



## **PDHonline Course C260 (3 PDH)**

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# **Planning Subsurface Investigations**

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## **Chapter 5**

### **Subsurface Investigations**

#### **5-1. Background**

Subsurface investigations require use of equipment to gain information below the ground surface. The equipment is typically invasive and requires disturbance of the ground to varying degrees. Most of these exploration techniques are relatively expensive and therefore should be carefully planned and controlled to yield the maximum amount of information possible. It should be kept in mind that the quality of the information produced can vary significantly. If procedures are not followed carefully and data not interpreted properly, radically different conclusions can be reached. For example, poor drilling techniques could produce samples that might yield lower strength values. Therefore, only competent, senior geotechnical personnel should be charged with planning a subsurface investigation, and only qualified geotechnical professionals and technicians should do the drilling and data collecting, reducing, analyzing, and interpreting.

#### **5-2. Location of Investigations**

An important piece of information for all geotechnical investigations that seems obvious but commonly not given sufficient attention is the accurate determination of the location of investigation. It is always preferable to select boring and test pit locations that fully characterize geotechnical conditions. Although correlation of information from offsite may be technically defensible, because of variability of geologic materials, the legal defensibility of a piece of information is commonly lost if it is even slightly removed from the site. Of course, it is not always possible to locate a boring on a structure because of obstacles or right-of-entry difficulties. Heavily urbanized areas present particular difficulties in these aspects. However, it is important to keep in mind that correlations and interpretations may be subject to later scrutiny should a change of conditions claim be filed. All locations should be determined using either conventional surveying methods or by a GPS (EM 1110-1-1003). A GPS has the significant advantage of having the positional information downloaded directly into a GIS.

#### **5-3. Protection of the Environment**

*a.* After the locations for field investigations work have been determined, routes of access to the area and the specific sites for borings and excavations should be selected with care to minimize damage to the environment. Environmental engineering aspects of civil works projects are discussed in EM 1110-2-1202, -1204, -1205, and -1206 and Keller (1992). Operation of equipment will be controlled at all times and the extent of damaged areas will be held to the minimum consistent with the requirements for obtaining adequate data. Local laws pertaining to permissible levels of sediment flow from the site should be investigated. After the exploratory sites have served their purpose, the disturbed areas will be restored to a natural appearance. All borings and test pits should be backfilled in accordance with state environmental regulations.

*b.* Most states are now the primary regulatory agency for ground water quality assurance. As part of this responsibility many now require the certification of drillers. These regulations primarily apply to water well installation, but they may also apply to investigation programs. Ground water quality assurance has been the subject of considerable discussion from the standpoint of Federal Government responsibility for compliance with these regulations. Generally, Government drillers are not required to

have state certification but, in some instances, may be forced to comply for political reasons. This is not a clear-cut issue, and it should be resolved before beginning a drilling program.

c. The Federal Government has responsibility to ensure that environmental consciousness is maintained during the conduct of geotechnical investigations. Unfortunately, drilling rigs are inherently dirty. Proper maintenance of drilling rigs will minimize this problem. For HTRW exploratory drilling, drilling rigs must be steam cleaned and all tools, equipment, and personnel decontaminated in accordance with procedures established in the quality assurance and control (QAAC) plan. Fluids used in drilling operations, be they hydrocarbons that have leaked from the hydraulic system or a constituent of a drilling mud, are potentially toxic and should be controlled or eliminated wherever possible. EM 1110-1-4000 discusses requirements for maintenance and operation of drilling equipment at USACE HTRW sites. Aller et al. (1989) provide further guidance on acceptable design and installation of monitoring wells.

### *Section I*

#### *Borings*

#### **5-4. Major Uses**

Borings are required to characterize the basic geologic materials at a project. The major uses for which borings are made are as follows:

- a. Define geologic stratigraphy and structure.
- b. Obtain samples for index testing.
- c. Obtain ground water data.
- d. Perform in situ tests.
- e. Obtain samples to determine engineering properties.
- f. Install instrumentation.
- g. Establish foundation elevations for structures.
- h. Determine the engineering characteristics of existing structures.

Borings are classified broadly as disturbed, undisturbed, and core. Borings are frequently used for more than one purpose, and it is not uncommon to use a boring for purposes not contemplated when it was made. Thus, it is important to have a complete log of every boring, even if there may not be an immediate use for some of the information. If there is doubt regarding the range of borehole use or insufficient information to determine optimum borehole size, then the hole should be drilled larger than currently thought needed. A slightly larger than needed borehole is considerably less expensive than a second borehole.

#### **5-5. Boring and Sampling Methods**

a. *Common methods discussed.* Many methods are used to make borings and retrieve samples. Some of the more common methods are discussed in the following paragraphs. Many of these are also

discussed in detail in Chapter 3, Appendix F; Das (1994); Hunt (1984); and Aller et al. (1989). Some factors that affect the choice of methods are:

- (1) Purpose and information required.
- (2) Equipment availability.
- (3) Depth of hole.
- (4) Experience and training of available personnel.
- (5) Types of materials anticipated.
- (6) Terrain and accessibility.
- (7) Cost.
- (8) Environmental impacts.
- (9) Disruption of existing structure.

*b. Auger borings.* Auger borings provide disturbed samples that are suitable for determining soil type, Atterberg limits, Proctor testing, and other index properties but generally give limited information on subsoil stratification, consistency, or sensitivity. Auger borings are most useful for preliminary investigations of soil type, advancing holes for other sampling methods, determining depth to top of rock, and for monitor well installation in soils. Auger borings can be made using hand, helical, barrel, hollow-stem, or bucket augers. Auger samples are difficult to obtain below the ground water table, except in clays. However, hollow-stem augers with a continuous split barrel sampler can retrieve some unconsolidated material from below the water table. Paragraph 3-4, Appendix F, describes the types of augers used in subsurface exploration. Paragraph 8-2, Appendix F, discusses sampling procedures when augering.

(1) Truck-mounted auger rigs currently come equipped with high yield and high tensile strength steel augers. New hydraulics technology can now apply torque pressures upward of 27,000 Nm (20,000 ft lb). With this amount of torque, augers are capable of boring large size holes and of being used in soft rock foundation investigations. Because augers use no drilling fluids, they are advantageous for avoiding environmental impacts. Appendix F, paragraph 3-3, describes auger drilling rigs. Another advantage of using augers is the ability (using hollow stems) for soil sampling, i.e., taking undisturbed samples below the bit.

(2) Currently, many drilling rigs are actually a combination of auger/core/downhole hammer units. A hollow-stem auger has the “drill through” capability (i.e., the auger can drill to refusal, then a wireline core barrel and drill rods can be inserted to finish the hole). The auger acts as a temporary casing to prevent caving of the softer materials as sampling progresses. However, the augers are not water tight and water loss should be anticipated. Hollow-stem augers should not be used as temporary casing in areas where HTRW is anticipated. Temporary steel casing driven into the surface of competent bedrock or PVC casing permanently grouted into the competent bedrock surface is required when HTRW is anticipated.

c. *Drive borings.* Drive borings provide disturbed samples that contain all soil constituents, generally retain natural stratification, and can supply data on penetration resistance. Drive boring is a nonrotating method for making a hole by continuous sampling using a heavy wall drive barrel. Push, or drive, samplers are of two types: open samplers and piston samplers. Open samplers have a vented sampler head attached to an open tube that admits soil as soon as the tube is brought in contact with the soil. Some open samplers are equipped with a cutting shoe and a sample retainer. Piston samplers have a movable piston located within the sampler tube. The piston helps to keep drilling fluid and soil cuttings out of the tube as the sampler advances. The piston also helps to retain the sample in the sampler tube. Where larger samples are required, the most suitable drill for this method is the cable tool rig. The cable tool rig has the capability to provide a downward driving force (drill stem on drive clamps) to make a hole and an upward force (drilling jars) to remove the drive barrel from the hole.

(1) Vibratory samplers offer a means of obtaining disturbed samples of saturated, cohesionless soils rapidly and with relatively inexpensive equipment (Appendix F). The simplest devices consist of a small gasoline engine providing hydraulic power to a vibrating head clamped to aluminum tubing secured on a tripod. The rapid vibrations within the head drives the sampling tube into the ground and forces the soil up into the tube. A rubber packer secured into the open end of the sampling tube after driving creates a seal to retain the sample as the tube is withdrawn with a hand winch.

(2) Another device, the Becker hammer drill, was devised specifically for use in sand, gravel, and boulders by Becker Drilling, LTD, Canada. The Becker drill uses a diesel-powered pile hammer to drive a special double-wall, toothed casing into the ground. Drilling fluid is pumped through an annulus to the bottom of the hole where it forces cuttings to the surface through the center of the casing. The cuttings are collected for examination. Becker drill casings are available in 14-cm (5.5-in.), 17-cm (6.6-in.), and 23-cm (9.0-in.) outside diameters (OD), with sampling inside diameters (ID) of 8.4 cm (3.3 in.), 10.9 cm (4.3 in.), and 15.2 cm (6.0 in.), respectively. Paragraph 5-23 and Appendix H describe Becker penetration test procedures. Appendix F, paragraph 3-3, discusses the Becker hammer drilling equipment and operation.

(3) The Standard Penetration Test (SPT) method of drive boring, described in ASTM D 1586-84 (ASTM 1996b), is probably the most commonly used method for advancing a hole by the drive method. Slight variations of this method, primarily concerning the sampling interval, cleanout method, and the refusal criteria exist from office to office but the fundamental procedure follows the ASTM standard. Appendix G presents procedures for SPT sampling and testing. Appendix G is compatible with the ASTM D 1586-84 standard and provides additional guidance in evaluating the test data. In this method, a standard configuration, 5-cm (2-in.) OD split barrel sampler at the end of a solid string of drill rods is advanced for a 0.45-m (1.5-ft) interval using a 623-Newton (N) (140-lb) hammer dropped through a 76-cm (30-in.) free fall. The blows required to advance the hole for each 15-cm (6-in.) interval are recorded on ENG Form 1836. The standard penetration resistance, or “N” value, is the sum of the blows required for the second and third 15-cm (6-in.) drives. The hole is then cleaned or reamed to the top of the next interval to be sampled and the procedure is repeated. Refusal is generally defined as 50 blows per 15 cm (per half foot) of penetration. When used to define the top of rock, great care and close examination of samples are required to minimize uncertainties. A few of the applications of SPT data are listed in paragraph 5-23a. This impact method may also be used with larger sample tubes and heavier hammers. Correlation studies to normalize data from larger holes to the SPT have been performed but are not completely reliable. The Becker hammer drill data can provide correlations of soil density and strength in coarse-grained soils similarly to the SPT test in finer-grained soils (paragraph 5-23a).

(4) Drive borings can be advanced quickly and economically with hollow-stem augers using a “plug” assembly that is either manually or mechanically set in the opening at the end of the auger string and then removed prior to sampling. Removal is commonly facilitated using a wire line system of retrieval. Where overburden prohibits the use of augers to advance the boring due to boulders or resistant rock lenses or ledges, other methods can be used. Traditionally, a roller rock bit using drilling mud will advance the hole at a modest cost in time and dollars. Where extremely difficult drilling conditions exist, an ODEX (eccentric reamer) down-the-hole air hammer system or other coring advancer apparatus can be used to penetrate the toughest boulders or ledges while still permitting the use of standard penetration or even undisturbed sampling to be conducted.

*d. Cone penetration borings.* The Cone Penetration Test (CPT) or Dutch cone boring is an in situ testing method for evaluating detailed soil stratigraphy as well as estimating geotechnical engineering properties (Schmertmann 1978a). The CPT involves hydraulically pushing a 3.6-cm (1.4-in.) diam special probe into the earth while performing two measurements, cone resistance and sleeve friction resistance. The probe is normally pushed from a special heavy duty truck but can also be performed from a trailer or drilling rig. Because of the weight of the truck or trailer needed to conduct CPT borings, access to soft ground sites is limited. Recent developments in CPT technology make it possible to retrieve physical soil samples and ground water or soil-gas samples with the same drive string used to perform the cone penetration test. CPT vehicles with push capacities up to 267 kiloNewtons (kN) (30 tons) have been developed. The Tri-Service Site Characterization and Analysis Penetrometer System (SCAPS), which is used to detect underground HTRW, is a technical variation of the CPT. The use of SCAPS reduces the time and cost of site characterization and restoration monitoring by providing rapid onsite real-time data acquisition/processing (i.e., in situ analysis) and onsite 3-D visualization of subsurface stratigraphy and regions of potential contamination. The Triservices operate several SCAPS vehicles including those of the U.S. Army Engineer District, (USAED) Kansas City, Savannah, and Tulsa, and the U.S. Army Engineer Waterways Experiment Station (USAEWES). Additional discussion of CPT is given in paragraph 5-23f.

*e. Undisturbed borings.* Appendix F, Chapters 5 and 6, discuss procedures for undisturbed sampling of soils. True “undisturbed” samples cannot be obtained because of the adverse effects resulting from sampling, shipping, or handling. However, modern samplers, used with great care, can obtain samples that are satisfactory for shear strength, consolidation, permeability, and density tests provided the possible effects of sample disturbance are considered. Undisturbed samples can be sliced to permit detailed study of subsoil stratification, joints, fissures, failure planes, and other details. Undisturbed samples of clays and silts can be obtained as well as nearly undisturbed samples of some sands.

(1) There are no standard or generally accepted methods for undisturbed sampling of noncohesive soils. One method that has been used is to obtain 7.6-cm (3-in.) Shelby (thin-wall) tube samples, drain them, and then freeze them prior to transporting them to the laboratory. Another method used consists of in situ freezing, followed by sampling with a rotary core barrel. Care is necessary in transporting any undisturbed sample, and special precautions must be taken if transporting sands and silts. For both methods, disturbance by cryogenic effects must be taken into account. Fixed-piston (Hvorslev) samplers, wherein a piston within a thin-walled tube is allowed to move up into the tube as the sampler is pushed into the soil, are adapted to sampling cohesionless and wet soils (Appendix F, paragraph 5-1a(2)).

(2) Undisturbed borings are normally made using one of two general methods: push samplers or rotary samplers. Push sampling types involve pushing a thin-walled tube using the hydraulic system of the drilling rig, then enlarging the diameter of the sampled interval by some “cleanout” method before beginning to sample again. Commonly used systems for push samples include the drill-rig drive,

whereby pressure is applied to a thin-walled (Shelby) sampling tube through the drill rods, the Hvorslev fixed-piston sampler, and the Osterberg hydraulic piston sampler. Rotary samplers involve a double tube arrangement similar to a rock coring operation except that the inner barrel shoe is adjustable but generally extends beyond the front of the rotating outer bit. This minimizes the disturbance to the sample from the drilling fluid and bit rotation. Commonly used rotational samplers include the Denison barrel and the Pitcher sampler. The Pitcher sampler has an inner barrel affixed to a spring-loaded inner sampler head that extends or retracts relative to the cutting bit with changes in soil stiffness. Drilling fluids are commonly used with rotary drilling equipment to transport cuttings to the surface and to increase the stability of the borehole. Chapter 4 of Appendix F discusses the types, preparation, and use of drilling fluids. The standard for thin-walled tube sampling of soils is ASTM D 1587-94 (ASTM 1996c), "Standard Practice for Thin-Walled Tube Sampling of Soils."

*f. Rock core boring.* Cored rock samples are retrieved by rotary drilling with hollow core barrels equipped with diamond- or carbide-embedded bits. The core is commonly retrieved in 1.5- to 3-m (5- to 10-ft) lengths. The "N" size hole (approximately 75 mm or 3 in.) is probably the core size most widely used by the Corps of Engineers for geotechnical investigations and produces a satisfactory sample for preliminary exploration work and, in many instances, for more advanced design studies. Other hole sizes, including B (approx 60 mm or 2.3 in.) and H (approximately 99 mm or 4 in.), are also quite satisfactory for geotechnical investigations. The decision on hole size should be based upon anticipated foundation conditions, laboratory testing requirements, and the engineering information desired. A double- or triple-tube core barrel is recommended because of its ability to recover soft or broken and fractured zones. The use of wireline drilling, whereby the core barrel is retrieved through the drill rod string, eliminates the need to remove the drill rods for sampling and saves a great deal of time in deep borings. Table 5-1 summarizes core and hole sizes commonly used in geotechnical studies. The rock boring is advanced without sampling using solid bits, including fishtail, or drag, bits, tri-cone and roller rock bits, or diamond plug bits.

(1) Most rock boring in the Corps of Engineers is accomplished using truck-mounted rotary drilling rigs. Skid-mounted rigs are also sometimes used in areas with poor access. Rotary drilling rigs are driven by the power takeoff from the truck engine or by independent engines. Boreholes are advanced by rotary action coupled with downward pressure applied to the drill bit and the cleaning action of the drilling fluid. Two types of pulldown mechanisms are normally used. Truck-mounted rotary drilling rigs equipped with a chain pulldown drive mechanism are capable of drilling to depths of 60 to 300 m (200 to 1,000 ft). Hydraulic feed drive rotary drilling rigs are capable of drilling to depths of 150 to 750 m (500 to 2,500 ft).

(2) Core recovery in zones of weak or intensely fractured rock is particularly important because these zones are typically the critical areas from the standpoint of foundation loading and stability. The use of larger-diameter core barrels in soft, weak, or fractured strata can improve core recovery and provides a statistically better size sample for laboratory testing. The advantages of larger cores must be weighed against their higher costs.

(3) Although the majority of rock core borings are drilled vertically, inclined, and horizontally oriented, borings may be required to adequately define stratification, jointing, and other discontinuities. A bias exists in the data favoring discontinuities lying nearly perpendicular to the boring. Discontinuities more nearly parallel to the boring are not intersected as often, and therefore, their frequency will appear to be much lower than it actually is. Inclined borings should be used to investigate steeply inclined jointing in abutments and valley sections for dams, along spillway and tunnel

**Table 5-1**  
**Typical Diamond Core Drill Bit and Reaming Shell Dimensions**

Size	Bit Size		Reaming Shell
	OD, mm (in.)	ID, mm (in.)	OD and hole diam, mm (in.)
<u>"W" Group - "G" and "M" Design</u>			
EWG (EWX), EWM	37.3 (1.470)	21.5 (0.845)	37.7 (1.485)
AWG (AWX), AWM	47.6 (1.875)	30.1 (1.185)	48.0 (1.890)
BWG (BWV), BWM	59.6 (2.345)	42.0 (1.655)	59.9 (2.360)
NWG (NWV), NWM	75.3 (2.965)	54.7 (2.155)	75.7 (2.980)
HWG	98.8 (3.890)	76.2 (3.000)	99.2 (3.907)
<u>"W" Group - "T" Design</u>			
RWT	29.5 (1.160)	18.7 (0.735)	29.9 (1.175)
EWT	37.3 (1.470)	23.0 (0.905)	37.7 (1.485)
AWT	47.6 (1.875)	32.5 (1.281)	48.0 (1.890)
BWT	59.6 (2.345)	44.4 (1.750)	59.9 (2.360)
NWT	75.3 (2.965)	58.8 (2.313)	75.7 (2.980)
HWT	98.8 (3.890)	81.0 (3.187)	99.2 (3.907)
<u>Large-Diameter Design</u>			
2-3/4 X 3-7/8	97.5 (3.840)	68.3 (2.690)	98.4 (3.875)
4 X 5-1/2	138.1 (5.435)	100.8 (3.970)	139.6 (5.495)
6 X 7-3/4	194.4 (7.655)	151.6 (5.970)	196.8 (7.750)
<u>Wireline Sizes</u>			
AQ		27.0 (1 <sup>1</sup> / <sub>16</sub> )	48.0 (1 <sup>57</sup> / <sub>64</sub> )
BQ		36.5 (1 <sup>7</sup> / <sub>16</sub> )	60.0 (2 <sup>23</sup> / <sub>64</sub> )
NQ		47.6 (1 <sup>7</sup> / <sub>8</sub> )	75.8 (2 <sup>63</sup> / <sub>64</sub> )
HQ		63.5 (2 <sup>1</sup> / <sub>2</sub> )	96.0 (3 <sup>25</sup> / <sub>32</sub> )
PQ		85.0 (3 <sup>11</sup> / <sub>32</sub> )	122.6 (4 <sup>53</sup> / <sub>64</sub> )

alignment, and in foundations for other structures. In nearly vertical bedding, inclined borings can be used to reduce the total number of borings needed to obtain core samples of all strata.

(4) If precise geological structure is to be evaluated from core samples, techniques involving oriented cores are required. In these procedures, the core is scribed or engraved with a special drilling tool (Goodman 1976) so that its orientation is preserved. In this manner, both the dip and strike of any joint, bedding plane, or other planar surface can be ascertained. A more common procedure for obtaining dip and strike of structural features is the use of borehole photography or television. If the orientation of bedding is consistent across the site, it can be used to orient cores from borings which are angled to this bedding. Once oriented, the attitudes of discontinuities can be measured directly from the core.

(5) Large-diameter borings or calyx holes, 0.6 m (2 ft) or more in diameter, are occasionally used in large or critical structures. Their use permits direct examination of the sidewalls of the boring or shaft and provides access for obtaining high quality undisturbed samples. Direct inspection of the sidewalls may reveal details, such as thin, weak layers or shear planes that may not be detected by continuous undisturbed sampling. Large-diameter borings are produced with augers in soil and soft rock, and with large-diameter core barrels in hard rock.

## 5-6. Drilling in Embankments

The Corps of Engineers developed a special regulation concerning drilling operations in dam and levee embankments and their soil foundations (ER 1110-1-1807). In the past, compressed air and other drilling fluids have been used as circulating media to remove drill cuttings, stabilize bore holes, and cool and lubricate drilling bits. There have been several incidents of damage to embankments and foundations when drilling with air, foam, or water as the circulating medium. Damage has included pneumatic fracturing of the embankment while using air or air with foam, and erosion of embankment or foundation materials and hydraulic fracturing while using water. The new ER establishes a policy for drilling in earth embankments and foundations and replaces ER 1110-1-1807. The following points summarize the guidance provided in the new document:

- a. Personnel involved in drilling in dam and levee embankments shall be senior and well qualified. Designs shall be prepared and approved by geotechnical engineers or engineering geologists. Drillers and “mud” specialists shall be experts in their fields.
- b. Drilling in embankments or their foundations using compressed air or other gas or water as the circulating medium is prohibited.
- c. Cable tool, auger, and rotary tool are recommended methods for drilling in embankments. One Corps District reports using a churn drill (a cable tool rig) to sample the clay core of a dam to a depth of 90 m (300 ft) with no damage to the core. If the cable tool method is used, drilling tools must be restricted to hollow sampling (drive) barrels in earth embankment and overburden materials. Appendix F, page 3-6, of this manual discusses the use of churn drills. If rotary drilling is used, an engineered drilling fluid (mud) designed to prevent caving and minimize intrusion of the drilling fluid into the embankment shall be used. An appendix in ER 1110-1-1807 provides detailed procedures for rotary drilling.

### *Section II* *Drillhole Inspection and Logging*

## 5-7. Objectives

A major part of field investigations is the compilation of accurate borehole logs on which subsequent geologic and geotechnical information and decisions are based. A field drilling log for each borehole can provide an accurate and comprehensive record of the lithology and stratigraphy of soils and rocks encountered in the borehole and other relevant information obtained during drilling, sampling, and in situ testing. To accomplish this objective, an experienced geologist, soils engineer, or civil engineer with good geotechnical training and experience should be present during drilling. The duties of the field inspector include the following:

- a. Making decisions on boring location, depth, and number and quality of samples required.
- b. Observing and describing drilling tools and procedures.
- c. Observing, classifying, and describing geologic materials and their discontinuities.
- d. Selecting and preserving samples.

- e.* Performing field tests on soils (hand penetrometer, torvane).
- f.* Photographing site conditions and rock cores.
- g.* Observing and recording drilling activities and ground water measurements.
- h.* Overseeing and recording instrument installation activities.
- i.* Completing the drilling log, ENG FORM 1836 and/or entering information in BLDM (Nash 1993).
- j.* Recording information and data from in situ tests.

The logs of borings are normally made available to contractors for use in preparing their bids. The descriptions contained on the logs of borings give the contractor an indication of the type of materials to be encountered and their in situ condition. Special care must be taken to ensure a clear differentiation in logs between field observations and laboratory test results. Guidance on soil identification and description, coring, and core logging is provided in the remainder of this section.

## **5-8. Soil Identification and Description**

A thorough and accurate description of soils is important in establishing general engineering properties for design and anticipated behavior during construction. The description must identify the type of soil (clay, sand, etc.), place it within established groupings, and include a general description of the condition of the material (soft, firm, loose, dense, dry, moist, etc.). Characterization of the soils within a site provides guidance for further subsurface exploration, selection of samples for detailed testing, and development of generalized subsurface profiles (Das 1994). Initial field soil classification with subsequent lab tests and other boring data are recorded on the logs of borings. Soils should be described in accordance with ASTM D 2488-93 (ASTM 1996d). For civil works, the most widely used classification is the Unified Soil Classification System (USCS). The USCS outlines field procedures for determining plasticity, dilatancy, dry strength, particle size, and other engineering parameters. The USCS is described by Schroeder (1984) and in Technical Memorandum 3-357 (USAEWES 1982). A number of references provide detailed procedures to evaluate the physical properties of soils, including Cernica (1993), Lambe and Whitman (1969), Terzaghi, Peck, and Mesri (1996), and Means and Parcher (1963). In some cases, a standardized description of color using Munsell charts is useful. Some of the procedures, such as determining dry strength, may be impractical under certain field conditions and may be omitted where necessary. However, the checklists included in the procedure, if followed conscientiously, provide for a thorough description of soils. Examples for presenting soils data on ENG FORM 1836 are shown in Appendix D. Examples of well logs in the Boring Log Data Manager format are also presented in Appendix D.

## **5-9. Coring**

Core drilling, if carefully executed and properly reported, can produce invaluable subsurface information. Basic procedures that should be followed and the information obtained can form the basis for comparison for widely diverse sites and conditions. The following subparagraphs outline procedures to report observations made during coring operations.

*a. Drilling observations.* During the coring operation, a great deal of information is available about the subsurface conditions that may or may not be apparent in the core recovered from the hole. Observation of the drilling action must be made and reported to present as complete a picture as possible of the subsurface conditions.

(1) If coring with water as a circulating medium, the inspector should note the amount of water return relative to the amount being injected through the drill rods and its color. Careful observation of drill water return changes can indicate potential intervals where pressure test takes can be anticipated and correlated. Changes in the color of the return water can indicate stratigraphic changes and degrees of weathering such as clay-filled joints and cavity fillings.

(2) If available, hydraulic pressure being exerted by the drill should be recorded on each run as well as the fluid water pressure. While the drill is turning, the inspector should correlate drilling depths to drilling action (e.g., smooth or rough), increases and decreases applied by the drill operator to the feed control valve, and the rate of penetration. Rod drop depths, which indicate open zones, should be recorded. Changes in drilling rates can be related to changes in composition and/or rock structure and, in areas of poor core recovery, may provide the only indication of the subsurface conditions.

*b. Procedural information.* Regardless of the program undertaken, all logs should at least include the following: size and type of core bit and barrel used; bit changes; size, type, and depth of casing; casing shoe and/or casing bit used; problems or observations made during placement of the casing; change in depth of casing setting during drilling; depth, length, and time for each run; length/depth of pull (the actual interval of core recovered in the core run); amount of core actually recovered; amount of core loss or gain; and amount of core left in the hole (tape check). The inspector should note the presence of a flange on the bottom of a core string because a flange indicates that the core was retrieved from the bottom of the drilled hole. From these data the unaccountable loss, i.e., the core that is missing and unaccounted for, should be computed. Core loss should be shown on the graphic log and by blocks or spacers in the core box at its most likely depth of occurrence based upon the drilling action and close examination of the core. The boring should be cleaned and the total depth taped to determine the amount of cored rock left in the hole on the final run.

## **5-10. Core Logging**

Each feature logged shall be described in such a way that other persons looking at the core log will recognize what the feature is, the depth at which it occurred in the boring, and its thickness or size. They should also be able to obtain some idea of the appearance of the core and an indication of its physical characteristics. The log shall contain all the information obtainable from the core pertaining to the rock as well as discontinuities. Examples for presenting core logging data on ENG FORM 1836 are shown in Appendix D.

*a. Rock description.* Each lithologic unit in the core shall be logged. The classification and description of each unit shall be as complete as possible. A recommended order of descriptions is as follows:

- (1) Unit designation (Miami oolite, Clayton formation, Chattanooga shale).
- (2) Rock type and lithology.
- (3) Hardness, relative strength, or induration..

- (4) Degree of weathering.
- (5) Texture.
- (6) Structure.
- (7) Discontinuities (faults, fractures, joints, seams).
  - (a) Orientation with respect to core axis.
  - (b) Asperity (surface roughness).
  - (c) Nature of infilling or coating, if present.
  - (d) Staining, if present.
  - (e) Tightness.
- (8) Color.
- (9) Solution and void conditions.
- (10) Swelling and slaking properties, if apparent.
- (11) Additional descriptions such as mineralization, inclusions, and fossils.

Criteria for these descriptive elements are contained in Table B-2 (Appendix B). Murphy (1985) provides guidelines for geotechnical descriptions of rock and rock masses. Geological Society Engineering Group Working Party Report (1995) suggests a description and classification scheme of weathered rocks for engineering purposes. Variation from the general description of the unit and features not included in the general description should be indicated at the depth and the interval in the core where the feature exists. These variations and features shall be identified by terms that will adequately describe the feature or variation so as to delineate it from the general description. Features include zones or seams of different color and texture; staining; shale seams, gypsum seams, chert nodules, and calcite masses; mineralized zones; vuggy zones; joints; fractures; open and/or stained bedding planes, roughness, planarity; faults, shear zones, and gouge; cavities, thickness, open or filled, and nature of filling; and core left in the bottom of the hole after the final pull.

*b. Rock quality designation.* A simple and widely used measure of the quality of the rock mass is provided by the Rock Quality Designation (RQD), which incorporates only sound, intact pieces 10 cm (4 in.) or longer in determining core recovery. In practice, the RQD is measured for each core run and reported on ENG Form 1836. Many of the rock mass classification systems in use today are based, in part, on the RQD. Its wide use and ease of measurement make it an important piece of information to be gathered on all core holes. It is also desirable because it is a quantitative measure of core quality at the time of drilling before handling and slaking have had major effect. Deere and Deere (1989) reevaluated the use of RQD from experience gained in the 20 years since its inception. They recommended modifications to the original procedure after evaluating results of field use. Figure 5-1 illustrates the modified procedure of Deere and Deere.

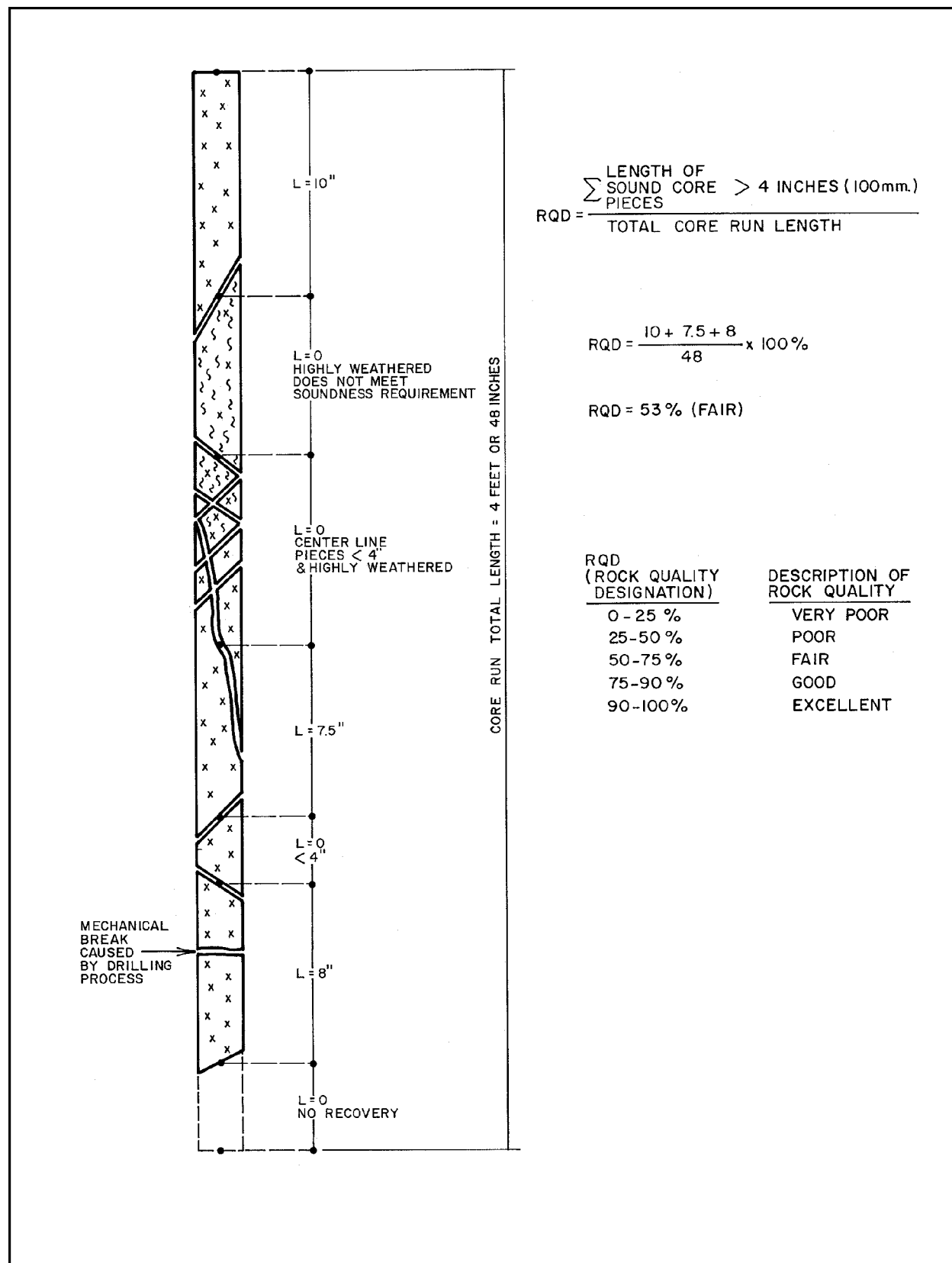


Figure 5-1. Illustration of Deere and Deere (1989) modified procedure for calculating RQD

(1) RQD was originally recommended for NX size (5.474-cm- or 2.155-in.-diam) core, but Deere and Deere expanded its use to the somewhat smaller NQ wireline sizes (4.763 cm or 1-7/8 in.) and to larger wireline sizes up to 8.493 cm (3-11/32 in.) and other core sizes up to 15 cm (6 in.). They discouraged RQD use with the smaller BQ (3.651-cm or 1-7/16-in.) and BX (4.204-cm or 1.655-in.) cores because of core breakage.

(2) Core segment lengths should be measured along the centerline or axis of the core, as illustrated in Figure 5-1.

(3) The inspector should disregard mechanical breaks (breaks caused by drilling action or handling) when calculating RQD.

(4) RQD should be performed at the time the core is retrieved to avoid the effects of postremoval slaking and separation of core along bedding planes, as in some shales.

(5) Emphasis should be placed on core being “sound.” Pieces of core that do not meet the subjective “soundness” test should not be counted. Indicators of “unsound” rock are discolored or bleached grains or crystals, heavy staining, pitting, or weak grain boundaries. Unsound rock is analogous to “highly weathered” rock, which is characterized by weathering extending throughout the rock mass.

Several papers have appeared since Deere and Deere (1989) suggesting alternatives or modified applications of RQD to systems of discontinuities that are perhaps less amenable to analysis by the original procedure. Boadu and Long (1994) established a relation between RQD and fractal dimension (the degree to which a system is self-similar at different scales). The relationships may have application in fracture geometries with complex distributions. Eissa and Sen (1991) suggest alternative analytical methods to RQD when dealing with fracture networks, that is, sets of fractures in more than one direction. Similar alternative approaches to systems of fractures in three dimensions (a volumetric approach) were proposed by Sen and Eissa (1991). Special attention should be paid to the nature of all discontinuities. These are most often what control the engineering behavior of the foundation rock mass and slope stability.

*c. Solution and void conditions.* Solution and void conditions shall be described in detail because these features can affect the strength of the rock and can indicate potential ground water seepage paths. Where cavities are detected by drilling action, the depth to top and bottom of the cavity should be determined by measuring. Filling material, where present and recovered, should be described in detail opposite the cavity location on the log. If no material is recovered from the cavity, the inspector should note the probable conditions of the cavity, as determined by observing the drilling action and the color of the drilling fluid. If drilling action indicates material is present, e.g., a slow rod drop, no loss of drill water, or noticeable change in color of water return, it should be noted on the log that the cavity was probably filled and the materials should be described as well as possible from the cuttings or traces left on the core. If drilling action indicates the cavity was open, i.e., no resistance to the drilling tools and/or loss of drilling fluid, it should be noted on the drilling log. By the same criteria, partially filled cavities should be noted. If possible, filling material should be sampled and preserved. During the field logging of the core at the drilling site, spacers should be placed in the proper position in core boxes to record voids and losses.

*d. Photographic and video record.* A color photographic record of all core samples should be made. Photographs should be taken as soon as possible after retrieving the core samples. The core photographs can be reproduced on 20- by 25-cm (8- by 10-in.) prints, two or three core boxes to a photograph, and the photographic sheets placed in a loose-leaf binder for convenient reference. Photographs often enhance the logged description of cores particularly where rock defects are abundant.

In the event that cores are lost or destroyed, the photographic record becomes the only direct, visual means for review of subsurface conditions without expensive redrilling. A video recording of the drilling operation provides an excellent record of drilling equipment and procedures. Moreover, video may provide a record of critical events or conditions that were not obvious at the time, or occurred too quickly to be recorded manually.

### **5-11. Drilling Log Form and the Boring Log Data Management Program**

All soil and rock drilling logs will be recorded using ENG FORM 1836 as the standard, official log of record. As a general rule, the depth scale on each sheet should normally be 3 m (10 ft) per page and no smaller than 6 m (20 ft). Examples of completed drilling logs are shown in Appendix D. A PC-based, menu-driven boring log data management program (BLDM) is available for free to COE personnel through CEWES-GS-S. The BLDM allows users to create and maintain boring log data, print reports, and create data files which can be exported to a GIS (Nash 1993). Examples of BLDM output are presented in Appendix D.

#### *Section III* *Borehole Examination and Testing*

### **5-12. Borehole Geophysical Testing**

A wide array of downhole geophysical probes is available to measure various formation properties (Tables 4-1 and 4-2). Geophysical probes are not a substitute for core sampling and analysis, however, but they are an economical and valuable supplement to the core sample record. Some very sophisticated analyses of rock mass engineering properties are possible through the use of downhole geophysics. These services are available through commercial logging companies and various Government agencies. Recent developments in microcomputer technology have made it possible to apply procedures known as crosshole tomography to borehole seismic and resistivity data (Cottin et al. 1986; Larkin et al. 1990). Through computer analysis of crosshole seismic and resistivity data, tomography produces a 3-D rendition of the subsurface. The level of detail possible depends upon the distance between holes, the power of the source, and the properties of the rock or soil mass. The method can be used for both indurated and nonindurated geomaterials.

### **5-13. Borehole Viewing and Photography**

The interpretation of subsurface conditions solely by observation, study, and testing of rock samples recovered from core borings often imposes an unnecessary limitation in obtaining the best possible picture of the site subsurface geology. The sidewalls of the borehole from which the core has been extracted offer a unique picture of the subsurface where all structural features of the rock formation are still in their original position. This view of the rock can be important, particularly if portions of rock core have been lost during the drilling operation and if the true dip and strike of the structural features are required. Borehole viewing and photography equipment includes borescopes, photographic cameras, TV cameras, sonic imagery loggers, caliper loggers, and alinement survey devices. Sonic imagery and caliper loggers are discussed in detail in EM 1110-1-1802. Alinement survey services are available from commercial logging or drilling firms and from the U.S. Army Engineer Waterways Experiment Station (CEWES-GG-F). Borehole viewing systems and services are often obtained now from private industry or from the few COE offices that have the capabilities.

#### **5-14. Borehole Camera and Borescope**

Borehole film cameras that have limited focus capability are satisfactory for examining rock features on the sidewalls of the borehole. However, the small viewing area and limited focus reduce the usefulness in borings that have caved or that have cavities. They are best used for examining soft zones for which core may not have been recovered in drilling, for determination of the dip and strike of important structural features of the rock formation, and to evaluate the intrusion of grout into the rock mass. The camera's film must be processed before the images can be examined. The borescope, basically a tubular periscope, has limited use because of its small viewing area, limited depth, and cumbersome operation. It is relatively inexpensive to use, however.

#### **5-15. Borehole TV Camera and Sonic Imagery**

The TV camera has variable focus and is suitable for examining the nature and approximate dimensions of caving sections of open boreholes or boreholes filled with clear water. The TV camera provides both real-time imagery and a permanent record of the viewing session. The sonic imagery (televiewer) system uses acoustic pulses to produce a borehole wall image and can be used in a hole filled with drilling mud. The TV camera is used to examine cavities in the rock such as solution voids in calcareous formations, open cooling joints, and lava tunnels in volcanic rocks, mines, tunnels, and shafts. Most TV systems are capable of both axial (downhole) and radial (sidewall) viewing. The televiewer can be used to distinguish fractures, soft seams, cavities, and other discontinuities. Changes in lithology and porosity may also be distinguished. Specially designed borehole television cameras and sonic imagers or televiewers can be used to determine the strike and dip of discontinuities in the borehole wall. The Corps of Engineers has this capability at the U.S. Army Engineer District, Walla Walla, WES, and the U.S. Army Engineer Division Laboratory, Southwestern.

#### **5-16. Alinement Surveys**

Alinement surveys are often necessary if the plumbness and/or orientation of a hole is important. Older methods employed a compass and photograph system which was relatively easy to use. More modern systems are electronic. Alinement surveys may be critical in deep holes where instrumentation packages are to be installed or where precise determinations of structural features in the rock formation are required.

#### *Section IV* *Exploratory Excavations*

#### **5-17. Test Pits and Trenches**

Test pits and trenches can be constructed quickly and economically by bulldozers, backhoes, pans, draglines, or ditching machines. Depths generally are less than 6 to 9 m (20 to 30 ft), and sides may require shoring if personnel must work in the excavations. Test pits, however, hand dug with pneumatic jackhammers and shored with steel cribbing, can be dug to depths exceeding 18 m (60 ft). Test pits and trenches generally are used only above the ground water level. Test pits that extend below the water table can be kept open with air or electric powered dewatering pumps. Exploratory trench excavations are often used in fault evaluation studies. An extension of a rock fault into much younger overburden materials exposed by trenching is usually considered proof of recent fault activity. Shallow test pits are commonly used for evaluating potential borrow areas, determining the geomorphic history, and assessing cultural resource potential.

## 5-18. Calyx Hole Method

Large-diameter calyx holes have been used successfully on some jobs to provide access for direct observation of critical features in the foundations. These holes are very expensive to drill (possibly \$2,300 per meter or \$700 per foot), so their use is very limited. However, where in situ observation of a very sensitive feature, such as a shear zone or solution feature in the abutment of an arch dam, cannot be achieved reasonably by any other means, the calyx hole may be the procedure of choice.

### *Section V*

#### *Ground Water and Foundation Seepage Studies*

## 5-19. General Investigation

The scope of ground water studies is determined by the size and nature of the proposed project. Efforts can range from broad regional studies at a reservoir project to site-specific studies, such as pumping tests for relief well design, water supply at a recreational area, or pressure tests performed to evaluate the need for foundation grouting. Ground water studies include observations and measurements of flows from springs and of water levels in existing production wells, boreholes, selected observation wells, and piezometers. This information is used with site and regional geologic information to determine water table or piezometric surface elevations and profiles, fluctuations in water table elevations, the possible existence and location of perched water tables, depths to water-bearing horizons, direction and rate of seepage flow, and potential for leakage from a proposed reservoir or beneath an embankment or levee. Complex investigations are made only after a thorough analysis has been made of existing or easily acquired data. Results from ground water and foundation seepage studies provide data needed to design dewatering and seepage control systems at construction projects, indicate the potential for pollution and contamination of existing ground water resources due to project operation, show potential for interference to aquifers by the construction of a project, and determine the chemical and biological quality of ground water and that relationship to project requirements. Investigation and continued monitoring of ground water fluctuations are key dam safety issues.

*a. Wells.* Existing wells located during field geologic reconnaissance should be sounded or water levels obtained from the well owners. Pumping quantities, seasonal variations in ground water and pumping levels, depths of wells and screen elevations, corrosion problems, and any other relevant information should be acquired wherever available. Any settlement records attributable to ground water lowering from pumping should be obtained. This information should be compared with water well records obtained during preliminary studies to develop a complete hydrologic picture for the project area.

*b. Borings.* Water levels recorded on drilling logs are another source of information. However, they may not reflect true water levels, depending on soil types and time of reading after initial drilling. The influence of drilling fluids on water level readings should be kept in mind when evaluating boring data. Loss of drilling fluids can indicate zones of high permeability. Where ground water level information is needed, installation of piezometers or observation wells in borings should be considered.

*c. Piezometers and observation wells.* The most reliable means for determining ground water levels is to install piezometers or observation wells. Piezometers measure excess hydrostatic pressures beneath dams and embankments. All information developed during preliminary studies on the regional ground water regime should be considered in selecting locations for piezometers and observation wells. For types of piezometers, construction details, and sounding devices, refer to EM 1110-2-1908, Part 1,

and TM 5-818-5/AFM 88-5, Chapter 6/NAVFAC P-418. All piezometer borings should be logged carefully and “as built” sketches prepared that show all construction and backfill details (Figure 5-2).

(1) The selection of the screened interval is critical to the information produced, since the water level recorded will be the highest of all intervals within the screen/filter length. Careful evaluation of the conditions encountered in the hole with regard to perched or confined aquifers is essential to a sensible selection of the screened interval and interpretation of the data. One of the greatest benefits of a piezometer or observation well is that it allows for measurement of fluctuations in piezometric levels over time. To take advantage of this benefit, it is necessary to provide for periodic readings. This can be accomplished through manual reading by an automated system, depending on the location and critical importance of the area being monitored.

(2) Other information that can be derived from observation wells and piezometers are temperature and water quality data. Tracer tests can sometimes be conducted to determine the direction and rate of ground water flow.

*d. Springs and surface water.* The water elevation, flow rate, and temperature of all springs located within the project area should be measured. Water should be sampled for chemical analysis to establish a baseline level. Soil or rock strata at the spring should be evaluated to locate permeable horizons. Flow rates at springs should be measured during dry and wet seasons to determine the influence of rainfall on seepage conditions. The elevation of water levels in lakes and ponds should be measured during the wet and dry seasons to evaluate the extent of surface water fluctuations.

*e. Geophysical methods.* Geophysical methods, such as seismic refraction, can be used to determine the depth to saturated material. Depending on the accuracy required and the accuracy of the method, a minimal number of piezometers should be installed to verify the geophysical data. Surface resistivity surveys can indicate the presence of and depth to water (Society of Exploration Geophysicist 1990). Ground penetrating radar can also be used to detect the presence and location of ground water (Annan 1992). Fetter (1988) discusses these and other geophysical methods to characterize the hydrology and hydrogeology of a site.

*f. Tracer testing.* In some areas, especially karst terrains, it is of particular interest to determine flow paths in the ground water system. Although complex, flow paths in karst, where seepage velocities are high, can be evaluated by conducting tracer tests using either environmentally benign dyes or biological tracers such as pollen. The tracer element is introduced into a boring or other access points and monitored at an exit point such as a spring. The travel time from the introduction to detection is recorded. Numerous tests at different locations can be run and a picture of the ground water flow regime developed.

## **5-20. Permeability Testing**

Permeabilities of foundation materials can be determined from slug and pumping tests in piezometers and wells, laboratory tests of undisturbed samples, and pressure tests in rock foundations. The permeability of sands can be roughly estimated from the  $D_{10}$  fraction (TM 5-818-5). Fracture and joint analysis is important in evaluating permeability of rock foundations. General reviews of methods to evaluate permeability of soil and rock in the subsurface include Bentall (1963), Davis and DeWiest (1966), Dawson and Istok (1991), Driscoll (1986), Fetter (1988), Heath (1983), Lohman (1972), and Walton (1970).