are better suited to fine-grained soils than the standpipe variety due to the response time and volume of water needed to record changes in water level in that type.

Piezometers should be placed at the desired sensing zone in a porous medium and sealed with the appropriate materials above and below this zone to assure measurement of the piezometric pressure in the desired location. Porous mediums or filter packs should be composed of pre-screened commercial-grade silica sand. All piezometers should be installed and initialized according to their manufacturer's specifications.

#### 3.7.3.5 Other Instruments

A vast array of geotechnical instruments is available for most applications. Strain gauges, extensometers, and load cells of all types and configurations for structural as well as geotechnical applications are obtainable from numerous vendors. Most vendors have prescribed applications as well as installation and monitoring procedures that should be followed when using their products on transportation projects. Professional knowledge, experience, and judgment must be applied to the use of all instruments to assure appropriate use of these instruments and the adequacy of data obtained.

## 3.8 Environmental Protection during Exploration

Compliance with all State, Federal, and Local ordinances, laws and regulations concerning environmental protection at all work locations is **mandatory** for any activity that may disturb the ground surface or vegetation. All environmental permits, clearances, or any other documentation needed for compliance with the pertinent environmental regulations must be ready prior to mobilization of exploration equipment.

The ODOT Programmatic Biological Opinion for Drilling, Surveying, and Hydraulic Engineering Activities may be applicable for some sites. This document can be referenced on the ODOT Geo-Environmental web page.

**Note:**
*Every precaution necessary to minimize environmental impacts during site investigation must be taken, and every effort made to restore the site to its original condition. All drilling fluids and cuttings must be disposed of safely and legally. In no circumstance should sediment-laden water or other pollutants be allowed to enter streams or other bodies of water. In the event where there is a potential for pollutants to contaminate such, all operations will be suspended until the situation can be rectified. Violation of Federal, State, and Local environmental protection laws can result in personal penalties, including arrest and incarceration.*

### 3.8.1 Protection of Fish, Wildlife, and Vegetation

Compliance with the Laws of the Oregon Department of Fish and Wildlife, National Marine Fisheries Service, United States Fish and Wildlife Service, and the rules and practices developed through the Oregon Plan for Salmon and Watersheds is also **mandatory**. All subsurface investigation activities shall be conducted to avoid any hazard to the safety and propagation of fish and shellfish in the waters of the State.

Unless specifically authorized by the State and by permit, the Contractor shall not:

- Use water jetting
- Release petroleum or other chemicals into the water, or where they may eventually enter the water
- Disturb spawning beds or other wildlife habitat
- Obstruct streams
- Cause silting or sedimentation of water
- Use chemically treated timbers or platforms
- Impede fish passage

The permitted work area boundaries will be defined by the permit for the project from the regulatory agencies.

### 3.8.2 Forestry Protection

All necessary permits must be obtained prior to exploration in accordance with ORS 477.625 and ORD 527.670, and comply with the laws of any authority having jurisdiction for protection of forests. At certain times of the year, the exploration activities will be subject to IFPL constraints, and operational schedules must be adjusted accordingly. Fire-suppression equipment may be required on site as well as a designated fire watch.

### 3.8.3 Wetland Protection

All operations shall comply with the Clean Water Act Section 404 (33 U.S.C. 1344); Federal Rivers and Harbors Act of 1899, Section 10 (33 U.S.C. 403 et seq.); Oregon Removal-Fill law (ORS 196.800 - 196.990); Oregon Removal and Filling in Scenic Waterways law (ORS 390.805 - 390.925), and other applicable Laws governing preservation of wetland resources.

**Note:**
*The terms "wetland," or "wetlands" are defined as "Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstance do support, vegetation typically adapted for life in saturated Soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." Wetlands also include all other jurisdictional waters of the U.S. and/or the State.*

If wetlands are known to be on the project site, they should be delineated by the region's wetland specialist or their contractor to prevent accidental entry by the exploration operation. Wetlands to be temporarily impacted should also be identified at this time. Wetlands to be protected will be considered as "no work zones."

Subsurface exploration operations must also comply with Clean Water Act Section 404 permits issued by the U.S. Army Corps of Engineers, and Fill/Removal permits issued by DSL. These permits allow specified quantities of fill and excavation, including soil and rock samples within specifically identified areas of wetlands.

### 3.8.4 Cultural Resources Protection

The exploration crew is also required to comply with all Laws governing preservation of cultural resources. Cultural resources may include, but are not limited to, dwellings, bridges, trails, fossils, and artifacts. Known locations of cultural resources will be considered as "no work zones."

If cultural resources are encountered in the project area, and their disposition is not addressed in the contract, the exploration crew shall:

- Immediately cease operations or move to another area of the project site
- Protect the cultural resource from disturbance or damage
- Notify the region's cultural resource specialist

The region's cultural resource specialist will:

- Arrange for immediate investigation
- Arrange for disposition of the cultural resources
- Notify the exploration crew when to begin or resume operations in the affected area

## 3.9 References


- AASHTO, 2007, *LRFD Bridge Design Specifications*, American Association of State Transportation and Highway Officials, 17th Edition (with current Interims), Washington, D.C., USA.
- American Association of State Highway and Transportation Officials, Inc., 1988, *Manual on Subsurface Investigations*.
- C.H. Dowding, Ed., *Site Characterization & Exploration, ASCE Specialty Workshop Proceedings*, Northwestern University, 1978.
- Dunnicliff, John 1988. *Geotechnical Instrumentation For Monitoring Field Performance*, John Wiley & Sons, New York.
- Oregon Department of Transportation, Hydraulics Manual, Geo-Environmental Section, 2005.
- Oregon Department of Transportation, Bridge Design and Drafting Manual, Bridge Engineering Section, most current version.
- U.S. Department of Transportation, Federal Highway Administration Evaluation of Soil and Rock Properties, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034, April, 2002.
- U.S. Department of Transportation, Federal Highway Administration Subsurface Investigation Participant's Manual, Publication No. FHWA HI-97-201, November, 1997.
- U.S. Department of Transportation, Federal Highway Administration *Subsurface Investigations - Geotechnical Site Characterization Reference Manual*, Publication No. FHWA NHI-01-031, May, 2002.
- Turner, Keith A., and Schuster, Robert L., Eds., LANDSLIDES Investigation and Mitigation, Transportation Research Board Special Report 247, 1996, Pages 129-177.
- Geophysical Exploration for Engineering and Environmental Investigations, U.S. Army Corps of Engineers Engineering and Design Manual, EM 1110-1-1802, August 1995.
- Geotechnical Investigations, U.S. Army Corps of Engineers Engineering and Design Manual, EM 1110-1-1804, January 2001.
- U.S. Department of the Interior, Bureau of Reclamation, 1994, Engineering Geology Field Manual.
- References are made to various ASTM standards. The ASTM International standards located at www.astm.org (the “ASTM Site”).

# Appendix 3-A Permit of Entry Form

***Oregon Department of Transportation***
**RIGHT OF ENTRY for EXPLORATION**
**REGION 3 GEOLOGY**
Phone: (541) 957-3602 FAX: (541) 957-3604
3500 NW Stewart Parkway
Roseburg, OR 97470

(1) (We) _______________ and ____________________________ hereinafter referred to as "grantor", do hereby grant to the STATE OF OREGON, by and through the Oregon Department of Transportation, and its officers, agents, and employees, the right and license to go upon the following described real property to drill or to gain access to highway Right-of -Way for exploration core drilling at:

Township 37 South, Range 2 West, Section 28
77 Hanley Road
Central Point, Oregon 97502

Property Description:

D-89-16328
37-2W-28 TL 800

IT IS UNDERSTOOD AND AGREED: That this right and license shall be valid until all exploration is completed unless revoked by grantor before completion. It is further understood that the Oregon Department of Transportation shall, to the extent permitted by Oregon law, be responsible for any unnecessary damage done, in connection with said exploration, this will include any crops or other improvements on said property.

Grantor hereby represents and warrants that he/she is the owner of said property or otherwise has the right to grant this permit of entry.

Date_____________ Day_________, 2003

Permission Acquired by: _______________________

Signature:_____________________________________

Title: Project Geologist

Owner(s)
Signature(s):_________________________________________________________________

# Appendix 3-B Utility Notification Worksheet

Memo to File

*UTILITY LOCATE DATA SHEET*
Region Geology Unit
*Oregon Department of Transportation*

Project Name:
Highway and Mile Point:

Utility Locate Called By:

Locators Called (When):

| **Required Information** | |
|---|---|
| Caller ID #: | |
| Type of Work: | |
| County/City | |
| Highway: | |
| Mile Point: | |
| Township/Range/ Quarter Section: | |
| Distance from Nearest Cross Street: | |
| Overhead Lines: | |
| Special Markings: | |
| **Date to Be Located:** | |
| **Ticket#:** | |
| **Name of Person Called:** | |
| **Utilities Notified:** | |

| **Utilities Field Marked:** | |
|---|---|
| Gas | |
| Electric | |
| Sewer | |
| Water | |
| Telephone | |
| Cable Television | |
| Irrigation | |
| Signals/Illumination | |
| Other | |