



PDHonline Course C252 (4 PDH)

Boring Log Preparation

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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.

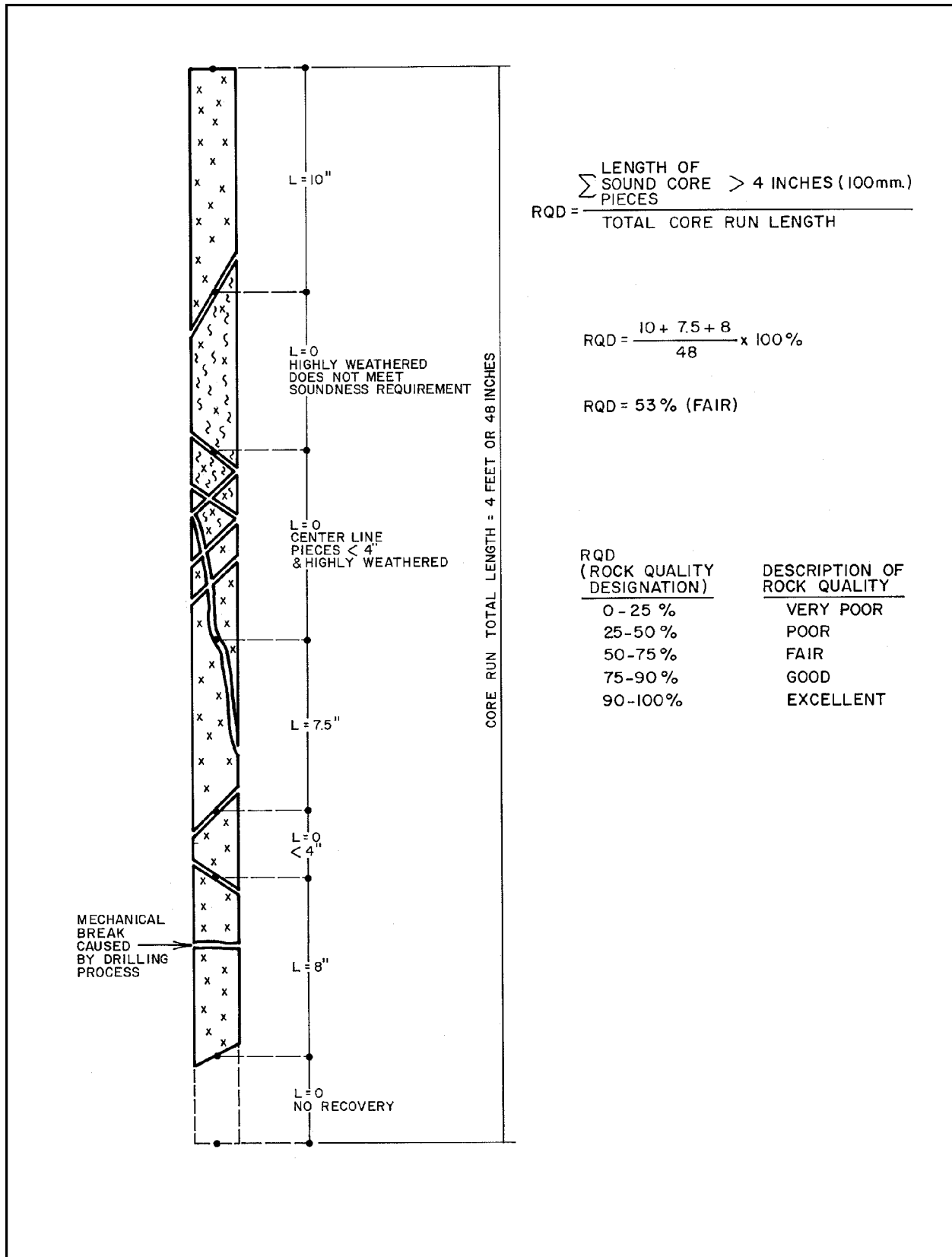


Figure 5-1. Illustration of Deere and Deere (1989) modified procedure for calculating RQD

(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 re-drilling. 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.