Chapter 4
Field Investigations

4-1. General

As previously shown in Table 2-1 for the feasibility phase and the preconstruction engineering and design phase of project development, geotechnical field investigations may be divided into two stages: Site Selection and Initial Field Investigations, and Foundation and Design Investigations. The need for this division depends on the planned size and complexity of the project. As a simple rule of thumb, if there is an envisioned need for test quarry and test fill operations, the two stages of field investigations are probably justified. Figures 4-1 and 4-2 show the required investigation steps for the two investigations stages. Guidance specific to the layout and conduct of the field investigations required to locate and design test quarry operations is provided in the following paragraphs.

4-2. Geologic Mapping

Surface geologic maps of potential test quarry sites should be prepared during the areal and site geotechnical mapping phase of the site selection investigations. The regional geologic maps, developed during the reconnaissance phase, commonly will have scales of 1:62,500 or larger. Depending on the size of the project, the areal (e.g. reservoir) geologic maps prepared during the current investigations phase may have scales of between 1:12,000 and 1:62,500. Structure site geologic maps would have scales of from 1:1,200 to 1:4,800. Potential test quarry sites should be mapped at scales comparable to larger scale site maps. The scales should be such that soil and rock type contacts can be shown, the location and shape of individual outcrop areas can be plotted, observed bedding and joint symbols can be plotted without cluttering the map, planned surface geophysical and core boring exploration plans can be shown, and planned excavation layouts can be shown. The outcrop mapping method is best for this type of work. An excellent reference for this type of mapping is Compton (1962). The geologic map produced and accompanying test data should include a complete lithologic classification description of the rock types present. In addition, the degree of weathering existing in the rocks at the site should be detailed.

4-3. Geophysical Investigations

Detailed guidance and information concerning the use of exploration geophysical methods and equipment are contained in EM 1110-1-1802. Of specific interest in quarry site explorations are: overburden depths, location and orientation of rock contacts, groundwater depths, seismic velocities, and rippability. Of the available surface geophysical exploration methods, seismic refraction, reflection profiling, and electrical resistivity are relatively economical and will provide the required information. Of the available borehole methods, up and downhole seismic, and electrical logging will provide the appropriate data. The spacing of surface seismic and electrical resistivity lines should be a function of the variability of top of rock elevations and rock-type distribution as inferred from the detailed geologic mapping.

4-4. Subsurface Explorations

The subsurface explorations stage can be carried out concurrently with or toward the end of the surface geophysical stage. Lagging behind the start of surface geophysics allows the results of the geophysical profiling to assist in the layout of the boreholes. Conversely, borehole information will assist in the interpretation of the geophysical data.

a. Core borings. For the purposes of exploring the sites of proposed rock excavations and test quarries, with rare exception, rock core borings are the most suitable drilling method. For most investigations in hard rock, "N" size diamond core borings which acquire a nominal 5.1 cm (2-in.) diameter core are satisfactory. For soft and/or highly fractured rocks, "H" size (nominal 7.6 cm (3-in.) diameter cores) or 10.2 cm to 14.0 cm (4 in. to 5.5 in.) diamond core borings may be necessary. As with the spacing of surface geophysics lines, the number and spacing of exploratory borings is a function of the anticipated rock variability. The borings should be arranged to facilitate the preparation of geologic cross sections with the borings at the ends of the anticipated cross sections outside the planned excavation limits; interpolation is much less risky than extrapolation. Borings should be located at the intersection of geophysical profiles to assist in correlation. Depending on the surface mapping results, it may be necessary to drill a number of angle holes to eliminate bias in borehole fracture surveys. Barring other

SITE SELECTION INVESTIGATIONS

DATA COLLECTION

AREAL AND SITE GEOTECHNICAL MAPPING

Prepare area and site maps for each candidate site; distribution of surface materials; outcrop locations; rock structure; springs; slope conditions; potential hazards; determine boring and geophysical survey locations.

GROUNDWATER DATA

Review data; compile water well and other piezometric data; determine needed additional data; start field collections

SURFACE GEOPHYSICAL SURVEYS

Subsurface material distribution at potential structure sites and quarry and borrow areas; water table depths; data on electrical and elastic material properties. If needed, start special surveys (e.g. to obtain dynamic properties or void detection)

SUBSURFACE EXPLORATIONS

Borings at potential structure and quarry and borrow areas; log soil and rock types, rock structure and drilling conditions; water pressure or pumping tests; camera or TV surveys; in hole geophysical surveys for correlation and, where needed, special properties.

MATERIAL TESTING

Classification and index tests on foundation, quarry and borrow materials; preliminary special tests where needed (e.g. for dynamic analyses).

DATA ANALYSIS

AREAL CONDITIONS

Compile geologic maps of project areas; show all pertinent geologic and soils conditions (e.g. landslides, sinkholes, potential reservoir leakage locations, etc.); develop geologic profiles; locate mineral resources.

SITE CONDITIONS

Compile detailed geology maps for each site; develop geologic sections; classify soils; describe rock types; show rock structure and fracturing; describe ground water conditions and hydraulic characteristics of materials; describe rock weathering; assess test results, discuss soil and rock engineering properties.

GROUNDWATER CONDITIONS

Determine extent and mode of project induced changes in ground water regime; show predicted changes for aquifers; discuss predicted impact on water supplies and water sensitive habitats.

EARTHQUAKE ANALYSES

Determine design earthquakes for each site; perform preliminary dynamic analyses; evaluate foundation areas for liquefaction and potential fault movement.

CONSTRUCTION MATERIALS

Locate and describe proposed quarry and borrow sites; prepare detailed geologic maps and sections for each; determine available volummes of material and depths of burden; describe properties; assess commercial sources.

MINERAL AND OTHER RESOURCES

Determine location and extent of resources which may be impacted by project.

Project areal and site geotechnical conditions developed and defined to extent necessary to select most effective and economical site, develop reliable cost estimates and to initiate detailed design studies. Environmental and HTRW conditions are defined and input to impact statements completed.

Figure 4-1. Schematic diagram of initial and site-selection investigations (adapted from EM 1110-1-1804)

considerations, or purposes for the borings, the depths of the core borings should be 1.25 to 1.33 times the depth from the ground surface to the bottom of the planned excavation.

DESIGN INVESTIGATIONS

DATA COLLECTION

ENVIRONMENTAL/GROUNDWATER
Continue needed ground water data collection; observation well readings, pump tests, etc.; collect geotechnical data needed to update environmental assessments.

SUBSURFACE EXPLORATIONS
Expand coverage at selected structure sites, excavations, material sources and relocations; log soil and rock types, structure and drilling conditions.

BOREHOLE PHOTOGRAPHY/TV
Obtain fracture frequency, orientation and aperture; macrotextural and structural features; boring wall condition.

BOREHOLE GEOPHYSICS
Expand coverage with non-core borings; obtain in situ properties and stratigraphic correlation.

WATER PRESSURE AND/OR PUMPING TESTS
Obtain permeabilities; monitor water levels.

MATERIAL TESTING
Complete classification and index testing; perform engineering properties tests; continue and complete special testing started in earlier stages.

EXPLORATORY EXCAVATIONS AND CONSTRUCTIONS
Trenches, pits, adits, calyx holes, test quarries and borrows, test fills, test grout panels, etc.; in situ examination; in situ materials properties tests.

INSTRUMENTATION
Install and initiate readings on foundation instrumentation (e.g. piezometer, slope indicators) to develop baseline conditions.

DATA ANALYSIS

GROUND WATER CONDITIONS/ASSESSMENT
Continue analyses started in earlier program; finalize statement of project impact on ground water.

PROJECT SITE CONDITIONS
Update site geologic maps, geologic sections, rock and soils classifications, rock structure, material hydraulic characteristics, ground water conditions; complete design earthquake, reservoir leakage, and other special studies.

STRUCTURE/EXCAVATION SITE CONDITIONS
Develop detailed distribution of subsurface materials, select pertinent engineering properties for each material; complete dynamic analyses; analyze data and describe encountered conditions from any test excavations, quarries, grout programs, etc.; discuss all conditions effecting design decisions.

CONSTRUCTION MATERIALS
Finalize volume estimates; show distribution of subsurface materials and their properties; analyze and describe results from test fills; finalize assessment of commercial materials sources.

INSTRUMENTATION
Reduce data from various sources; correlate data with events occurring; produce baseline plots for construction and post construction conditions.

RELOCATIONS
Develop pertinent data for each relocations increment in the same manner as structure/excavation sites.

Geotechnical conditions developed in sufficient detail to establish final design and operating requirements for a safe, functional project, develop design details, prepare final cost estimates, prepare plans and specifications, negotiate relocation agreements, acquire necessary lands and complete environmental and HTRW assessments.

Figure 4-2. Schematic diagram for design investigations (adapted from EM 1110-1-1804)

b. Drilling, inspection, and sampling. General guidance for drilling, inspection, and core logging is contained in EM 1110-1-1804. The U.S. Bureau of Reclamation Engineering Geology Field Manual (1989) and Murphy (1985) contain comprehensive information on both core and soils logging and on rock mass descriptions. All of the rock descriptors recommended in the cited references are important to test quarry applications. Of particular importance are weathering, presence of clay or gouge seams, and the in situ gradation. Given a rock material of certain hardness and density, these types of descriptors will form the basis for estimates of waste and the need for and design of rock processing equipment. The degree of weathering should be described according to some standard such as that contained in EM 1110-1-1804. In situ fracture frequency and orientation can provide the information required to calculate in situ rock block-size distribution. In addition, correlations have been developed between rock-quality designation (RQD) and mean fracture frequency. The general use of RQD is treated in ETL 1110-1-145. When logging rock core, in addition to logging core loss and RQD, the geologist/inspector should note the depth and angle (with respect to borehole axis) of every identifiable fracture and note its genesis (joint, bedding plane, drill break, etc.). As a practical matter, when the fracture spacing is less than 3.0 cm (0.1 ft), that interval of core may be logged as “broken.” This data will allow the prediction of in situ rock block-size distributions. In addition, it will be of value for the geologist/inspector to note those parameters which are used in currently popular rock mass classification systems such as “RMR” or “Q” systems (ASTM 1988). The use of rock mass classification systems is discussed further in Chapters 6 and 7. Information and guidance on sampling and sample preservation of soils and rock core are contained in EM 1110-1-1906, and ASTM Designations: D 4220 (ASTM 1994a) and D 5079 (ASTM 1994b). Sample preservation for moisture content is generally not necessary in hard, crystalline rocks. Such rocks generally exhibit intact rock material porosities less than one percent and moisture content is inconsequential to densities and other parameters. In softer sedimentary or chemical precipitate rocks, the porosities are sufficiently great that moisture content does affect bulk densities and other parameters. In these rocks, the geologist/inspector should select and preserve representative samples for moisture content determinations.

c. Borehole examination and in-hole testing. Borehole examination and in-hole testing includes borehole photography, TV and sonic imaging, borehole geophysics, hydraulic or water pressure testing, water table measurements, and in-hole deformation or jacking tests. Guidance and information on these methods are contained in EM 1110-1-1802, EM 1110-1-1804, the Corps of Engineers Rock Testing Handbook (USAEWES 1993), and the U.S. Bureau of Reclamation Engineering Geology Field Manual (1989). The borehole geophysical methods most pertinent to test quarry explorations have been described in paragraph 4-3. Tests to determine in situ stresses would be warranted only if there were indications of abnormally high horizontal stresses which might affect excavation slope stability and markedly affect rock breakage. For test quarry explorations, water pressure testing normally would not be necessary. Water table measurements are necessary for excavation slope and dewatering design purposes. For test quarry explorations, borehole photography, TV, and sonic imaging are the most important measurements. Because they provide detailed information on rock structure, these measurements will provide input to design analyses of probable rock waste, in situ rock block-size distribution, trial blast patterns and loading, and rock excavation slope stability calculations and slope design.