Subsurface Drilling and Sampling

Course Number: GE-02-601

PDH: 4

Approved for: AK, AL, AR, GA, IA, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

New Jersey Professional Competency Approval #24GP00025600
North Carolina Approved Sponsor #S-0695
Maryland Approved Provider of Continuing Professional Competency
Indiana Continuing Education Provider #CE21800088

This document is the course text. You may review this material at your leisure before or after you purchase the course. In order to obtain credit for this course, complete the following steps:

1) Log in to My Account and purchase the course. If you don't have an account, go to New User to create an account.

2) After the course has been purchased, review the technical material and then complete the quiz at your convenience.

3) A Certificate of Completion is available once you pass the exam (70% or greater). If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained (up to one year from the purchase date).

If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH-Pro.com.

U.S. Department
of Transportation
Federal Highway
Administration

Publication No. FHWA NHI-01-031

NHI Course No. 132031

Subsurface Investigations
— Geotechnical Site Characterization

Reference Manual






National Highway Institute

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.

(a)

(b)

(c)

(d)

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.

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.

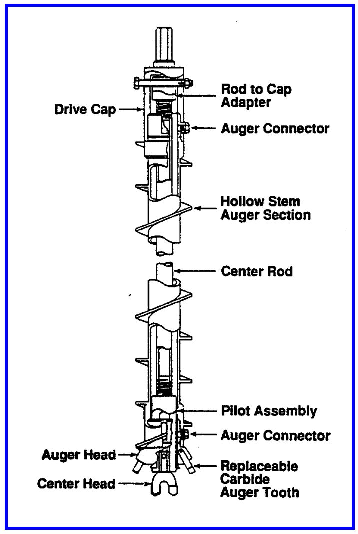


Figure 3-2. Hollow Stem Auger Components (ASTM D 4700).

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/

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.

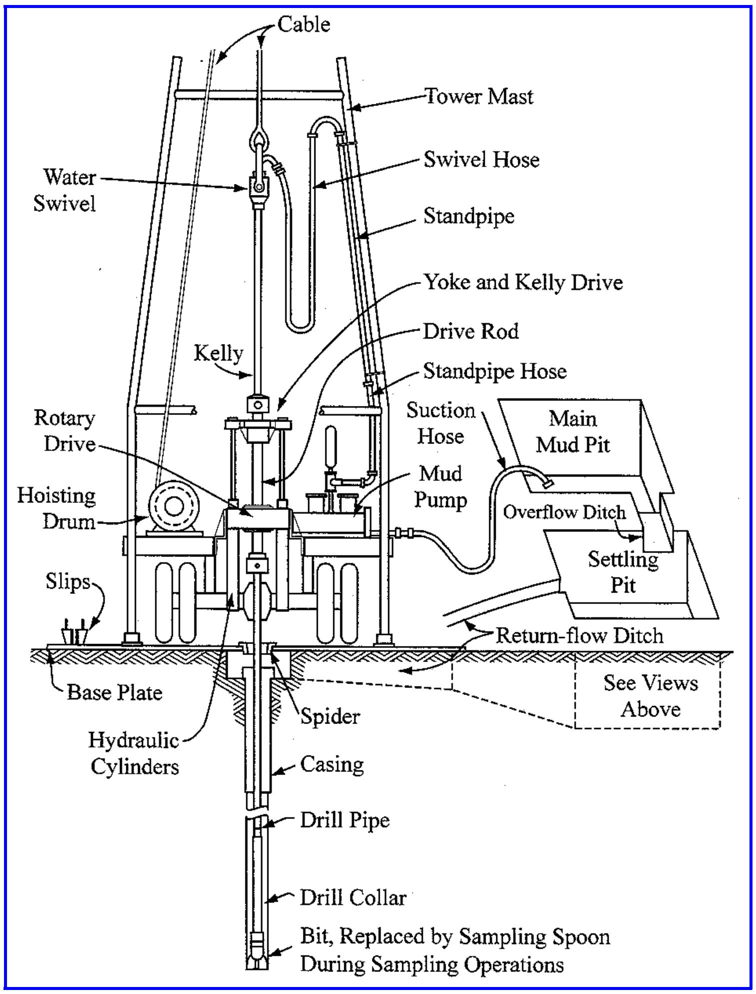


Figure 3-4. Schematic of Drilling Rig for Rotary Wash Methods (After Hvorslev, 1948).

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

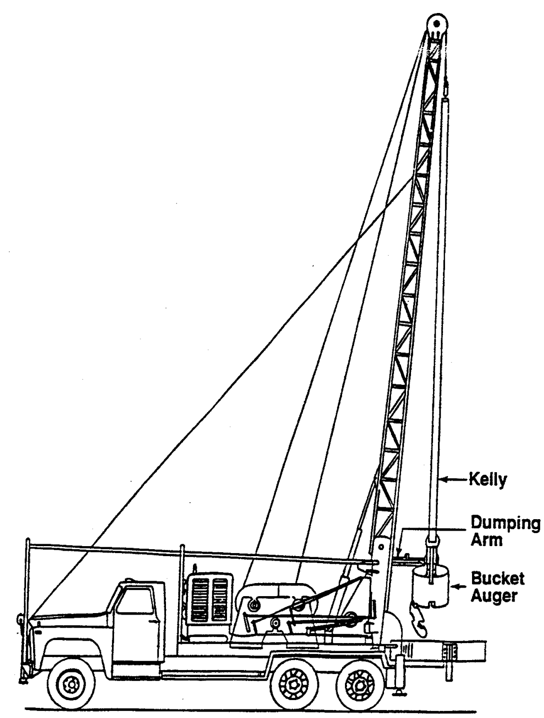


Figure 3-6. Setup of Bucket Auger & Rig (from ASTM D 4700)

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 SAMPLI NG 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).

(a) (b)

Figure 3-8. Split Barrel Sampler: (a) Open sampler with soil sample and cutting shoe; (b) Sample jar, split-spoon, shelby tube, and storage box for transport of jar samples.

(a) (b)

Figure 3-9. Split Barrel Sampler. (a) Stainless steel and brass retainer rings (b) Sample catchers.

In U.S. practice, it is normal to omit the inside liner in the split-spoon barrel. The resistance of the sampler to driving is altered depending upon whether or not a liner is used (Skempton, 1986; Kulhawy & Mayne, 1990). Therefore, in the case that a liner is used, then the boring logs used be clearly noted to reflect this variation from standard U.S. procedures, as the reported numbers in driving may affect the engineering analysis.

Thin Wall Sampler

The thin-wall tube (Shelby) sampler is commonly used to obtain relatively undisturbed samples of cohesive soils for strength and consolidation testing. The sampler commonly used (Figures 3-10) has a 76 mm (3.071 in) outside diameter and a 73 mm (2.875 in) inside diameter, resulting in an area ratio of 9 percent. Thin wall samplers vary in outside diameter between 51 mm (2.0 in) and 76 mm (3.0 in) and typically come in lengths from 700 mm (27.56 in) to 900 mm (35.43 in), as shown in Figure 3-11. Larger diameter sampler tubes are used where higher quality samples are required and sampling disturbance must be reduced. The test method for thin-walled tube sampling is described in AASHTO T 207 and ASTM D 1587.

The thin-walled tubes are manufactured using carbon steel, galvanized-coated carbon steel, stainless steel, and brass. The carbon steel tubes are often the lowest cost tubes but are unsuitable if the samples are to be stored in the tubes for more than a few days or if the inside of the tubes become rusty, significantly increasing the friction between the tube and the soil sample. In stiff soils, galvanized carbon steel tubes are preferred since carbon steel is stronger, less expensive, and galvanizing provides additional resistance to corrosion. For offshore bridge borings, salt-water conditions, or long storage times, stainless steel tubes are preferred. The thin-walled tube is manufactured with a beveled front edge for cutting a reduced-diameter sample [commonly 72 mm (2.835 in) inside diameter] to reduce friction. The thin-wall tubes can be pushed with a fixed head or piston head, as described later.

The thin-wall tube sampler should not be pushed more than the total length up to the connecting cap less 75 mm (3 in). The remaining 75 mm (3 in) of tube length is provided to accommodate the slough that accumulates to a greater or lesser extent at the bottom of the boring. The sample length is approximately 600 mm (24 in). Where low density soils or collapsible materials are being sampled, a reduced push of 300 mm (12 in) to 450 mm (18 in) may be appropriate to prevent the disturbance of the sample. The thin-walled tube sampler should be pushed slowly with a single, continuous motion using the drill rig's hydraulic system. The hydraulic pressure required to advance the thin-walled tube sampler should be noted and recorded on the log. The sampler head contains a check valve that allows water to pass through the sampling head into the drill rods. This check valve must be clear of mud and sand and should be checked prior to each sampling attempt. After the push is completed, the driller should wait at least ten minutes to allow the sample to swell slightly within the tube, then rotate the drill rod string through two complete revolutions to shear off the sample, and then slowly and carefully bring the sample to the surface. In stiff soils it is often unnecessary to rotate the sampler.

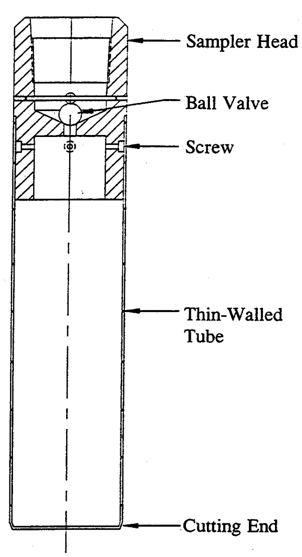


Figure 3-10. Schematic of Thin-Walled Shelby Tube (After ASTM D 4700).

Figure 3-11. Selected Sizes and Types of Thin-Walled Shelby Tubes.

After taking a thin-walled tube sample, slough or cuttings from the upper end of the tube should be removed using a cleanout tool. The length of sample recovered should be measured and the soil classified for the log. About 25-mm of material at the bottom end of the tube should be removed and the cuttings placed in a properly labeled storage jar. Both ends of the tube should then be sealed with at least a 25 mm (1 in) thick layer of microcrystalline (nonshrinking) wax after placing a plastic disk to protect the ends of the sample (Figure 3-12a). The remaining void above the top of the sample should be filled with moist sand. Plastic end caps should then be placed over both ends of the tube and electrician's tape placed over the joint between the collar of the cap and the tube and over the screw holes. The capped ends of the tubes are then dipped in molten wax. Alternatively, O-ring packers can be inserted into the sample ends and then sealed (Figure 3-12b). This may be preferable as it is cleaner and more rapid. In both cases, the sample must be sealed to ensure proper preservation of the sample. Samples must be stored upright in a protected environment to prevent freezing, desiccation, and alteration of the moisture content (ASTM D 4220).

In some areas of the country, the thin-walled tube samples are field extruded, rather than transported to the laboratory in the tube. This practice is not recommended due to the uncontrolled conditions typical of field operations, and must not be used if the driller does not have established procedures and equipment for preservation and transportation of the extruded samples. Rather, the tube sample should be transported following ASTM D 4220 guidelines to the laboratory and then carefully extruded following a standardized procedure.

The following information should be written on the top half of the tube and on the top end cap: project number, boring number, sample number, and depth interval. The field supervisor should also write on the tube the project name and the date the sample was taken. Near the upper end of the tube, the word "top" and an arrow pointing toward the top of the sample should be included. Putting sample information on both the tube and the end cap facilitates retrieval of tubes from laboratory storage and helps prevent mix-ups in the laboratory when several tubes may have their end caps removed at the same time.

Piston Sampler

The piston sampler (Figure 3-13) is basically a thin-wall tube sampler with a piston, rod, and a modified sampler head. This sampler, also known as an Osterberg or Hvorslev sampler, is particularly useful for sampling soft soils where sample recovery is often difficult although it can also be used in stiff soils.

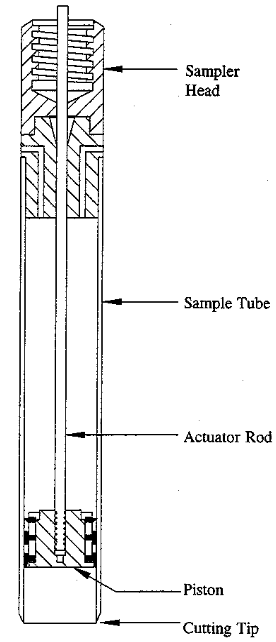
(a) (b)

Figure 3-12. Shelby Tube Sealing Methods. (a) Microcrystalline wax (b) O-ring packer.

The sampler, with its piston located at the base of the sampling tube, is lowered into the borehole. When the sampler reaches the bottom of the hole, the piston rod is held fixed relative to the ground surface and the thin-wall tube is pushed into the soil slowly by hydraulic pressure or mechanical jacking. The sampler is never driven. Upon completion of sampling, the sampler is removed from the borehole and the vacuum between the piston and the top of the sample is broken. The piston head and the piston are then removed from the tube and jar samples are taken from the top and bottom of the sample for identification purposes. The tube is then labeled and sealed in the same way as a Shelby tube described in the previous section.

The quality of the samples obtained is excellent and the probability of obtaining a satisfactory sample is high. One of the major advantages is that the fixed piston helps prevent the entrance of excess soil at the beginning of sampling, thereby precluding recovery ratios greater than 100 percent. It also helps the soil enter the sampler at a constant rate throughout the sampling push. Thus, the opportunity for 100 percent recovery is increased. The head used on this sampler also acts creates a better vacuum which helps retain the sample better than the ball valve in thin-walled tube (Shelby) samplers.

(a)



(b)

Figure 3-13. Piston Sampler: (a) Picture with thin-walled tube cut-out to show piston; (b) Schematic (After ASTM D 4700).

Pitcher Tube Sampler

The pitcher tube sampler is used in stiff to hard clays and soft rocks, and is well adapted to sampling deposits consisting of alternately hard and soft layers. This sampler is pictured in Figure 3-14 and the primary components shown in Figure 3-15a. These include an outer rotating core barrel with a bit and an inner stationary, spring-loaded, thin-wall sampling tube that leads or trails the outer barrel drilling bit, depending on the hardness of the material being penetrated.

Figure 3-14. Pitcher Tube Sampler.

When the drill hole has been cleaned, the sampler is lowered to the bottom of the hole (Figure 3-15a). When the sampler reaches the bottom of the hole, the inner tube meets resistance first and the outer barrel slides past the tube until the spring at the top of the tube contacts the top of the outer barrel. At the same time, the sliding valve closes so that the drilling fluid is forced to flow downward in the annular space between the tube and the outer core barrel and then upward between the sampler and the wall of the hole. If the soil to be penetrated is soft, the spring will compress slightly (Figure 3-15b) and the cutting edge of the tube will be forced into the soil as downward pressure is applied. This causes the cutting edge to lead the bit of the outer core barrel. If the material is hard, the spring compresses a greater amount and the outer barrel passes the tube so that the bit leads the cutting edge of the tube (Figure 3-15c). The amount by which the tube or barrel leads is controlled by the hardness of the material being penetrated. The tube may lead the barrel by as much as 150 mm (6 in) and the barrel may lead the tube by as much as 12 mm (0.5 in).

Sampling is accomplished by rotating the outer barrel at 100 to 200 revolutions per minute (rpm) while exerting downward pressure. In soft materials sampling is essentially the same as with a thin-wall sampler and the bit serves merely to remove the material from around the tube. In hard materials the outer barrel cuts a core, which is shaved to the inside diameter of the sample tube by the cutting edge and enters the tube as the sampler penetrates. In either case, the tube protects the sample from the erosive action of the drilling fluid at the base of the sampler. The filled sampling tube is then removed from the sampler and is marked, preserved, and transported in the same manner described above for thin-walled tubes.

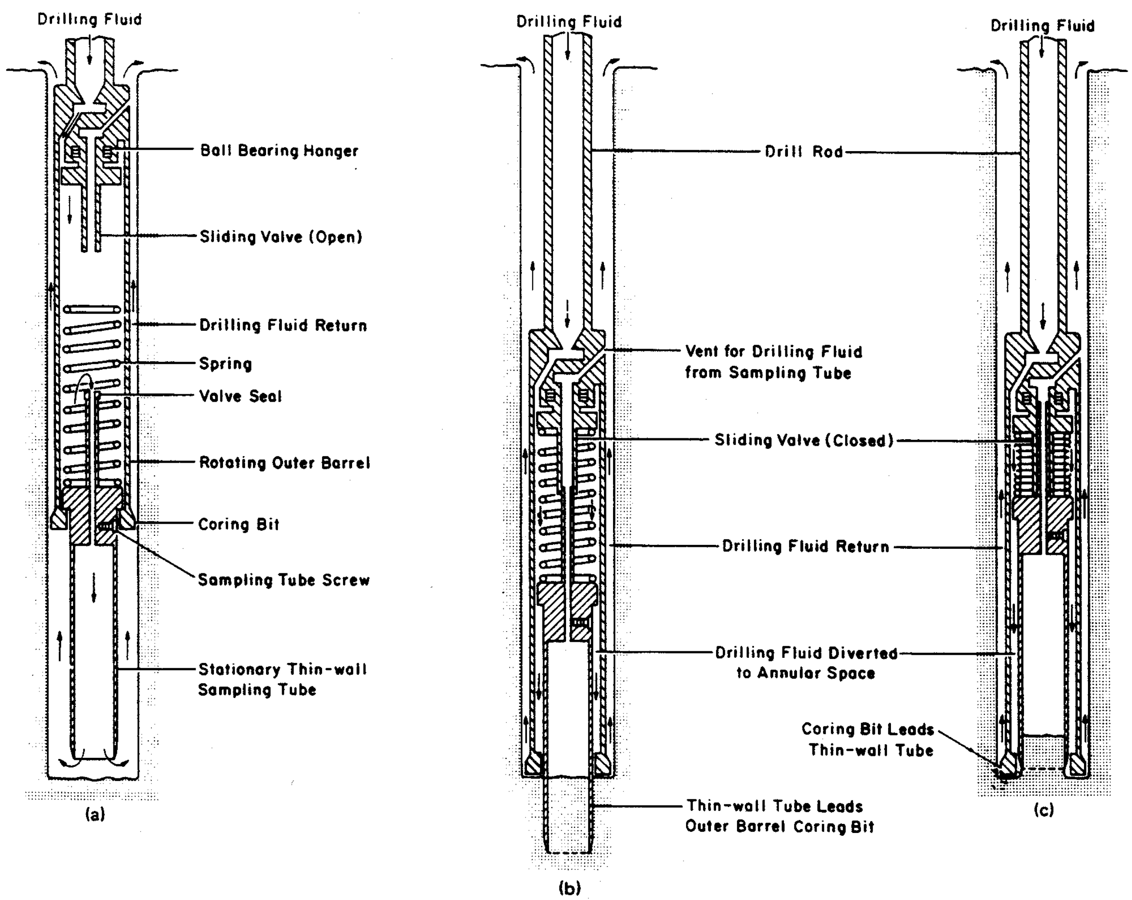


Figure 3-15. Pitcher Sampler. (a) Sampler Being Lowered into Drill Hole; (b) Sampler During Sampling of Soft Soils; (c) Sampler During Sampling of Stiff or Dense Soils (Courtesy of Mobile Drilling, Inc.).

Denison Sampler

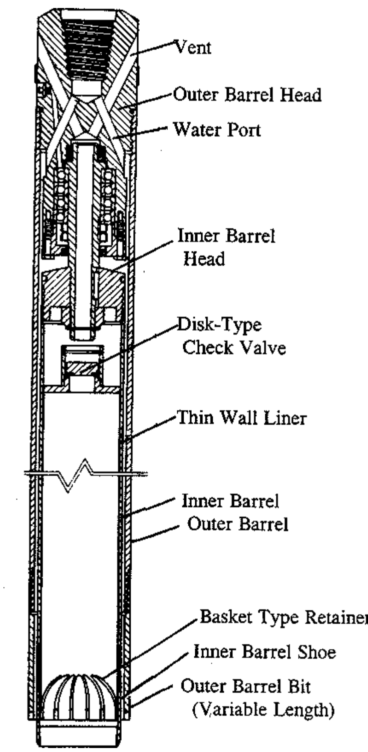


Figure 3-16. Denison Double-Tube Core Barrel Soil Sampler (Courtesy of Sprague & Henwood, Inc.)

A Denison sampler is similar to a pitcher sampler except that the projection of the sampler tube ahead of the outer rotating barrel is manually adjusted before commencement of sampling operations, rather than spring-controlled during sampler penetration. The basic components of the sampler (Figure 3-16) are an outer rotating core barrel with a bit, an inner stationary sample barrel with a cutting shoe, inner and outer barrel heads, an inner barrel liner, and an optional basket-type core retainer. The coring bit may either be a carbide insert bit or a hardened steel sawtooth bit. The shoe of the inner barrel has a sharp cutting edge. The cutting edge may be made to lead the bit by 12 mm (0.5 in) to 75 mm (3 in) through the use of coring bits of different lengths. The longest lead is used in soft and loose soils because the shoe can easily penetrate these materials and the longer penetration is required to provide the soil core with maximum protection against erosion by the drilling fluid used in the coring. The minimum lead is used in hard materials or soils containing gravel.

The Denison sampler is used primarily in stiff to hard cohesive soils and in sands, which are not easily sampled with thin-wall samplers owing to the large jacking force required for penetration. Samples of clean sands may be recovered by using driller's mud, a vacuum valve, and a basket catch. The sampler is also suitable for sampling soft clays and silts.

Modified California Sampler

The Modified California sampler is a large lined tube sampler used in the Midwest and West, but uncommon in the East and South U.S.A. The sampler is thick-walled (area ratio of 77 percent) with an outside diameter of 64 mm (2.5 in) and an inside diameter of 51 mm (2 in). It has a cutting shoe similar to the split-barrel sampler, but with an inside diameter of generally 49 mm (1.93 in). Four 102-mm (4.0-in) long brass liners with inside diameters of 49 mm (1.93 in) are used to contain the sample. In the West, the Modified California sampler is driven with standard penetration energy. The unadjusted blow count is recorded on the boring log. In the Midwest the sampler is generally pushed hydraulically. When pushed, the hydraulic pressure required to advance the Modified California sampler should be noted and recorded on the log. The driving resistance obtained using a Modified California sampler is not equal to the standard penetration test resistance and must be adjusted if comparisons are necessary.

Continuous Soil Samplers

Several types of continuous soil samplers have been developed. The conventional continuous sampler consists of a 1.5 m (5 ft) long thick-walled tube which obtains "continuous" samples of soil as hollow-stem augers are advanced into soil formations. These systems use bearings or fixed hexagonal rods to restrain or reduce rotation of the continuous sampler as the hollow-stem augers are advanced and the tube is pushed into undisturbed soil below the augers. Recently, continuous hydraulic push samplers have been developed that are quick & economical (e.g., Geoprobe, Powerprobe). These samplers have inside diameters ranging from 15 mm (0.6 in) to 38.1 mm (1.5 in). A steel mandrel is pushed into the ground at a steady rate and the soil is recovered within disposable plastic liners. These devices typically are stand alone and do not require any drilling. If hard layers are encountered, a percussive vibrating procedure is used for penetration.

The continuous samples are generally disturbed and therefore are only appropriate for visual observation, index tests, and classification-type laboratory tests (moisture, density). Continuous samplers have been shown to work well in most clayey soils and in soils with thin sand layers. Less success is typically observed when sampling cohesionless soil below the groundwater level, soft soils, or samples that swell following sampling although modifications are available to increase sample recovery. Information is limited regarding the suitability of the continuous samples for strength and consolidation tests and therefore must be used with caution.

Other Soil Samplers

A variety of special samplers are available to obtain samples of soil and soft rocks. These methods include the retractable plug, Sherbrooke, and Laval samplers. These sampling methods are used in difficult soils where the more routine methods do not recover samples.

Bulk Samples

Bulk samples are suitable for soil classification, index testing, R-value, compaction, California Bearing Ratio (CBR), and tests used to quantify the properties of compacted geomaterials. The bulk samples may be obtained using hand tools without any precautions to minimize sample disturbance. The sample may be taken from the base or walls of a test pit or a trench, from drill cuttings, from a hole dug with a shovel and other hand tools, by backhoe, or from a stockpile. The sample should be put into a container that will retain all of the particle sizes. For large samples, plastic or metal buckets or metal barrels are used; for smaller samples, heavy plastic bags that can be sealed to maintain the water content of the samples are used.

Usually, the bulk sample provides representative materials that will serve as borrow for controlled fill in construction. Laboratory testing for soil properties will then rely on compacted specimens. If the material is relatively homogeneous, then bulk samples may be taken equally well by hand or by machine. However, in stratified materials, hand excavation may be required. In the sampling of such materials it is necessary to consider the manner in which the material will be excavated for construction. If it is likely that the material will be removed layer by layer through the use of scrapers, samples of each individual material will be required and hand excavation from base or wall of the pit may be a necessity to prevent unwanted mixing of the soils. If, on the other hand, the material is to be excavated from a vertical face, then the sampling must be done in a manner that will produce a mixture having the same relative amounts of each layer as will be obtained during the borrow area excavation. This can usually be accomplished by hand-excavating a shallow trench down the walls of the test pit within the depth range of the materials to be mixed.

Block Samples

For projects where the determination of the undisturbed properties is very critical, and where the soil layers of interest are accessible, undisturbed block samples can be of great value. Of all the undisturbed testing methods discussed in this manual, properly-obtained block samples produce samples with the least amount of disturbance. Such samples can be obtained from the hillsides, cuts, test pits, tunnel walls and other exposed sidewalls. Undisturbed block sampling is limited to cohesive soils and rocks. The procedures used for obtaining undisturbed samples vary from cutting large blocks of soil using a combination of shovels, hand tools and wire saws, to using small knives and spatulas to obtain small blocks.

In addition, special down-hole block sampling methods have been developed to better obtain samples in their in-situ condition. For cohesive soils, the Sherbrooke sampler has been developed and is able to obtain samples 250 mm (9.85 in) diameter and 350 mm (13.78 in) height (Lefebvre and Poulin 1979). In-situ freezing methods for saturated granular soils and resin impregnation methods have been implemented to “lock” the soil in the in-situ condition prior to sampling. When implemented, these methods have been shown to produce high quality undisturbed samples. However, the methods are rather involved and time consuming and therefore have not seen widespread use in practice.

Once samples are obtained and transported to the laboratory in suitable containers, they are trimmed to appropriate size and shape for testing. Block samples should be wrapped with a household plastic membrane and heavy duty foil and stored in block form and only trimmed shortly before testing. Every sample must be identified with the following information: project number, boring or exploration pit number, sample number, sample depth, and orientation.

3.1.4 Sampling Interval and Appropriate Type of Sampler

In general, SPT samples are taken in both granular and cohesive soils, and thin-walled tube samples are taken in cohesive soils. The sampling interval will vary between individual projects and between regions. A common practice is to obtain split barrel samples at 0.75 m (2.5 ft) intervals in the upper 3 m (10 ft) and at 1.5 m (5 ft) intervals below 3 m (10 ft). In some instances, a greater sample interval, often 3 m (10 ft), is allowed below depths of 30 m (100 ft). In other cases, continuous samples may be required for some portion of the boring.

In cohesive soils, at least one undisturbed soil sample should be obtained from each different stratum encountered. If a uniform cohesive soil deposit extends for a considerable depth, additional undisturbed samples are commonly obtained at 3 m (10 ft) to 6 m (10 ft) intervals. Where borings are widely spaced, it may be appropriate to obtain undisturbed samples in each boring; however, for closely spaced borings, or in deposits which are generally uniform in lateral extent, undisturbed samples are commonly obtained only in selected borings. In erratic geologic formations or thin clay layers it is sometimes necessary to drill a separate boring adjacent to a previously completed boring to obtain an undisturbed sample from a specific depth which may have been missed in the first boring.

3.1.5 Sample Recovery

Occasionally, sampling is attempted and little or no material is recovered. In cases where a split barrel, or an other disturbed-type sample is to be obtained, it is appropriate to make a second attempt to recover the soil sample immediately following the first failed attempt. In such instances, the sampling device is often modified to include a retainer basket, a hinged trap valve, or other measures to help retain the material within the sampler.

In cases where an undisturbed sample is desired, the field supervisor should direct the driller to drill to the bottom of the attempted sampling interval and repeat the sampling attempt. The method of sampling should be reviewed, and the sampling equipment should be checked to understand why no sample was recovered (such as a plugged ball valve). It may be appropriate to change the sampling method and/or the sampling equipment, such as waiting a longer period of time before extracting the sampler, extracting the sampler more slowly and with greater care, etc. This process should be repeated or a second boring may be advanced to obtain a sample at the same depth.

3.1.6 Sample Identification

Every sample which is attempted, whether recovered or not, should be assigned a unique number composed of designators for the project number or name, boring number, sequential sample attempt number, and sample depth. Where tube samples are obtained, any disturbed tubes should be clearly marked with the sample identification number and the top and bottom of the sample labeled.

3.1.7 Relative Strength Tests

In addition to the visual observations of soil consistency, a pocket (hand) penetrometer can be used to estimate the strength of soil samples. The hand penetrometer estimates the unconfined strength and is suitable for firm to very stiff clay soils. A larger foot/adaptor is needed to test softer soils. It should be emphasized that this test does not produce absolute values; rather it should be used as a guide in estimating the relative strength of soils. **Values obtained with a hand penetrometer should not be used in design**. Instead, when the strength of soils (and other engineering properties) is required, in-situ tests and/or a series of laboratory tests (as described in Chapter 7) on undistrubed samples should be performed.

Another useful test device is a torvane, which is a small diameter vane shear testing device that provides an estimate of the shear strength of cohesive soils. Variable diameter vanes are available for use in very soft to very stiff cohesive soils. Again, this field test yields values that can be used for comparison purposes only, and **the torvane results should not be used in any geotechnical engineering analysis or design**.

Testing with a penetrometer or torvane should always be done in natural soils as near as possible to the center of the top or bottom end of the sample. Testing on the sides of extruded samples is not acceptable. ***Strength values obtained from pocket penetrometer or torvane should not be used for design purposes.***

3.1.8 Care and Preservation of Undisturbed Soil Samples

Each step in sampling, extruding, storing and testing introduces varying degrees of disturbance to the sample. Proper sampling, handling, and storage methods are essential to minimize disturbances. The geotechnical engineer must be cognizant of disturbance introduced during the various steps in sampling through testing. The field supervisors should be sensitized about disturbance and the consequences. A detailed discussion of sample preservation and transportation is presented in ASTM D 4220 along with a recommended transportation container design.

When tube samples are to be obtained, each tube should be examined to assure that it is not bent, that the cutting edges are not damaged, and that the interior of the tubes are not corroded. If the tube walls are corroded or irregular, or if samples are stored in tubes for long periods of time, the force required to extract the samples sometimes may exceed the shear strength of the sample causing increased sample disturbance.

All samples should be protected from extreme temperatures. Samples should be kept out of direct sunlight and should be covered with wet burlap or other material in hot weather. In winter months, special precautions should be taken to prevent samples from freezing during handling, shipping and storage. As much as is practical, the thin-walled tubes should be kept vertical, with the top of the sample oriented in the up position. If available, the thin-walled tubes should be kept in a carrier with an individual slot for each tube. Padding should be placed below and between the tubes to cushion the tubes and to prevent them from striking one another. The entire carrier should be secured with rope or cable to the body of the transporting vehicle so that the entire case will not tilt or tip over while the vehicle is in motion.

Soil sample extrusion from tubes in the field is an undesired practice and often results in sample swelling and an unnecessary high degree of disturbance. The stress relief undoubtably allows the specimens to soften and expand. The samples are also more susceptible to handling disturbances during transport to the laboratory. High-quality specimens are best obtained by soil extraction from tubes in the laboratory just prior to consolidation, triaxial, direct shear, permeability, and resonant column testing. However, to save money, some organizations extrude samples in the field in order to re-use the tubes and these samples are often wrapped in aluminum foil. Depending on the pH of the soil, the aluminum foil may react with the surface of the soil and develop a thin layer of discolored soil, thus making visual identification difficult and confusing. It may also result in changes in the moisture distribution across the sample. Even though plastic sheeting is also susceptible to reacting with the soil contacted, past observation shows that plastic has less effect than foil. Thus it is recommended that extruded soil samples which are to be preserved be wrapped in plastic sheeting and then wrapped with foil. However, if possible, samples should not be extracted from tubes in the field in order to minimize swelling, disturbance, transport, and handling issues.

Storage of undisturbed samples (in or out of tubes) for long periods of time under any condition is not recommended. Storage exceeding one month may substantially alter soil strength & compressibility as measured by lab tests.

3.2 EXPLORATION OF ROCK

The methods used for exploration and investigation of rock include:

- Drilling
- Exploration pits (test pits)
- Geologic mapping
- Geophysical methods

Core drilling which is used to obtain intact samples of rock for testing purposes and for assessing rock quality and structure, is the primary investigative method. Test pits, non-core drilling, and geophysical methods are often used to identify the top of rock.

Geophysical methods such as seismic refraction and ground penetrating radar (GPR) may be used to obtain the depth to rock. Finally, geologic mapping of rock exposures or outcrops provides a means for assessing the composition and discontinuities of rock strata on a large scale which may be valuable for many engineering applications particularly rock slope design. This section contains a discussion of drilling and geologic mapping. Some geophysical methods are discussed in section 5.7.

3.2.1 Rock Drilling and Sampling

Where borings must extend into weathered and unweathered rock formations, rock drilling and sampling procedures are required. The use of ISRM (International Society for Rock Mechanics) Commission on Standardization of Laboratory and Field Tests (1978, 1981) guidelines are recommended for detailed guidance for rock drilling, coring, sampling, and logging of boreholes in rock masses. This section provides an abbreviated discussion of rock drilling and sampling methods.

Defining the top of rock from drilling operations can be difficult, especially where large boulders exist, below irregular residual soil profiles, and in karst terrain. In all cases, the determination of the top of rock must be done with care, as an improper identification of the top of rock may lead to miscalculated rock excavation volume or erroneous pile length. As per ASTM D 2113, core drilling procedures are used when formations are encountered that are too hard to be sampled by soil sampling methods. A penetration of 25 mm (1 in) or less by a 51 mm (2 in) diameter split-barrel sampler following 50 blows using standard penetration energy or other criteria established by the geologist or engineer should indicate that soil sampling methods are not applicable and rock drilling or coring is required. In many instances, geophysical methods, such as seismic refraction, can be used to assist in evaluating the top of rock elevations in an expedient and economical manner. The refraction data can also provide information between confirmatory boring locations.

3.2.2 Non-Core (Destructive) Drilling

Non-core rock drilling is a relatively quick and inexpensive means of advancing a boring which can be considered when an intact rock sample is not required. Non-core drilling is typically used for determining the top of rock and is useful in solution cavity identification in karstic terrain. Types of non-core drilling include air-track drilling, down-the-hole percussive drilling, rotary tricone (roller bit) drilling, rotary drag bit drilling, and augering with carbide-tipped bits in very soft rocks. Drilling fluid may be water, mud, foam, or compressed air. Caution should be exercised when using these methods to define the top of soft rock since drilling proceeds rapidly, and cuts weathered and soft rock easily, frequently misrepresenting the top of rock for elevation or pile driving applications.

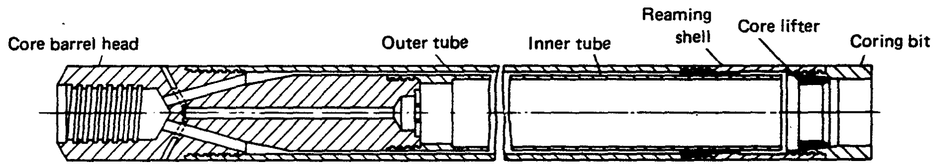
Because intact rock samples are not recovered in non-core drilling, it is particularly important for the field supervisor to carefully record observations during drilling. The following information pertaining to drilling characteristics should be recorded in the remarks section of the boring log:

- Penetration rate or drilling speed in minutes per 0.3 meter (1 ft)
- Dropping of rods
- Changes in drill operation by driller (down pressures, rotation speeds, etc.)
- Changes in drill bit condition
- Unusual drilling action (chatter, bouncing, binding, sudden drop)
- Loss of drilling fluid, color change of fluid, or change in drilling pressure

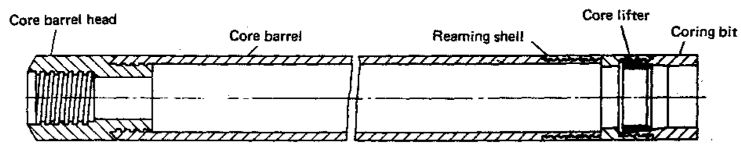
3.2.3 Types of Core Drilling

A detailed discussion of diamond core drilling is presented in AASHTO T 225 and ASTM D 2113. Types of core barrels may be single-tube, double-tube, or triple-tube, as shown in Figures 3-17a,b,c. Table 3-5 presents various types of core barrels available on the market. The standard is a double-tube core barrel, which offers better recovery by isolating the rock core from the drilling fluid stream and consists of an inner and outer core barrel as pictured in Figure 3-18. The inner tube can be rigid or fixed to the core barrel head and rotate around the core or it can be mounted on roller bearings which allow the inner tube to remain stationary while the outer tube rotates. The second or swivel type core barrel is less disturbing to the core as it enters the inner barrel and is useful in coring fractured and friable rock. In some regions only triple tube core barrels are used in rock coring. In a multi-tube system, the inner tube may be longitudinally split to allow observation and removal of the core with reduced disturbance.

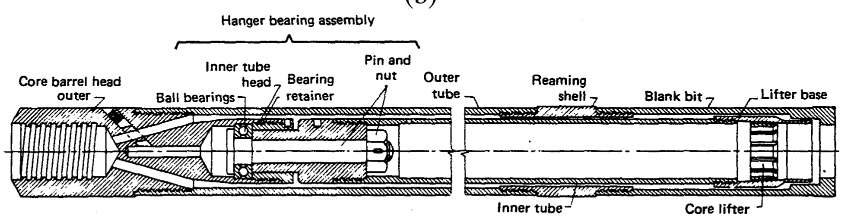
Rock coring can be accomplished with either conventional or wireline equipment. With conventional drilling equipment, the entire string of rods and core barrel are brought to the surface after each core run to retrieve the rock core. Wireline drilling equipment allows the inner tube to be uncoupled from the outer tube and raised rapidly to the surface by means of a wire line hoist. The main advantage of wireline drilling over conventional drilling is the increased drilling production resulting from the rapid removal of the core from the hole which, in turn, decreases labor costs. It also provides improved quality of recovered core, particularly in soft rock, since this method avoids rough handling of the core barrel during retrieval of the barrel from the borehole and when the core barrel is opened. (Drillers often hammer on the core barrel to break it from the drill rods and to open the core barrel, causing the core to break.) Wireline drilling can be used on any rock coring job, but typically, it is used on projects where bore holes are greater than 25 m deep and rapid removal of the core from the hole has a greater effect on cost. Wireline drilling is also an effective method for both rock and soil exploration though cobbles or boulders, which tend to shift and block off the bore hole.



(a)



(b)



(c)

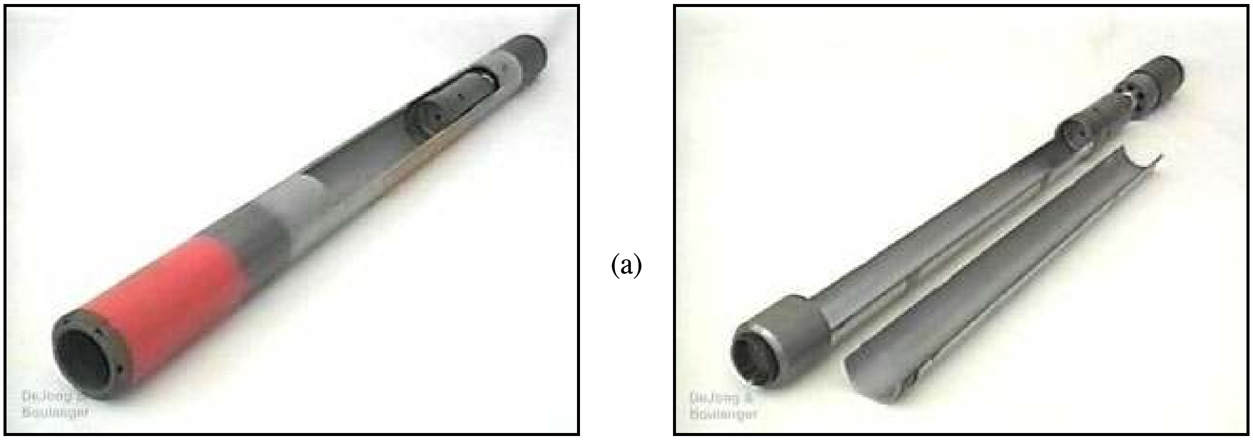
Figure 3-17. (a) Single Tube Core Barrel; (b) Rigid Type Double Tube Core Barrel; (c) Swivel Type Double Tube Core Barrel, Series "M" with Ball Bearings (Courtesy of Sprague & Henwood, Inc.).

TABLE 3-5.

DIMENSIONS OF CORE SIZES

(after Christensen Dia-Min Tools, Inc.)

Size	Diameter of Core mm (in)	Diameter of Borehole mm (in)
EX,EXM	21.5 (0.846)	37.7 (1.484)
EWD3	21.2 (0.835)	37.7 (1.484)
AX	30.1 (1.185)	48.0 (1.890)
AWD4, AWD3	28.9 (1.138)	48.0 (1.890)
AWM	30.1 (1.185)	48.0 (1.890)
AQ Wireline, AV	27.1 (1.067)	48.0 (1.890)
BX	42.0 (1.654)	59.9 (2.358)
BWD4, BWD3	41.0 (1.614)	59.9 (2.358)
BXB Wireline, BWC3	36.4 (1.433)	59.9 (2.358)
BQ Wireline, BV	36.4 (1.433)	59.9 (2.358)
NX	54.7 (2.154)	75.7 (2.980)
NWD4,NWD3	52.3 (2.059)	75.7 (2.980)
NXB Wireline, NWC3	47.6 (1.874)	75.7 (2.980)
NQ Wireline, NV	47.6 (1.874)	75.7 (2.980)
HWD4,HXB Wireline, HWD3	61.1 (2.406)	92.7 (3.650)
HQ Wireline	63.5 (2.500)	96.3 (3.791)
CP, PQ Wireline	85.0 (3.346)	122.6 (4.827)



(a)

(a) (b)

Figure 3-18. Double Tube Core Barrel. (a) Outer barrel assembly (b) Inner barrel assembly.

Although NX is the size most frequently used for engineering explorations, larger and smaller sizes are in use. Generally, a larger core size will produce greater recovery and less mechanical breakage. Because of their effect on core recovery, the size and type of coring equipment used should be carefully recorded in the appropriate places on the boring log.

The length of each core run should be limited to 3 m maximum. Core run lengths should be reduced to 1.5 m (5 ft), or less, just below the rock surface and in highly fractured or weathered rock zones. Shorter core runs often reduce the degree of damage to the core and improve core recovery in poor quality rock.

Figure 3-19. Coring Bits. From left to right: Diamond, Carbide, & Sawtooth.

Coring Bits

The coring bit is the bottommost component of the core barrel assembly. It is the grinding action of this component that cuts the core from the rock mass. Three basic categories of bits are in use: diamond, carbide insert, and sawtooth (Figure 3-19). Coring bits are generally selected by the driller and are often approved by the geotechnical engineer. Bit selection should be based on general knowledge of drill bit performance for the expected formations and the proposed drilling fluid.

Diamond coring bits which may be of surface set or impregnated-diamond type are the most versatile since they can produce high-quality cores in rock materials ranging from soft to extremely hard. Compared to other types, diamond bits in general permit more rapid coring and as noted by Hvorslev (1949), exert lower torsional stresses on the core. Lower torsional stresses permit the retrieval of longer cores and cores of small diameter. The wide variation in the hardness, abrasiveness, and degree of fracturing encountered in rock has led to the design of bits to meet specific conditions known to exist or encountered at given sites. Thus, wide variations in the quality, size, and spacing of diamonds, in the composition of the metal matrix, in the face contour, and in the type and number of waterways are found in bits of this type. Similarly, the diamond content and the composition of the metal matrix of impregnated bits are varied to meet differing rock conditions.

Carbide bits use tungsten carbide in lieu of diamonds and are of several types (the standard type is shown in Figure 3-19). Bits of this type are used to core soft to medium-hard rock. They are less expensive than diamond bits. However, the rate of drilling is slower than with diamond bits.

Sawtooth bits consist of teeth cut into the bottom of the bit. The teeth are faced and tipped with a hard metal alloy such as tungsten carbide to provide water resistance and thereby to increase the life of the bit. Although these bits are less expensive than diamond bits, they do not provide as high a rate of coring and do not have a salvage value. The saw tooth bit is used primarily to core overburden and very soft rock.

An important feature of all bits which should be noted is the type of waterways provided in the bits for passage of drilling fluid. Bits are available with so-called "conventional" waterways, which are passages cut on the interior face of the bit), or with bottom discharge waterways, which are internal and discharge at the bottom face of the bit behind a metal skirt separating the core from the discharge fluid. Bottom discharge bits should be used when coring soft rock or rock having soil-filled joints to prevent erosion of the core by the drilling fluid before the core enters the core barrel.

Drilling Fluid

In many instances, clear water is used as the drilling fluid in rock coring. If drilling mud is required to stabilize collapsing holes or to seal zones when there is loss of drill water, the design engineer, the geologist and the geotechnical engineer should be notified to confirm that the type of drilling mud is acceptable. Drilling mud will clog open joints and fractures, which adversely affects permeability measurements and piezometer installations. Drilling fluid should be contained in a settling basin to remove drill cuttings and to allow recirculation of the fluid. Generally, drilling fluids can be discharged onto the ground surface. However, special precautions or handling may be required if the material is contaminated with oil or other substances and may require disposal off site. Water flow over the ground surface should be avoided, as much as possible.

3.2.4 Observation During Core Drilling

Drilling Rate/Time

The drilling rate should be monitored and recorded on the boring log in the units of minutes per 0.3 m (1 ft). Only time spent advancing the boring should be used to determine the drilling rate.

Core Photographs

Cores in the split core barrel should be photographed immediately upon removal from the borehole. A label should be included in the photograph to identify the borehole, the depth interval and the number of the core runs. It may be desirable to get a "close-up" of interesting features in the core. Wetting the surface of the recovered core using a spray bottle and/or sponge prior to photographing will often enhance the color contrasts of the core.

A tape measure or ruler should be placed across the top or bottom edge of the box to provide a scale in the photograph. The tape or ruler should be at least 1 meter (3 ft) long, and it should have relatively large, high contrast markings to be visible in the photograph.

A color bar chart is often desirable in the photograph to provide indications of the effects of variation in film age, film processing, and the ambient light source. The photographer should strive to maintain uniform light conditions from day to day, and those lighting conditions should be compatible with the type of film selected for the project.

Rock Classification

The rock type and its inherent discontinuities, joints, seams, and other facets should be documented. See Section 4.7 for a discussion of rock classification and other information to be recorded for rock core.

Recovery

The core recovery is the length of rock core recovered from a core run, and the recovery ratio is the ratio of the length of core recovered to the total length of the core drilled on a given run, expressed as either a fraction or a percentage. Core length should be measured along the core centerline. When the recovery is less than the length of the core run, the non-recovered section should be assumed to be at the end of the run unless there is reason to suspect otherwise (e.g., weathered zone, drop of rods, plugging during drilling, loss of fluid, and rolled or recut pieces of core). Non-recovery should be marked as NCR (no core recovery) on the boring log, and entries should not be made for bedding, fracturing, or weathering in that interval.

Recoveries greater than 100 percent may occur if core that was not recovered during a run is subsequently recovered in a later run. These should be recorded and adjustments to data should not be made in the field.

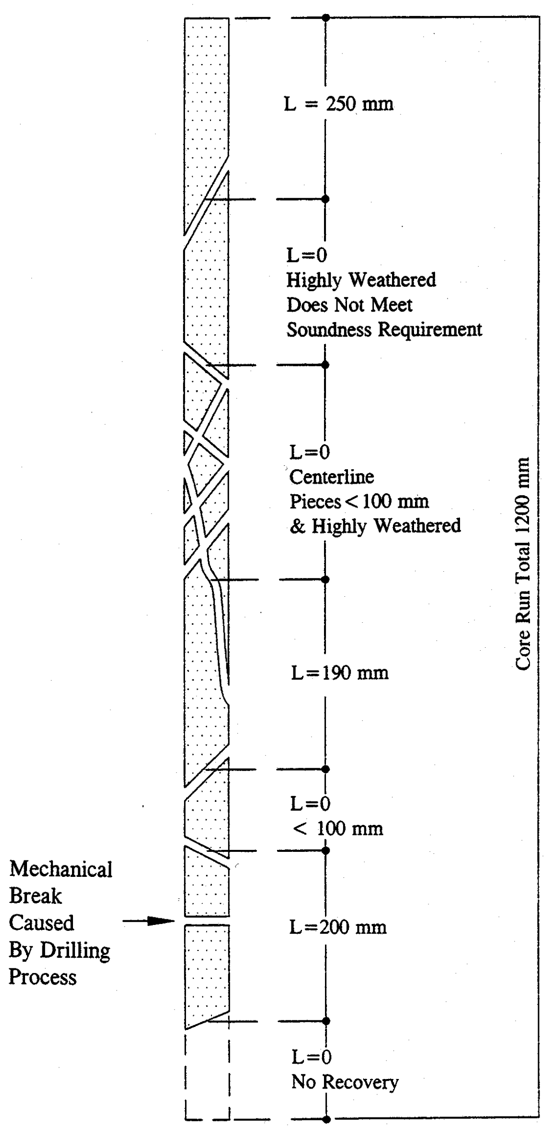
Rock Quality Designation (RQD)

The RQD is a modified core recovery percentage in which the lengths of all pieces of sound core over 100 mm (4 in) long are summed and divided by the length of the core run. The correct procedure for measuring RQD is illustrated in Figure 3-20. The RQD is an index of rock quality in that problematic rock that is highly weathered, soft, fractured, sheared, and jointed typically yields lower RQD values. Thus, RQD is simply a measurement of the percentage of "good" rock recovered from an interval of a borehole. It should be noted that the original correlation for RQD (Rock Quality Designation) reported by Deere (1963) was based on measurements made on NX-size core. Experience in recent years reported by Deere and Deere (1989) indicates that cores with diameters both slightly larger and smaller than NX may be used for computing RQD. The wire line cores using NQ, HQ, and PQ are also considered acceptable. The smaller BQ and BX sizes are discouraged because of a higher potential for core breakage and loss.

<u>Length Measurements of Core Pieces</u>

The same piece of core could be measured three ways: along the centerline, from tip to tip, or along the fully circular barrel section (Figure 3-21). The recommended procedure is to measure the core length along the centerline. This method is advocated by the International Society for Rock Mechanics (ISRM), Commission on Standardization of Laboratory and Field Tests (1978, 1981). The centerline measurement is preferred because: (1) it results in a standardized RQD not dependent on the core diameter, and (2) it avoids unduly penalizing of the rock quality for cases where the fractures parallel the borehole and are cut by a second set.

Core breaks caused by the drilling process should be fitted together and counted as one piece. Drilling breaks are usually evidenced by rough fresh surfaces. For schistose and laminated rocks, it is often difficult to discern the difference between natural breaks and drilling breaks. When in doubt about a break, it should be considered as natural in order to be conservative in the calculation of RQD for most uses. It is noted that this practice would not be conservative when the RQD is used as part of a ripping or dredging estimate.



$$RQD = \frac{\sum \text{Length of Sound Core Pieces} > 100\,\text{mm}}{\text{Total Core Run Length}}$$

$$RQD = \frac{250 + 190 + 200}{1200} \times 100\%$$

RQD = 53% (Fair)

Rock Quality Description

RQD (Rock Quality Designation)	Description of Rock Quality
0 - 25%	Very Poor
25 - 50%	Poor
50 - 75%	Fair
75 - 90%	Good
90 - 100%	Excellent

Figure 3-20. Modified Core Recovery as an Index of Rock Mass Quality.

Assessment of Soundness

Pieces of core which are not "hard and sound" should not be counted for the RQD even though they possess the requisite 100 mm (3.94 in) length. The purpose of the soundness requirement is to downgrade the rock quality where the rock has been altered and weakened either by agents of surface weathering or by hydrothermal activity. Obviously, in many instances, a judgment decision must be made as to whether or not the degree of chemical alteration is sufficient to reject the core piece.

One commonly used procedure is not to count a piece of core if there is any doubt about its meeting the soundness requirement (because of discolored or bleached grains, heavy staining, pitting, or weak grain boundaries). This procedure may unduly penalize the rock quality, but it errs on the side of conservatism. A second procedure which occasionally has been used is to include the altered rock within the RQD summed percentage, but to indicate by means of an asterisk (RQD*) that the soundness requirements have not been met. The advantage of the method is that the RQD* will provide some indication of the rock quality with respect to the degree of fracturing, while also noting its lack of soundness.

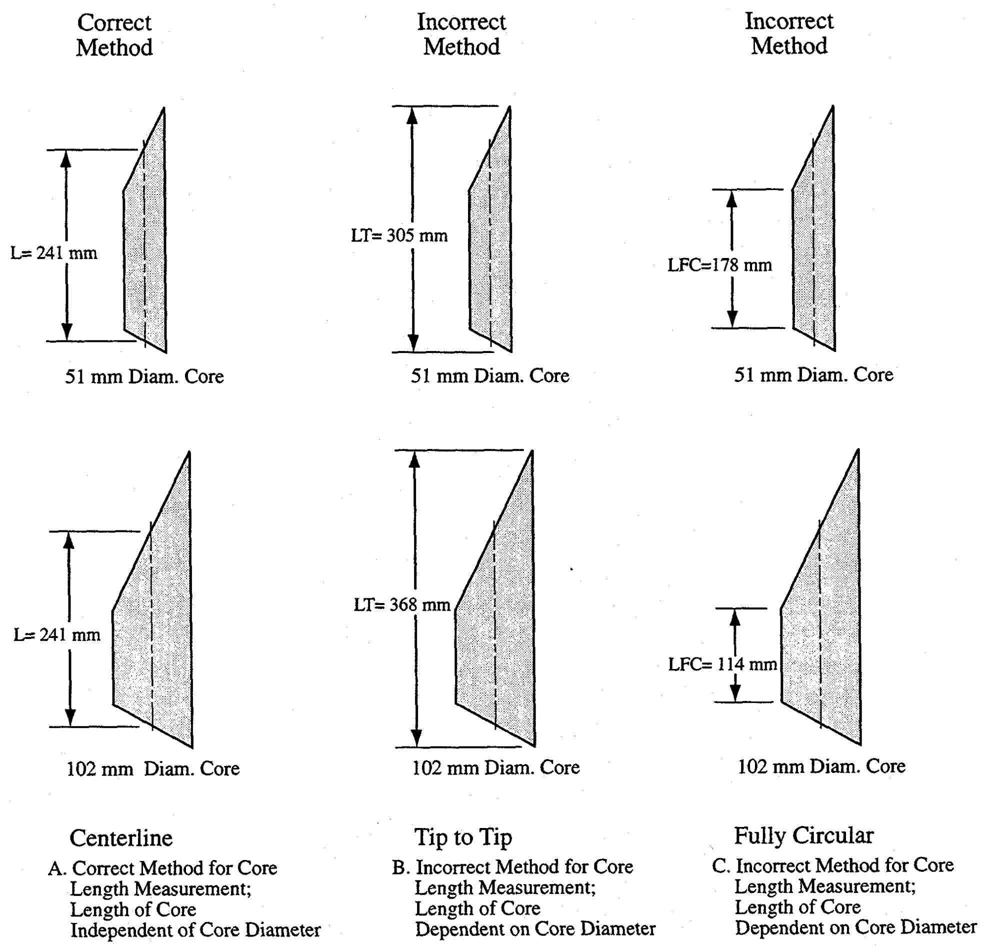


Figure 3-21. Length Measurement of Core RQD Determination.

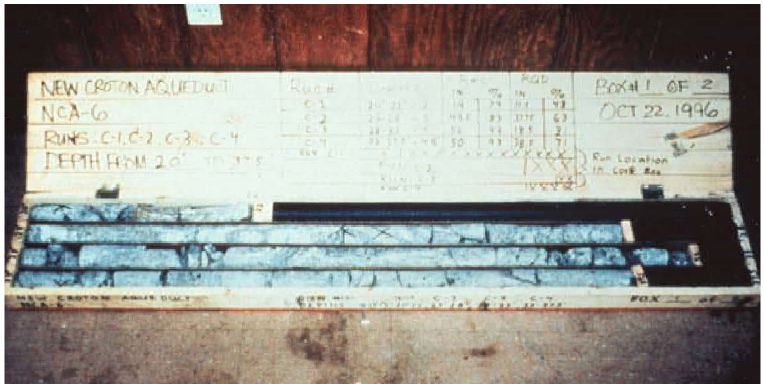
Drilling Fluid Recovery

The loss of drilling fluid during the advancement of a boring can be indicative of the presence of open joints, fracture zones or voids in the rock mass being drilled. Therefore, the volumes of fluid losses and the intervals over which they occur should be recorded. For example, "no fluid loss" means that no fluid was lost except through spillage and filling the hole. "Partial fluid loss" means that a return was achieved, but the amount of return was significantly less than the amount being pumped in. "Complete water loss" means that no fluid returned to the surface during the pumping operation. A combination of opinions from the field personnel and the driller on this matter will result in the best estimate.

Core Handling and Labeling

Rock cores from geotechnical explorations should be stored in structurally sound core boxes made of wood or corrugated waxed cardboard (Figure 3-22). Wooden boxes should be provided with hinged lids, with the hinges on the upper side of the box and a latch to secure the lid in a closed position.

Cores should be handled carefully during transfer from barrel to box to preserve mating across fractures and fracture-filling materials. Breaks in core that occur during or after the core is transferred to the core box



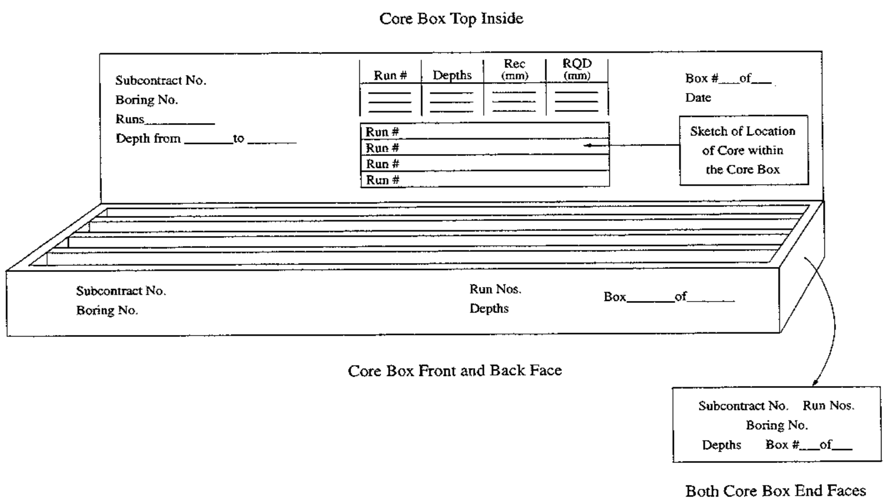


Figure 3-22. Core Box for Storage of Recovered Rock and Labeling.

should be refitted and marked with three short parallel lines across the fracture trace to indicate a mechanical break. Breaks made to fit the core into the core box and breaks made to examine an inner core surface should be marked as such. These deliberate breaks should be avoided unless absolutely necessary. Cores should be placed in the boxes from left to right, top to bottom. When the upper compartment of the box is filled, the next lower (or adjoining) compartment (and so on until the box is filled) should be filled, beginning in each case at the left-hand side. The depths of the top and bottom of the core and each noticeable gap in the formation should be marked by a clearly labeled wooden spacer block.

If there is less than 100 percent core recovery for a run, a cardboard tube spacer of the same length as the core loss should be placed in the core box either at the depth of core loss, if known, or at the bottom of the run. The depth of core loss, if known, or length of core loss should be marked on the spacer with a black permanent marker. The core box labels should be completed using an indelible black marking pen. An example of recommended core box markings is given in Figure 3-22. The core box lid should have identical markings both inside and out, and both exterior ends of the box should be marked as shown. For angled borings, depths marked on core boxes and boring logs should be those measured along the axis of the boring. The angle and orientation of the boring should be noted on the core box and the boring log.

Care and Preservation of Rock Samples

A detailed discussion of sample preservation and transportation is presented in ASTM D 5079. Four levels of sample protection are identified:

- Routine care
- Special care
- Soil-like care
- Critical care

Most geotechnical explorations will use routine care in placing rock core in core boxes. ASTM D 5079 suggests enclosing the core in a loose-fitting polyethylene sleeve prior to placing the core in the core box. Special care is considered appropriate if the moisture state of the rock core (especially shale, claystone and siltstone) and the corresponding properties of the core may be affected by exposure. This same procedure can also apply if it is important to maintain fluids other than water in the sample. Critical care is needed to protect samples against shock and vibration or variations in temperature, or both. For soil-like care, samples should be treated as indicated in ASTM D 4220.

Figure 3-23. Rock Formations Showing Joints, Cut Slopes, Planes, and Stabilization Measures.

3.2.5 Geologic Mapping

Geologic mapping is briefly discussed here, with a more thorough review in FHWA Module 5 (Rock Slopes). Geologic mapping is the systematic collection of local, detailed geologic data, and, for engineering purposes, is used to characterize and document the condition of a rock mass or outcrop. The data derived from geologic mapping is a portion of the data required for design of a cut slope or for stabilization of an existing slope. Geologic mapping can often provide more extensive and less costly information than drilling. The guidelines presented are intended for rock and rock-like materials. Soil and soil-like materials, although occasionally mapped, are not considered in this section.

Qualified personnel trained in geology or engineering geology should perform the mapping or provide supervision and be responsible for the mapping activities and data collection. The first step in geologic mapping is to review and become familiar with the local and regional geology from published and non-published reports, maps and investigations. The mapping team should be knowledgeable of the rock units and structural and historical geologic aspects of the area. A team approach (minimum of two people, the "buddy system") is recommended for mapping as a safety precaution when mapping in isolated areas.

Procedures for mapping are outlined in an FHWA Manual (1989) on rock slope design, excavation and stabilization and in ASTM D 4879. The first reference describes the parameters to be considered when mapping for cut slope design, which include:

- Discontinuity type
- Discontinuity orientation
- Discontinuity in filling
- Surface properties
- Discontinuity spacing
- Persistence
- Other rock mass parameters

These parameters can be easily recorded on a structural mapping coding form shown in Figure 3-24. ASTM D 4879 also describes similar parameters and presents commonly used geologic symbols for mapping purposes. It also presents a suggested report outline. Presentation of discontinuity orientation data can be graphically plotted using stereographic projections. These projections are very useful in rock slope stability analyses. Chapter 3 (Graphical presentation of geological data) in the FHWA manual cited above describes the stereographic projection methods in detail.

3.3 BORING CLOSURE

All borings should be properly closed at the completion of the field exploration. This is typically required for safety considerations and to prevent cross contamination of soil strata and groundwater. Boring closure is particularly important for tunnel projects since an open borehole exposed during tunneling may lead to uncontrolled inflow of water or escape of compressed air.

In many parts of the country, methods to be used for the closure of boreholes are regulated by state agencies**.** National Cooperative Highway Research Program Report No. 378 (1995) titled "Recommended Guidelines for Sealing Geotechnical Holes" contains extensive information on sealing and grouting. The regulations in general, require that any time groundwater or contamination is encountered the borehole be grouted using a mixture of powdered bentonite, Portland cement and potable water. Some state agencies require grouting of all boreholes exceeding a certain depth. The geotechnical engineer and the field supervisor should be knowledgeable about local requirements prior to commencing the borings.

It is good practice to grout all boreholes. Holes in pavements and slabs should be filled with quick setting concrete, or with asphaltic concrete, as appropriate. Backfilling of boreholes is generally accomplished using a grout mixture . The grout mix is normally pumped though drill rods or other pipes inserted into the borehole. In boreholes filled with water or other drilling fluids the tremied grout will displace the drill fluid. Provisions should be made to collect and dispose of all displaced drill fluid and waste grout.

3.4 SAFETY GUIDELINES FOR GEOTECHNICAL BORINGS

All field personnel, including geologists, engineers, technicians, and drill crews, should be familiar with the general health and safety procedures, as well as any additional requirements of the project or governing agency.

	Day	Month	Year		Discontinuity data
Date				Inspector	Sheet No. of

NATURE AND ORIENTATION OF DISCONTINUITY

Station or No.	Type	Dip	Dip direction	Persistence	Aperture	Nature of filling	Strength of filling	Surface Roughness	Trend of lineation	Waviness wavelength	Waviness amplitude	Water/ Flow	Remarks

Type

0. Fault zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear
6. Fissure
7. Tension crack
8. Foliation
9. Bedding

Persistence

1. Very low persistence	<1 m
2. Low Persistence	1-3 m
3. Medium persistence	3-10 m
4. High persistence	10-20 m
5. Very high persistence	>20 m

Aperture

1. Very tight (<0.1 mm)
2. Tight (0.1-0.25 mm)
3. Partly open (0.25-0.5 mm)
4. Open (0.5-2.5 mm)
5. Moderately wide (2.5-10 mm)
6. Wide (>10 mm)
7. Very wide (1-10 cm)
8. Extremely wide (10 - 100 cm)
9. Cavernous

Nature of filling

1. Clean
2. Surface staining
3. Non-cohesive
4. Inactive clay or clay matrix
5. Swelling clay or clay matrix
6. Cemented
7. Chlorite, talc, or gypsum
8. Others - specify

Compressive strength of infilling

	MPa
1. Very strong rock	>200
2. Strong rock	100-200
3. Moderately strong rock	50-100
4. Moderately weak rock	25-50
5. Very weak rock	1-25
6. Very stiff soil	0.6-1.0
7. Stiff soil	0.15-0.6
8. Firm soil	0.08-0.15
9. Soft soil	0.04-0.08
10. Very soft soil	<0.04

Roughness

1. Rough (or irregular), stepped
2. Smooth, stepped
3. Slickensided stepped
4. Rough (or irregular), undulating
5. Smooth, undulating
6. Slickensided, undulating
7. Rough (or irregular), planar
8. Smooth, planar
9. Slickensided

Water Flow (Infilled)

Seepage Rating	Description
I	The discontinuity is very tight and dry; water flow along it does not appear possible.
II	The discontinuity is dry with no evidence of water flow.
III	The discontinuity is dry but shows evidence of water flow, i.e. rust staining, etc.
IV	The discontinuity is damp but no free water is present.
V	The discontinuity shows seepage, occasional drops of water, but no continuous flow.
VI	The discontinuity shows a continuous flow of water (Estimate l/min and describe pressure, i.e. low, medium, high).

Water Flow (Filled)

- W1 The filling materials are heavily consolidated and dry; significant flow appears unlikely due to very low permeability.
- W2 The filling materials are damp, but no free water is present.
- W3 The filling materials are wet; occasional drops of water.
- W4 The filling materials show signs of outwash, continuous flow of water (estimate liters/minute).
- W5 The filling materials are washed out locally; considerable water flow along out-wash channels (estimate liters/minute and describe pressure, i.e. low, medium, high).

Figure 3-24. **(a) Structural Mapping Coding Form for Discontinuity Survey Data.**

ROCK MASS DESCRIPTION

GENERAL INFORMATION

Subdivision | Km | Date: Day, Month, Year | Inspector

Locality Type

1. Natural exposure
2. Construction excavation
3. Trial pit
4. Trench
5. Adit
6. Tunnel

Slope Length

Slope Height

No. of supplementary sheets of discontinuity data

Sketch | Photograph

0. No
1. Yes

SLOPE STABILITY ASSESSMENT

Inspection Rating

1. **Urgent** - recent fall/visual evidence of significant movement - hazard
2. **Priority** - evidence of movement or change in conditions from previous years
3. **Observe** - identification of a specific area of potential instability
4. **OK** - no potential instability

Required Action

1. **Inspect** - inspection required within the new three months approximately - state time
2. **Immediate Work** - stabilization work of specific location required in current year - state time
3. **Slow Order** - traffic at restricted speed/stopped/watchman until stabilization work carried out
4. **1-5 Years** - possible stabilization - state time
5. **Long-term** - substantial stabilization program
6. **No Action**

Assessment of Site Conditions

1. Open fractures indicative of past movement.
2. Fractures oriented such that blocks could slide or topple on to the track.
3. Evidence of recent movement.
4. Probability that rockfall/slide would be of sufficient size to reach tracks and cause derailment.
5. Serious consequence of derailment (e.g. track on narrow bench or supported by retaining wall).

Remarks (consequences, stabilization, rockfalls, slide fence)

ROCK MATERIAL INFORMATION

Color

1. Light
2. Dark

1. Pinkish
2. Reddish
3. Yellowish
4. Brownish
5. Olive
6. Greenish
7. Bluish
8. Greyish

1. Pink
2. Red
3. Yellow
4. Brown
5. Olive
6. Green
7. Blue
8. White
9. Grey
0. Black

Grain Size

1. Very coarse (>60 mm)
2. Coarse (2-60 mm)
3. Medium (60 μ-20 mm)
4. Fine (2-60 μ)
5. Very fine (<2μ)

Compressive strength

	MPa
1. Very strong rock	>200
2. Strong rock	100-200
3. Moderately strong rock	50-100
4. Moderately weak rock	25-50
5. Very weak rock	1-25
6. Very stiff soil	0.6-1.0
7. Stiff soil	0.15-0.6
8. Firm soil	0.08-0.15
9. Soft Soil	0.04-0.08
10. Very soft soil	<0.04

Method of determining compressive strength

1. Measured
2. Assessed

Rock Type

Qualifying terms to decribe rock

ROCK MASS INFORMATION

Fabric

1. Blocky
2. Tabular
3. Columnar

Block size

1. Very large (>8 m³)
2. Large (0.2-8 m³)
3. Medium (0.008-0.2 m³)
4. Small (0.0002-0.008 m³)
5. Very small (<0.0002 m³)

State of weathering

1. Fresh
2. Slightly
3. Moderately
4. Highly
5. Completely
6. Residual soil

No. of major discontinuity sets

LINE SURVEYS TO DETERMINE DISCONTINUITY SPACINGS

	Plunge of line	Trend of line	Length of line (m)	No. of fractures	Spacing	Remarks
Line 1						
Line 2						
Line 3						

Discontinuity spacing

1. Extremely close (<20 mm)
2. Very close (20-60 mm)
3. Close (60-200 mm)
4. Moderate (200-600 mm)
5. Wide (600-2000 mm)
6. Very wide (2000-60000 mm)
7. Ext. Wide (>6000 mm)

Figure 3-24. (b) Structural Mapping Coding Form for Slope Assessment.

Typical safety guidelines for drilling into soil and rock are presented in Appendix A. Minimum protective gear for all personnel should include hard hat, safety boots, eye protection, and gloves.

It is not unusual to encounter unknown or unexpected environmental problems during a site investigation. For example, discolored soils or rock fragments from prior spills, or contaminated groundwater may be detected. The geotechnical engineer and the field supervisor should attempt to identify possible contamination sources prior to initiating fieldwork. Based on this evaluation, a decision should be made whether a site safety plan should be prepared. Environmental problems can adversely affect investigation schedules and cost, and may require the obtaining of permits from State or Federal agencies prior to drilling or sampling.

At geotechnical exploration sites where unknown or unexpected contamination is found during the fieldwork, the following steps should be taken:

1. The field supervisor should immediately stop drilling and notify the geotechnical engineer. The field supervisor should identify the evidence of contamination, the depth of contamination, and the estimated depth to the water table (if known). If liquid-phase product is encountered (at or above the water table), the boring should be abandoned immediately and sealed with hydrated bentonite chips or grout.

2. The project manager should advise the environmental officer of the governing agency and decide if special health and safety protocol should be implemented. Initial actions may require demobilization from the site.

3.5 COMMON SENSE DRILLING

Drillers performance is commonly judged by the quantity of production rather than the quality of the borings and samples. Not surprisingly, similar problems develop throughout the country. All geotechnical engineers and field supervisors need to be trained to recognize these problems, and to assure that field information and samples are properly obtained. The following is a partial listing of common errors:

- Not properly cleaning slough and cuttings from the bottom of the bore hole. The driller should not sample through slough, but should re-enter the boring and remove the slough before proceeding.

- In cohesionless soils, jetting should not be used to advance a split barrel sampler to the bottom of the boring.

- Poor sample recovery due to use of improper sampling equipment or procedures.

- When sampling soft or non-cohesive soils with thin wall tube samplers (i.e., Shelby tube) it may not be possible to recover an undisturbed sample because the sample will not stay in the barrel. The driller should be clearly instructed not to force recovery by overdriving the sampling barrel to grab a sample.

- Improper sample types or insufficient quantity of samples. The driller should be given clear instructions regarding the sample frequency and types of samples required. The field supervisor must keep track of the depth of the borings at all stages of the exploration to confirm proper sampling of the soil and/or rock formations.

- Improper hole stabilization. Rotary wash borings and hollow-stem auger borings below the groundwater level require a head of water to be maintained at the top of the casing/augers at all times. When the drill rods are withdrawn or as the hollow stem auger is advanced, this water level will tend to drop, and must be maintained by the addition of more drilling fluid. Without this precaution, the sides of the boring may collapse or the bottom of the boring may heave.

- Sampler rods lowered into the boring with pipe wrenches rather than hoisting plug. The rods may be inclined and the sampler can hit the boring walls, filling the sampler with debris.

- Improper procedures while performing Standard Penetration Tests. The field supervisor and driller must assure that the proper weight and hammer drop are being used, and that friction at the cathead and along any hammer guides is minimized.

Figure 3-25. Views of Rotary Drill Rigs Mounted on Trucks for Soil & Rock Exploration.