Chapter 3
Field Investigations and Laboratory Testing

3-1. Geological and Subsurface Explorations and Field Tests

a. General requirements.

(1) Geological and subsurface investigations at the sites of structures and at possible borrow areas must be adequate to determine suitability of the foundation and abutments, required foundation treatment, excavation slopes, and availability and characteristics of embankment materials. This information frequently governs selection of a specific site and type of dam. Required foundation treatment may be a major factor in determining project feasibility. These investigations should cover classification, physical properties, location and extent of soil and rock strata, and variations in piezometric levels in groundwater at different depths.

(2) A knowledge of the regional and local geology is essential in developing a plan of subsurface investigation, interpreting conditions between and beyond boring locations, and revealing possible sources of trouble.

(3) The magnitude of the foundation exploration program is governed principally by the complexity of the foundation problem and the size of the project. Explorations of borrow and excavation areas should be undertaken early in the investigational program so that quantities and properties of soils and rock available for embankment construction can be determined before detailed studies of embankment sections are made.

(4) Foundation rock characteristics such as depth of bedding, solution cavities, fissures, orientation of joints, clay seams, gouge zones, and faults which may affect the stability of rock foundations and slopes, particularly in association with seepage, must be investigated to determine the type and scope of treatment required. Furthermore, foundations and slopes of clay shales (compaction shales) often undergo loss in strength under reduction of loading or by disintegration upon weathering. Careful investigation of stability aspects of previous excavations and of natural slopes should be made. Foundations of clay shales should be assumed to contain sufficient fissures so that the residual shear strength is applicable unless sufficient investigations are made to prove otherwise.

(5) Procedures for surface and subsurface geotechnical investigations and geophysical explorations are given in EM 1110-1-1804 and EM 1110-1-1802, respectively. Soil sampling equipment and procedures are discussed in Appendix F, EM 1110-1-1804.

b. Foundations.

(1) The foundation is the valley floor and terraces on which the embankment and appurtenant structures rest. Comprehensive field investigations and/or laboratory testing are required where conditions such as those listed below are found in the foundation:

(a) Deposits that may liquefy under earthquake shock or other stresses.

(b) Weak or sensitive clays.

(c) Dispersive soils.

(d) Varved clays.

(e) Organic soils.

(f) Expansive soils, especially soils containing montmorillonite, vermiculite, and some mixed layer minerals.

(g) Collapsible soils, usually fine-grained soils of low cohesion (silts and some clays) that have low natural densities and are susceptible to volume reductions when loaded and wetted.

(h) Clay shales (compaction shales) that expand and lose strength upon unloading and/or exposure to weathering frequently have low in situ shear strengths. Although clay shales are most troublesome, all types of shales may present problems when they contain sheared and slickensided zones.

(i) Limestones or calcareous soil deposits containing solution channels.

(j) Gypsiferous rocks or soils.

(k) Subsurface openings from abandoned mines.

(l) Clay seams, shear zones, or mylonite seams in rock foundations.

(m) Rock formations in which the rock quality designation (RQD) is low (less than 50 percent).

(2) Subsurface investigation for foundations should develop the following data:

(a) Subsurface profiles showing rock and soil materials and geological formations, including presence of faults, buried channels, and weak layers or zones. The RQD is useful in the assessment of the engineering qualities of bedrock (see Deere and Deere 1989).

(b) Characteristics and properties of soils and the weaker types of rock.

(c) Piezometric levels of groundwater in various strata and their variation with time including artisan pressures in rock or soil.

(3) Exploratory adits in abutments, test pits, test trenches, large-diameter calyx holes, and large-diameter core boring are often necessary to satisfactorily investigate foundation and abutment conditions and to investigate reasons for core losses or rod droppings. Borehole photography and borehole television may also be useful. Core losses and badly broken cores often indicate zones that control the stability of a foundation or excavation slope and indicate a need for additional exploration.

(4) Estimates of foundation permeability from laboratory tests are often misleading. It is difficult to obtain adequate subsurface data to evaluate permeability of gravelly strata in the foundation. Churn drilling has often proven satisfactory for this purpose. Pumping tests are required in pervious foundations to determine foundation permeability where seepage cutoffs are not provided or where deep foundation unwatering is required (see EM 1110-2-1901).

c. Abutments. The abutments of a dam include that portion of the valley sides to which the ends of the dam join and also those portions beyond the dam which might present seepage or stability problems affecting the dam. Right and left abutments are so designated looking in a downstream direction. Abutment areas require essentially the same investigations as foundation areas. Serious seepage problems have developed in a number of cases because of inadequate investigations during design.

d. Valley walls close to dam. Underground river channels or porous seepage zones may pass around the abutments. The valley walls immediately upstream and downstream from the abutment may have steep natural slopes and slide-prone areas that may be a hazard to tunnel approach and outlet channels. Such areas should be investigated sufficiently to determine if corrective measures are required.

e. Spillway and outlet channel locations. These areas require comprehensive investigations of the orientation and quality of rock or firm foundation stratum. Explorations should provide sufficient information on the overburden and rock to permit checking stability of excavated slopes and determining the best utilization of excavated material within the embankment. Where a spillway is to be located close to the end of a dam, the rock or earth mass between the dam and spillway must be investigated carefully.

f. Saddle dams. The extent of foundation investigations required at saddle dams will depend upon the heights of the embankments and the foundation conditions involved. Exploratory borings should be made at all such structures.

g. Reservoir crossings. The extent of foundation investigations required for highway and railway crossing of the reservoir depends on the type of structure, its height, and the foundation conditions. Such embankments may be subjected to considerable wave action and require slope protection. The slope protection will be designed for the significant wave based on a wave hind cast analysis as described in Appendix C and the referenced design document. Select the design water level and wind speed based on an analysis of the risk involved in failure of the embankment. For example, an evacuation route needs a higher degree of protection, perhaps equal to the dam face, than an access road to a recreational facility which may be cheaper to replace than to protect.

h. Reservoir investigations. The sides and bottom of a reservoir should be investigated to determine if the reservoir will hold water and if the side slopes will remain stable during reservoir filling, subsequent drawdowns, and when subjected to earthquake shocks. Detailed analyses of possible slide areas should be made since large waves and overtopping can be caused by slides into the reservoir with possible serious consequences (see Hendron and Patton 1985a, 1985b). Water table studies of reservoir walls and surrounding area are useful, and should include, when available, data on local water wells. In limestone regions, sinks, caverns, and other solution features in the reservoir walls should be studied to determine if reservoir water will be lost through them. Areas containing old mines should be studied. In areas where there are known oil fields, existing records should be surveyed and reviewed to determine if plugging old wells or other treatment is required.

i. Borrow areas and excavation areas. Borrow areas and areas of required excavation require investigations to delineate usable materials as to type, gradation, depth, and extent; provide sufficient disturbed samples to determine permeability, compaction characteristics, compacted shear strength, volume change characteristics, and natural water contents; and provide undisturbed samples to ascertain the natural densities and estimated yield in each area. The organic content or near-surface borrow soils should be investigated to establish stripping requirements. It may be necessary to leave a natural impervious blanket over pervious material in upstream borrow areas for underseepage control. Of prime concern in considering possible valley bottom areas upstream of the embankment is flooding of these bottom areas. The sequence of construction and flooding must be studied to ensure that sufficient borrow materials will be available from higher elevations or stockpiles to permit completion of the dam. Sufficient borrow must be in a nonflooding area to complete the embankment after final closure, or provision must be made to stockpile low-lying material at a higher elevation. The extent of explorations will be determined largely by the degree of uniformity of conditions found. Measurements to determine seasonal fluctuation of the groundwater table and changes in water content should be made. Test pits, dozer trenches, and large-diameter auger holes are particularly valuable in investigating borrow areas and have additional value when left open for inspection by prospective bidders.

j. Test quarries. The purposes of test quarries are to assist in cut slope design, evaluate the controlling geologic structure, provide information on blasting techniques and rock fragmentation, including size and shape of rocks, provide representative materials for test fills, give prospective bidders a better understanding of the drilling and blasting behavior of the rock, and determine if quarry-run rock is suitable or if grizzled rock-fill is required (see EM 1110-2-2302).

k. Test fills. In the design of earth and rock-fill dams, the construction of test embankments can often be of considerable value, and in some cases is absolutely necessary. Factors involved in the design of earth and rock-fill dams include the most effective type of compaction equipment, lift thickness, number of passes, and placement water contents; the maximum particle size allowable; the amount of degradation or segregation during handling and compaction; and physical properties such as compacted density, permeability, grain-size distribution, and shear strength of proposed embankment materials. Often this information is not available from previous experience with similar borrow materials and can be obtained only by a combination of test fills and laboratory tests. Test fills can provide a rough estimate of permeability through observations of the rate at which water drains from a drill hole or from a test pit in the fill. To measure the field permeability of test fills, use a double-ring infiltrometer with a sealed inner ring (described in ASTM D 5093-90; see American Society for Testing and Materials 1990). It is important that test fills be performed on the same materials that will be used in construction of the embankment. The test fills shall be performed with the same quarry or borrow area materials which will be developed during construction and shall be compacted with various types of equipment to determine the most efficient type and required compaction effort. It is imperative that as much as possible all materials which may be encountered during construction be included in the test fills. Equipment known not to be acceptable should be included in the test fill specifications so as not to leave any "gray areas" for possible disagreements as to what will or will not be acceptable. Plans and specifications for test quarries and test fills of both earth and rock-fill materials are to be submitted to the Headquarters, U.S. Army Corps of Engineers, for approval. Test fills can often be included as part of access road construction but must be completed prior to completion of the embankment design. Summarized data from rock test fills for several Corps of Engineers projects are available (Hammer and Torrey 1973).

l. Retention of samples. Representative samples from the foundation, abutment, spillway excavation, and borrow areas should be retained and stored under suitable conditions at least until construction has been completed and any claims settled. Samples should be available for examination or testing in connection with unexpected problems or contractor claims.

3-2. Laboratory Testing

a. Presentation. A discussion of laboratory tests and presentation of test data for soils investigations in connection with earth dams are contained in EM 1110-2-1906. Additional information concerning laboratory compaction of earth-rock mixtures is given by Torrey and Donaghe (1991a, 1991b) and Torrey (1992). Applicability of the various types of shear tests to be used in stability analyses for earth dams is given in EM 1110-2-1902. Rock testing methods are given in the *Rock Testing Handbook* (U.S. Army Corps of Engineers 1990). Since shear strength tests are expensive and time-consuming, testing programs are generally limited to representative foundation and borrow materials. Samples to be tested should be selected only after careful analysis of boring logs, including index property determinations. Mixing of different soil strata for test specimens should be avoided unless it can be shown that mixing of different strata during construction will produce a fill with characteristics identical to those of the laboratory specimens.

b. Procedure. Laboratory test procedures for determining all of the properties of rock-fill and earth-rock mixtures have not been standardized (see Torrey and Donaghe 1991a, 1991b; Torrey 1992). A few division laboratories have consolidation and triaxial compression equipment capable of testing 12-in.-diam specimens.

c. Sample. For design purposes, shear strength of rock-fill and earth-rock mixtures should be determined in the laboratory on representative samples obtained from test fills. Triaxial tests should be performed on

specimens compacted to in-place densities and having grain-size distributions paralleling test fill gradations. Core samples crushed in a jaw crusher or similar device should not be used because the resulting gradation, particle shape, and soundness are not typical of quarry-run material. For 12-in.-diameter specimens, maximum particle size should be 2 in.