CHAPTER 3.0

DRILLING AND SAMPLING OF SOIL AND ROCK

This chapter describes the equipment and procedures commonly used for the drilling and sampling of soil and rock. The methods addressed in this chapter are used to retrieve soil samples and rock cores for visual examination and laboratory testing. Chapter 5 discusses in-situ testing methods which should be included in subsurface investigation programs and performed in conjunction with conventional drilling and sampling operations.

3.1 SOIL EXPLORATION

3.1.1 Soil Drilling

A wide variety of equipment is available for performing borings and obtaining soil samples. The method used to advance the boring should be compatible with the soil and groundwater conditions to assure that soil samples of suitable quality are obtained. Particular care should be exercised to properly remove all slough or loose soil from the boring before sampling. Below the groundwater level, drilling fluids are often needed to stabilize the sidewalls and bottom of the boring in soft clays or cohesionless soils . Without stabilization, the bottom of the boring may heave or the sidewalls may contract, either disturbing the soil prior to sampling or preventing the sampler from reaching the bottom of the boring. In most geotechnical explorations, borings are usually advanced with solid stem continuous flight, hollow-stem augers, or rotary wash boring methods.

Solid Stem Continuous Flight Augers

Solid stem continuous flight auger drilling is generally limited to stiff cohesive soils where the boring walls are stable for the entire depth of the boring. Figure 3-1a shows continuous flight augers being used with a drill rig. A drill bit is attached to the leading section of flight to cut the soil. The flights act as a screw conveyor, bringing cuttings to the top of the hole. As the auger drills into the earth, additional auger sections are added until the required depth is reached.

Due to their limited application, continuous flight augers are generally not suitable for use in investigations requiring soil sampling. When used, careful observation of the resistance to penetration and the vibrations or "chatter" of the drilling bit can provide valuable data for interpretation of the subsurface conditions. Clay, or "fishtail", drill bits are commonly used in stiff clay formations (Figure 3-1b). Carbide-tipped "finger" bits are commonly used where hard clay formations or interbedded rock or cemented layers are encountered. Since finger bits commonly leave a much larger amount of loose soil, called slough, at the bottom of the hole, they should only be used when necessary. Solid stem drill rods are available in many sizes ranging in outside diameter from 102 mm (4.0 in) to 305 mm (12.0 in) (Figure 3-1c), with the 102 mm (4.0 in) diameter being the most common. The lead assembly in which the drill bit is connected to the lead auger flight using cotter pins is shown in Figure 3-1d. It is often desirable to twist the continuous-flight augers into the ground with rapid advancement and to withdraw the augers without rotation, often termed “dead-stick withdrawal”, to maintain the cuttings on the auger flights with minimum mixing. This drilling method aids visual identification of changes in the soil formations. In all instances, the cuttings and the reaction of the drilling equipment should be regularly monitored to identify stratification changes between sample locations.

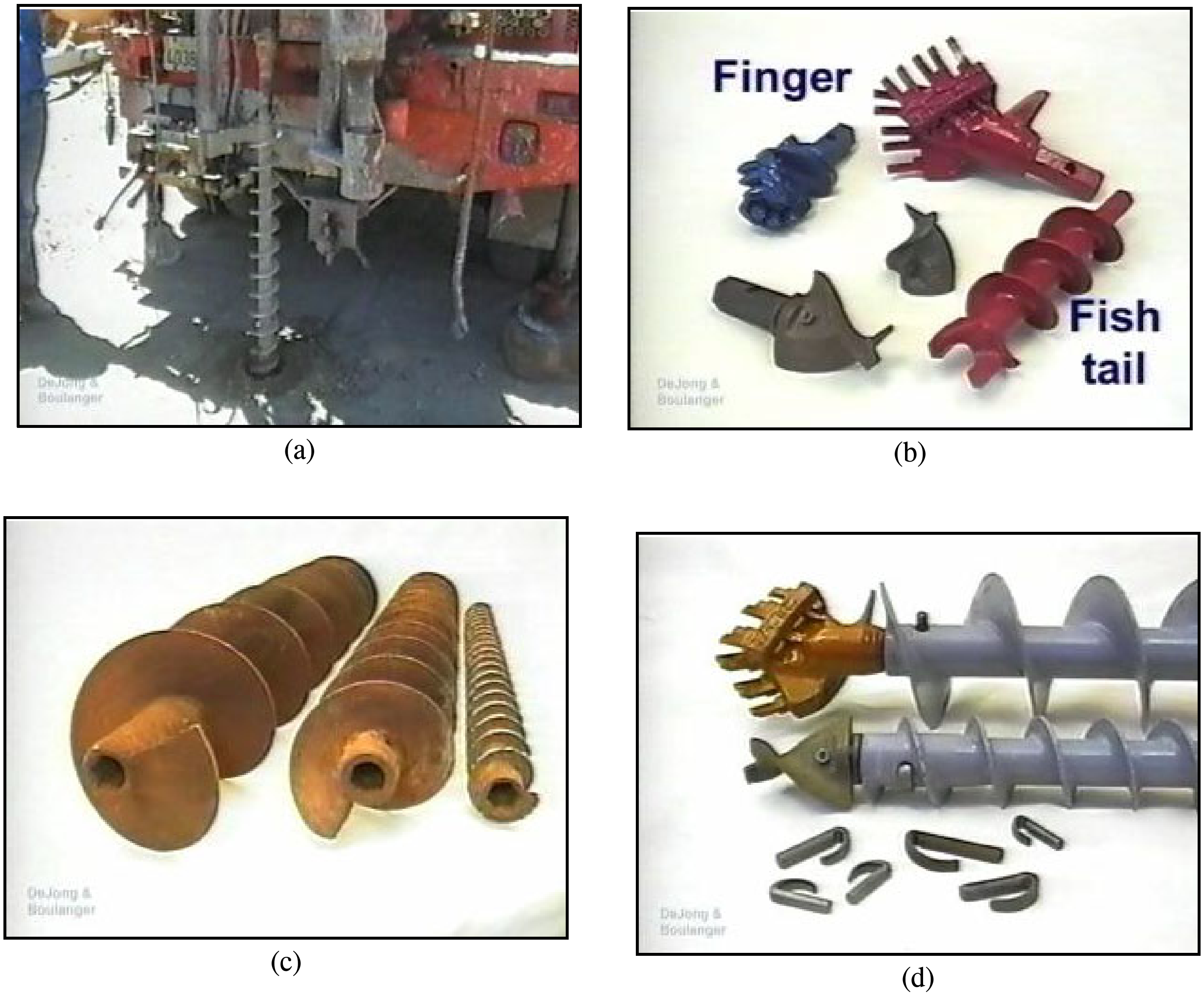

Figure 3-1. Solid Stem Continuous Flight Auger Drilling System: (a) In use on drill rig, (b) Finger and fishtail bits, (c) Sizes of solid stem auger flights, (d) Different assemblies of bits and auger flights. (All pictures in the above format are courtesy of DeJong and Boulanger, 2000)

Hollow Stem Continuous Flight Augers

In general hollow stem augers are very similar to the continuous flight auger except, as the name suggests, it has a large hollow center. This is visually evident in Figure 3-3a, where a solid stem flight and a hollow stem flight are pictured side-by-side. The various components of the hollow stem auger system are shown schematically in Figure 3-2 and pictured in Figure 3-3b to 3-3f. Table 3-1 presents dimensions of hollow-stem augers available on the market, some of which are pictured in Figure 3-3c. When the hole is being advanced, a center stem and plug are inserted into the hollow center of the auger. The center plug with a drag bit attached and located in the face of the cutter head aids in the advancement of the hole and also prevents soil cuttings from entering the hollow-stem auger. The center stem consists of rods that connect at the bottom of the plug or bit insert and at the top to a drive adapter to ensure that the center stem and bit rotate with the augers. Some drillers prefer to advance the boring without the center plug, allowing a natural "plug" of compacted cuttings to form. This practice should not be used since the extent of this plug is difficult to control and determine.

Once the augers have advanced the hole to the desired sample depth, the stem and plug are removed. A sampler may then be lowered through the hollow stem to sample the soil at the bottom of the hole. If the augers have been seated into rock, then a standard core barrel can be used.

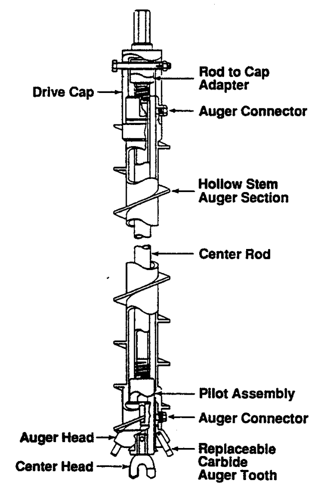

Figure 3-2. Hollow Stem Auger Components (ASTM D 4700).

Hollow-stem augering methods are commonly used in clay soils or in granular soils above the groundwater level, where the boring walls may be unstable. The augers form a temporary casing to allow sampling of the "undisturbed soil" below the bit. The cuttings produced from this drilling method are mixed as they move up the auger flights and therefore are of limited use for visual observation purposes. At greater depths there may be considerable differences between the soil being augered at the bottom of the boring and the cuttings appearing at the ground surface. The field supervisor must be aware of these limitations in identification of soil conditions between sample locations.

Significant problems can occur where hollow-stem augers are used to sample soils below the groundwater level. The hydrostatic water pressure acting against the soil at the bottom of the boring can significantly disturb the soil, particularly in granular soils or soft clays. Often the soils will heave and plug the auger, preventing the sampler from reaching the bottom of the boring. Where heave or disturbance occurs, the penetration resistance to the driven sampler can be significantly reduced. When this condition exists, it is advisable to halt the use of hollow-stem augers at the groundwater level and to convert to rotary wash boring methods. Alternatively the hollow-stem auger can be flooded with water or drilling fluid to balance the head; however, this approach is less desirable due to difficulties in maintaining an adequate head of water.

TABLE 3-1.

DIMENSIONS OF COMMON HOLLOW-STEM AUGERS

Inside Diameter of Hollow Stem mm (in)	Outside Diameter of Flighting mm (in)	Cutting Diameter of Auger Head mm (in)
57 (2.250)	143 (5.625)	159 (6.250)
70 (2.750)	156 (6.125)	171 (6.750)
83 (3.250)	168 (6.625)	184 (7.250)
95 (3.750)	181 (7.125)	197 (7.750)
108 (4.250)	194 (7.625)	210 (8.250)
159 (6.250)	244 (9.625)	260 (10.250)
184 (7.250)	295 (11.250)	318 (12.000)
210 (8.250)	311 (12.250)	330 (13.000)
260 (10.250)	356 (14.000)	375 (14.750)
311 (12.250)	446 (17.500)	470 (18.500)

Note: Adapted after Central Mine Equipment Company. For updates, see: http://www.cmeco.com/

(a)

(b)

(c)

(d)

(e)

(f)

Figure 3-3. Hollow Stem Continuous Flight Auger Drilling Systems: (a) Comparison with solid stem auger; (b) Typical drilling configuration; (c) Sizes of hollow stem auger flights; (d) Stepwise center bit; (e) Outer bits; (f) Outer and inner assembly.

Rotary Wash Borings

The rotary wash boring method (Figures 3-4 and 3-5) is generally the most appropriate method for use in soil formations below the groundwater level. In rotary wash borings, the sides of the borehole are supported either with casing or with the use of a drilling fluid. Where drill casing is used, the boring or is advanced sequentially by: (a) driving the casing to the desired sample depth,(b) cleaning out the hole to the bottom of the casing, and (c) inserting the sampling device and obtaining the sample from below the bottom of the casing.

The casing (Figure 3-5b) is usually selected based on the outside diameter of the sampling or coring tools to be advanced through the casing, but may also be influenced by other factors such as stiffness considerations for borings in water bodies or very soft soils, or dimensions of the casing couplings. Casing for rotary wash borings is typically furnished with inside diameters ranging from 60 mm (2.374 in) to 130 mm (5.125 in). Even with the use of casing, care must be taken when drilling below the groundwater table to maintain a head of water within the casing above the groundwater level. Particular attention must be given to adding water to the hole as the drill rods are removed after cleaning out the hole prior to sampling. Failure to maintain an adequate head of water may result in loosening or heaving (blow-up) of the soil to be sampled beneath the casing. Tables 3-2 and 3-3 present data on available drill rods and casings, respectively.

For holes drilled using drilling fluids to stabilize the borehole walls, casing should still be used at the top of the hole to protect against sloughing of the ground due to surface activity, and to facilitate circulation of the drilling fluid. In addition to stabilizing the borehole walls, the drilling fluid (water, bentonite, foam, Revert or other synthetic drilling products) also removes the drill cuttings from the boring. In granular soils and soft cohesive soils, bentonite or polymer additives are typically used to increase the weight of the drill fluid and thereby minimize stress reduction in the soil at the bottom of the boring. For borings advanced with the use of drilling fluids, it is important to maintain the level of the drilling fluid at or above the ground surface to maintain a positive pressure for the full depth of the boring.

Two types of bits are often used with the rotary wash method (Figure 3-5c). Drag bits are commonly used in clays and loose sands, whereas roller bits are used to penetrate dense coarse-grained granular soils, cemented zones, and soft or weathered rock.

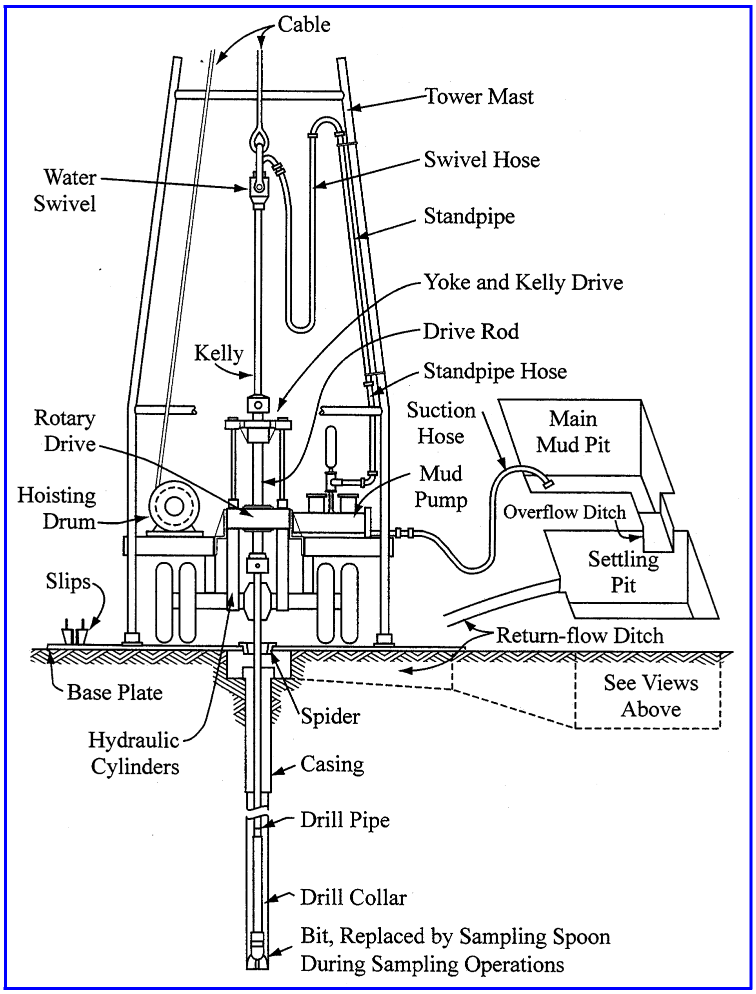

Figure 3-4. Schematic of Drilling Rig for Rotary Wash Methods (After Hvorslev, 1948).

Examination of the cuttings suspended in the wash fluid provides an opportunity to identify changes in the soil conditions between sample locations (Figure 3-6d). A strainer is held in the drill fluid discharge stream to catch the suspended material (Figure 3-6e,f). In some instances (especially with uncased holes) the drill fluid return is reduced or lost. This is indicative of open joints, fissures, cavities, gravel layers, highly permeable zones and other stratigraphic conditions that may cause a sudden loss in pore fluid and must be noted on the logs.

The properties of the drilling fluid and the quantity of water pumped through the bit will determine the size of particles that can be removed from the boring with the circulating fluid. In formations containing gravel, cobbles, or larger particles, coarse material may be left in the bottom of the boring. In these instances, clearing the bottom of the boring with a larger-diameter sampler (such as a 76 mm (3.0 in) OD split-barrel sampler) may be needed to obtain a representative sample of the formation.

TABLE 3-2.

DIMENSIONS OF COMMON DRILL RODS

Size	Outside Diameter of Rod mm (in)	Inside Diameter of Rod mm (in)	Inside Diameter of Coupling mm (in)
RW	27.8 (1.095)	18.3 (0.720)	10.3 (0.405)
EW	34.9 (1.375)	22.2 (0.875)	12.7 (0.500)
AW	44.4 (1.750)	31.0 (1.250)	15.9 (0.625)
BW	54.0 (2.125)	44.5 (1.750)	19.0 (0.750)
NW	66.7 (2.625)	57.2 (2.250)	34.9 (1.375)

Note 1: “W” and “X” type rods are the most common types of drill rod and require a separate coupling to connect rods in series. Other types of rods have been developed for wireline sampling (“WL”) and other specific applications.
Note 2: Adapted after Boart Longyear Company and Christensen Dia-Min Tools, Inc. For updates, see: http://www.boartlongyear.com/

TABLE 3-3.

DIMENSIONS OF COMMON FLUSH-JOINT CASINGS

Size	Outside Diameter of Casing mm (in)	Inside Diameter of Casing mm (in)
RW	36.5 (1.437)	30.1 (1.185)
EW	46.0 (1.811)	38.1 (1.500)
AW	57.1 (2.250)	48.4 (1.906)
BW	73.0 (2.875)	60.3 (2.375)
NW	88.9 (3.500)	76.2 (3.000)

Note 1: Coupling system is incorporated into casing and are flush, internally and externally.
Note 2: Adapted after Boart Longyear Company and Christensen Dia-Min Tools, Inc. For updates, see: http://www.boartlongyear.com/

(a) (b)

(c) (d)

(e) (f)

Figure 3-5. Rotary Wash Drilling System: (a) Typical drilling configuration; (b) Casing and driving shoe; (c) Diamond, drag, and roller bits; (d) Drill fluid discharge; (e) Fluid cuttings catch screen; (f) Settling basin (mud tank).

Bucket Auger Borings

Bucket auger drills are used where it is desirable to remove and/or obtain large volumes of disturbed soil samples, such as for projects where slope stability is an issue. Occasionally, bucket auger borings can be used to make observations of the subsurface by personnel. However this practice is not recommended due to safety concerns. Video logging provides an effective method for downhole observation.

A common bucket auger drilling configuration is shown in Figure 3-6. Bucket auger borings are usually drilled with a 600 mm (24 in) to 1200 mm (48 in) diameter bucket. The bucket length is generally 600 mm (24 in) to 900 mm (36 in) and is basically an open-top metal cylinder having one or more slots cut in its base to permit the entrance of soil and rock as the bucket is rotated. At the slots, the metal of the base is reinforced and teeth or sharpened cutting edges are provided to break up the material being sampled.

The boring is advanced by a rotating drilling bucket with cutting teeth mounted to the bottom. The drilling bucket is attached to the bottom of a "kelly bar", which typically consists of two to four square steel tubes assembled one inside another enabling the kelly bar to telescope to the bottom of the hole. At completion of each advancement, the bucket is retrieved from the boring and emptied on the ground near the drill rig.

Bucket auger borings are typically advanced by a truck-mounted drill. Small skid-mounted and A-frame drill rigs are available for special uses, such as drilling on steep hillsides or under low clearance (less than 2.5 m (8 ft)). Depending on the size of the rig and subsurface conditions, bucket augers are typically used to drill to depths of about 30 m (100 ft) or less, although large rigs with capabilities to drill to depths of 60 m (200 ft) or greater are available.

The bucket auger is appropriate for most soil types and for soft to firm bedrock. Drilling below the water table can be completed where materials are firm and not prone to large-scale sloughing or water infiltration. For these cases the boring can be advanced by filling it with fluid (water or drilling mud), which provides a positive head and reduces the tendency for wall instability. Manual down-hole inspection and logging should not be performed unless the hole is cased. Only trained personnel should enter a bucket auger boring strict safety procedures established by the appropriate regulatory agencies (e.g. ADSC 1995). Inspection and downhole logging can more safely be accomplished using video techniques.

The bucket auger method is particularly useful for drilling in materials containing gravel and cobbles because the drilling bucket can auger through cobbles that may cause refusal for conventional drilling equipment. Also, since drilling is advanced in 300 mm (12 in) to 600 mm (24 in) increments and is emptied after each of these advances, the bucket augering boring method is advantageous where large-volume samples from specific subsurface locations are required, such as for aggregate studies.

In hard materials (concretions or rocks larger than can enter the bucket), special-purpose buckets and attachments can be substituted for the standard "digging bucket". Examples of

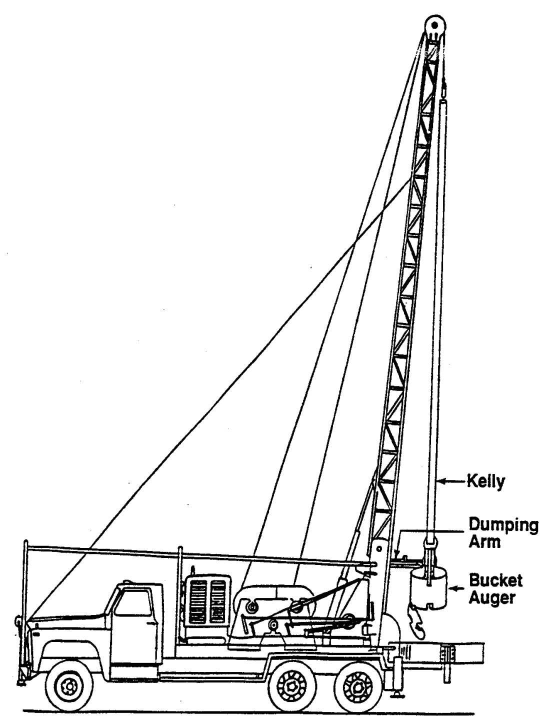

Figure 3-6. Setup of Bucket Auger & Rig (from ASTM D 4700)

special attachments include coring buckets with carbide cutting teeth mounted along the bottom edge, rock buckets that have heavy-duty digging teeth and wider openings to collect broken materials, single-shank breaking bars that are attached to the kelly bar and dropped to break up hard rock, and clam shells that are used to pick up cobbles and large rock fragments from the bottom of borings.

Area Specific Methods

Drilling contractors in different parts of the country occasionally develop their own subsurface exploration methods which may differ significantly from the standard methods or may be a modification of standard methods. These methods are typically developed to meet the requirements of local site conditions. For example, a hammer drill manufactured by Becker Drilling Ltd. of Canada (Becker Hammer) is used to penetrate gravel, dense sand and boulders.

Hand Auger Borings

Hand augers are often used to obtain shallow subsurface information from sites with difficult access or terrain where vehicle accessibility is not possible. Several types of hand augers are available with the standard post hole type barrel auger as the most common. In stable cohesive soils, hand augers can be advanced up to 8 m (25 ft). Clearly maintaining an open hole in granular soils may be difficult and cobbles & boulders will create significant problems. Hand held power augers may be used, but are obviously more difficult to carry into remote areas. Cuttings contained in the barrel can be logged and tube samples can be advanced at any depth. Although Shelby tube samples can be taken, small 25- to 50- mm (1.0- to 2.0- inch) diameter tubes are often used to facilitate handling. Other hand auger sampling methods are reviewed in ASTM D 4700.

Exploration Pit Excavation

Exploration pits and trenches permit detailed examination of the soil and rock conditions at shallow depths and relatively low cost. Exploration pits can be an important part of geotechnical explorations where significant variations in soil conditions occur (vertically and horizontally), large soil and/or non-soil materials exist (boulders, cobbles, debris) that cannot be sampled with conventional methods, or buried features must be identified and/or measured.

Exploration pits are generally excavated with mechanical equipment (backhoe, bulldozer) rather than by hand excavation. The depth of the exploration pit is determined by the exploration requirements, but is typically about 2 m (6.5 ft) to 3 m (10 ft). In areas with high groundwater level, the depth of the pit may be limited by the water table. Exploration pit excavations are generally unsafe and/or uneconomical at depths greater than about 5 m (16 ft) depending on the soil conditions.

During excavation, the bottom of the pit should be kept relatively level so that each lift represents a uniform horizon of the deposit. At the surface, the excavated material should be placed in an orderly manner adjoining the pit with separate stacks to identify the depth of the material. The sides of the pit should be cleaned by chipping continuously in vertical bands, or by other appropriate methods, so as to expose a clean face of rock or soil.

Survey control at exploration pits should be done using optical survey methods to accurately determine the ground surface elevation and plan locations of the exploration pit. Measurements should be taken and recorded documenting the orientation, plan dimensions and depth of the pit, and the depths and the thickness of each stratum exposed in the pit.

Exploration pits can, generally, be backfilled with the spoils generated during the excavation. The backfilled material should be compacted to avoid excessive settlements. Tampers or rolling equipment may be used to facilitate compaction of the backfill.

The U.S. Department of Labor's Construction Safety and Health Regulations, as well as regulations of any other governing agency must be reviewed and followed prior to excavation of the exploration pit, particularly in regard to shoring requirements.

Logging Procedures

The appropriate scale to be used in logging the exploration pit will depend on the complexity of geologic structures revealed in the pit and the size of the pit. The normal scale for detailed logging is 1:20 or 1:10, with no vertical exaggeration.

In logging the exploration pit a vertical profile should be made parallel with one pit wall. The contacts between geologic units should be identified and drawn on the profile, and the units sampled (if considered appropriate by the geotechnical engineer). Characteristics and types of soil or lithologic contacts should be noted. Variations within the geologic units must be described and indicated on the pit log wherever the variations occur. Sample locations should be shown in the exploration pit log and their locations written on a sample tag showing the station location and elevation. Groundwater should also be noted on the exploration pit log.

Photography and Video Logging

After the pit is logged, the shoring will be removed and the pit may be photographed or video logged at the discretion of the geotechnical engineer. Photographs and/or video logs should be located with reference to project stationing and baseline elevation. A visual scale should be included in each photo and video.

3.1.2 Soil Samples

Soil samples obtained for engineering testing and analysis, in general, are of two main categories:

- Disturbed (but representative)
- Undisturbed

Disturbed Samples

Disturbed samples are those obtained using equipment that destroy the macro structure of the soil but do not alter its mineralogical composition. Specimens from these samples can be used for determining the general lithology of soil deposits, for identification of soil components and general classification purposes, for determining grain size, Atterberg limits,and compaction characteristics of soils. Disturbed samples can be obtained with a number of different methods as summarized in Table 3-4.

Undisturbed Samples

Undisturbed samples are obtained in clay soil strata for use in laboratory testing to determine the engineering properties of those soils. Undisturbed samples of granular soils can be obtained, but often specialized procedures are required such as freezing or resin impregnation and block or core type sampling. It should be noted that the term "undisturbed" soil sample refers to the relative degree of disturbance to the soil's in-situ properties. Undisturbed samples are obtained with specialized equipment designed to minimize the disturbance to the in-situ structure and moisture content of the soils. Specimens obtained by undisturbed sampling methods are used to determine the strength, stratification, permeability, density, consolidation, dynamic properties, and other engineering characteristics of soils. Common methods for obtaining undisturbed samples are summarized in Table 3-4.

3.1.3 Soil Samplers

A wide variety of samplers are available to obtain soil samples for geotechnical engineering projects. These include standard sampling tools which are widely used as well as specialized types which may be unique to certain regions of the country to accommodate local conditions and preferences. The following discussions are general guidelines to assist geotechnical engineers and field supervisors select appropriate samplers, but in many instances local practice will control. Following is a discussion of the more commonly used types of samplers.

TABLE 3-4.

COMMON SAMPLING METHODS

Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially Undisturbed	Sands, silts, & clays	Hydraulic push with plastic lining	4
Piston	Undisturbed	Silts and clays	Hydraulic Push	1
Pitcher	Undisturbed	Stiff to hard clay, silt, sand, partially weather rock, and frozen or resin impregnated granular soil	Rotation and hydraulic pressure	<1
Denison	Undisturbed	Stiff to hard clay, silt, sand and partially weather rock	Rotation and hydraulic pressure	<1
Modified California	Disturbed	Sands, silts, clays, and gravels	Hammer driven (large split spoon)	<1
Continuous Auger	Disturbed	Cohesive soils	Drilling w/ Hollow Stem Augers	<1
Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

Split Barrel Sampler

The split-barrel (or split spoon) sampler is used to obtain disturbed samples in all types of soils. The split spoon sampler is typically used in conjunction with the *Standard Penetration Test* (SPT), as specified in AASHTO T206 and ASTM D1586, in which the sampler is driven with a 63.5-kg (140-lb) hammer dropping from a height of 760 mm (30 in). Details of the Standard Penetration Test are discussed in Section 5.1.

In general, the split-barrel samplers are available in standard lengths of 457 mm (18 in) and 610 mm (24 in) with inside diameters ranging from 38.1 mm (1.5 in) to 114.3 mm (4.5 in) in 12.7 mm (0.5 in) increments (Figure 3-7a,b). The 38.1 mm (1.5 in) inside diameter sampler is popular because correlations have been developed between the number of blows required for penetration and a few select soil properties. The larger-diameter samplers (inside diameter larger than 51 mm (2 in) are sometimes used when gravel particles are present or when more material is needed for classification tests.

The 38.1 mm (1.5 in) inside diameter standard split-barrel sampler has an outside diameter of 51 mm (2.0 in) and a cutting shoe with an inside diameter of 34.9 mm (1.375 in). This corresponds to a relatively thick-walled sampler with an area ratio [$A_r = 100 * (D_{external}^2 - D_{internal}^2) / D_{internal}^2$] of 112 percent (Hvorslev, 1949). This high area ratio disturbs the natural characteristics of the soil being sampled, thus disturbed samples are obtained.

A ball check valve incorporated in the sampler head facilitates the recovery of cohesionless materials. This valve seats when the sampler is being withdrawn from the borehole, thereby preventing water pressure on the top of the sample from pushing it out. If the sample tends to slide out because of its weight, vacuum will develop at the top of the sample to retain it.

As shown in Figure 3-8a, when the shoe and the sleeve of this type of sampler are unscrewed from the split barrel, the two halves of the barrel may be separated and the sample may be extracted easily. The soil sample is removed from the split-barrel sampler it is either placed and sealed in a glass jar, sealed in a plastic bag, or sealed in a brass liner (Figure 3-8b). Separate containers should be used if the sample contains different soil types. Alternatively, liners may be placed inside the sampler with the same inside diameter as the cutting shoe (Figure 3-9a). This allows samples to remain intact during transport to the laboratory. In both cases, samples obtained with split barrels are disturbed and therefore are only suitable for soil identification and general classification tests.

Steel or plastic sample retainers are often required to keep samples of clean granular soils in the split-barrel sampler. Figure 3-9b shows a basket shoe retainer, a spring retainer and a trap valve retainer. They are inserted inside the sampler between the shoe and the sample barrel to help retain loose or flowing materials. These retainers permit the soil to enter the sampler during driving but upon withdrawal they close and thereby retain the sample. Use of sample retainers should be noted on the boring log.

(a)

(b)

Figure 3-7. Split-Barrel Samplers: (a) Lengths of 457 mm (18 in) and 610 mm (24 in); (b) Inside diameters from 38.1 mm (1.5 in) to 89 mm (3.5 in).