Chapter 2
Field Investigations

2-1. Preliminary and Final Stage

Many field investigations are conducted in two stages: a preliminary stage and a final (design) stage. Normally, a field investigation in the preliminary stage is not extensive since its purpose is simply to provide general information for project feasibility studies. It will usually consist of a general geological reconnaissance with only limited subsurface exploration and simple soil tests. In the design stage, more comprehensive exploration is usually necessary, with more extensive geological reconnaissance, borings, test pits, and possibly geophysical studies. The extent of the field investigation depends on several factors. Table 2-1 lists these factors together with conditions requiring extensive field investigations and design studies. Sometimes field tests such as vane shear tests, groundwater observations, and field pumping tests are necessary. Table 2-2 summarizes, in general, the broad features of geologic and subsurface investigations.

Section I
Geological Study

2-2. Scope

A geological study usually consists of an office review of all available geological information on the area of interest and an on-site (field) survey. Since most levees are located in alluvial floodplains, the distribution and engineering characteristics of alluvial deposits in the vicinity of proposed levees must be evaluated. The general distribution, nature, and types of floodplain deposits are directly related to changes in the depositional environment of the river and its tributaries. Each local area in the floodplain bears traces of river action, and the alluvial deposits there may vary widely from those in adjacent areas. The general nature and distribution of sediments can be determined through a study of the pattern of local river changes as a basis for selection of boring locations.

Table 2-1
Factors Requiring Intensive Field Investigations and Design Studies

Factor	Field Investigations and Design Studies Should be more Extensive Where:
Previous experience	There is little or no previous experience in the area particularly with respect to levee performance
Consequences of failure	Consequences of failure involving life and property are great (urban areas for instance)
Levee height	Levee heights exceed 3 m (10 ft)
Foundation conditions	Foundation soils are weak and compressible
	Foundation soils are highly variable along the alignment
	Potential underseepage problems are severe
	Foundation sands may be liquefaction susceptible
Duration of high water	High water levels against the levee exist over relatively long periods
Borrow materials	Available borrow is of low quality, water contents are high, or borrow materials are variable along the alignment
Structure in levees	Reaches of levees are adjacent to concrete structures

Table 2-2
Stages of Field Investigations

1. Investigation or analysis produced by field reconnaissance and discussion with knowledgeable people is adequate for design where:

   a. Levees are 3 m (10 ft) or less in height.

   b. Experience has shown foundations to be stable and presenting no underseepage problems.

   Use standard levee section developed through experience.

2. *Preliminary geological investigation*:

   a. Office *study*: Collection and study of

   (1) Topographic, soil, and geological maps.
   (2) Aerial photographs.
   (3) Boring logs and well data.
   (4) Information on existing engineering projects.

   b. *Field survey*: Observations and geology of area, documented by written notes and photographs, including such features as:

   (1) Riverbank slopes, rock outcrops, earth and rock cuts or fills.
   (2) Surface materials.
   (3) Poorly drained areas.
   (4) Evidence of instability of foundations and slopes.
   (5) Emerging seepage.
   (6) Natural and man-made physiographic features.

3. *Subsurface exploration and field testing and more detailed geologic study*: Required for all cases except those in 1 above. Use to decide the need for and scope of subsurface exploration and field testing:

   a. *Preliminary phase*:

   (1) Widely but not necessarily uniformly spaced disturbed sample borings (may include split-spoon penetration tests).
   (2) Test pits excavated by backhoes, dozers, or farm tractors.
   (3) Geophysical surveys (e.g., seismic or electrical resistivity) or cone penetrometer test to interpolate between widely spaced borings.
   (4) Borehole geophysical tests.

   b. *Final phase*:

   (1) Additional disturbed sample borings.
   (2) Undisturbed sample borings.
   (3) Field vane shear tests for special purposes.
   (4) Field pumping tests (primarily in vicinity of structures).
   (5) Water table observations (using piezometers) in foundations and borrow areas.

2-3. Office Study

The office study begins with a search of available information, such as topographic, soil, and geological maps and aerial photographs. Pertinent information on existing construction in the area should be obtained. This includes design, construction, and performance data on utilities, highways, railroads, and hydraulic structures. Available boring logs should be secured. Federal, state, county, and local agencies and private organizations should be contacted for information. The GIS (Geographic Information System) became used extensively in major range of projects. It is capable of compiling large multi-layered data bases, interactively analyzing and manipulating those data bases, and generating and displaying resultant thematic maps and statistics to aid in engineering management decisions. Federal, state, and private organizations provide free internet access to such systems. Table 2-3 shows some of the contour maps GIS systems provide.

Table 2-3
Types of Contour Maps

Contour Type	Uses	
Geologic Structure Elevation Maps	Contour maps in which each line represents the elevation of the top of a geological material or facies	GIS can produce these maps based on the selection of one of four structure parameters
Geologic formations	Contours the top of a user-defined geologic formation	
Blow counts	Contours the top of a structure identified by the first, second, or third occurrence of a specified range of blow counts	A blow count is defined as the number of standard blows required to advance a sampling device into 150 mm (6 in.) of soil
Soil units	Contours the top of a structure identified by the first, second, or third occurrence of one or more soil types	
Fluid level elevation - water table contour maps	Show elevation data (hydraulic head) from unconfined water bearing units where the fluid surface is in equilibrium with atmospheric pressure	Help to evaluate the direction of ground water flow and the energy gradient under which it is flowing
Fluid level elevation - potentiometric surface maps	Show elevation data from confined water bearing units where the fluid surface is under pressure because of the presence of a confining geologic unit	
Hydraulic conductivity	Show the rate of water flow through soil under a unit gradient per unit area	GIS stores vertical and horizontal conductivity data for up to five water bearing zones
	Portray the variations in the water-bearing properties of materials which comprise each water bearing zone	Necessary parameter for computing ground water flow rates, which is important since groundwater velocity exerts a major control on plume shape

2-4. Field Survey

The field survey is commenced after becoming familiar with the area through the office study. Walking the proposed alignment and visiting proposed borrow areas are always an excellent means of obtaining useful information. Physical features to be observed are listed in Table 2-2. These items and any others of significance should be documented by detailed notes, supplemented by photographs. Local people or organizations having knowledge of foundation conditions in the area should be interviewed.

2-5. Report

When all available information has been gathered and assimilated, a report should be written that in essence constitutes a geological, foundation, and materials evaluation report for the proposed levee. All significant factors that might affect the alignment and/or design should be clearly pointed out and any desirable changes in alignment suggested. All maps should be to the same scale, and overlays of maps, e.g., topography and soil type, aerial photograph and topography, etc., to facilitate information correlation is desirable. The development of a project GIS will simplify and expedite consistently georeferenced map products.

Section II
Subsurface Exploration

2-6. General

a. Because preliminary field investigations usually involve only limited subsurface exploration, only portions of the following discussion may be applicable to the preliminary stage, depending on the nature of the project.

b. The subsurface exploration for the design stage generally is accomplished in two phases, which may be separate in sequence, or concurrent: (1) Phase 1, the main purpose of which is to better define the geology of the area, the soil types present and to develop general ideas of soil strengths and permeabilities; (2) Phase 2, provides additional information on soil types present and usually includes the taking of undisturbed samples for testing purposes.

2-7. Phase 1 Exploration

Phase 1 exploration consists almost entirely of disturbed sample borings and perhaps test pits excavated with backhoes, dozers, farm tractors, etc., as summarized in Table 2-4, but may also include geophysical surveys which are discussed later.

Table 2-4
Phase I Boring and Sampling Techniques

Technique	Remarks
1. Disturbed sample borings	
a. Split-spoon or standard penetration test	1-a. Primarily for soil identification but permits estimate of shear strength of clays and crude estimate of density of sands; see paragraph 5-3d of EM 1110-1-1906 Preferred for general exploration of levee foundations; indicates need and locations for undisturbed samples
b. Auger borings	1-b. Bag and jar samples can be obtained for testing
2. Test pits	2. Use backhoes, dozers, and farm tractors
3. Trenches	3. Occasionally useful in borrow areas and levee foundations

2-8. Phase 2 Exploration

Phase 2 subsurface exploration consists of both disturbed and undisturbed sample borings and also may include geophysical methods. Undisturbed samples for testing purposes are sometimes obtained by handcarving block samples from test pits but more usually by rotary and push-type drilling methods (using samplers such as the Denison sampler in extremely hard soils or the thin-walled Shelby tube fixed piston sampler in most soils). Samples for determining consolidation and shear strength characteristics and values of density and permeability should be obtained using undisturbed borings in which 127-mm- (5-in.-) diameter samples are taken in cohesive materials and 76.2-mm- (3-in.-) diameter samples are taken in cohesionless materials. EM 1110-1-1906 gives details of drilling and sampling techniques.

2-9. Borings

a. *Location and spacing*. The spacing of borings and test pits in Phase 1 is based on examination of airphotos and geological conditions determined in the preliminary stage or known from prior experience in the area, and by the nature of the project. Initial spacing of borings usually varies from 60 to 300 m (nominally 200 to 1,000 ft) along the alignment, being closer spaced in expected problem areas and wider spaced in nonproblem areas. The spacing of borings should not be arbitrarily uniform but rather should be based on available geologic information. Borings are normally laid out along the levee centerline but can be staggered along the alignment in order to cover more area and to provide some data on nearby borrow materials. At least one boring should be located at every major structure during Phase 1. In Phase 2, the locations of additional general sample borings are selected based on Phase 1 results. Undisturbed sample borings are located where data on soil shear strength are most needed. The best procedure is to group the foundation profiles developed on the basis of geological studies and exploration into reaches of similar conditions and then locate undisturbed sample borings so as to define soil properties in critical reaches.

b. *Depth*. Depth of borings along the alignment should be at least equal to the height of proposed levee at its highest point but not less than 3 m (nominally 10 ft). Boring depths should always be deep enough to provide data for stability analyses of the levee and foundation. This is especially important when the levee is located near the riverbank where borings must provide data for stability analyses involving both levee foundation and riverbank. Where pervious or soft materials are encountered, borings should extend through the permeable material to impervious material or through the soft material to firm material. Borings at structure locations should extend well below invert or foundation elevations and below the zone of significant influence created by the load. The borings must be deep enough to permit analysis of approach and exit channel stability and of underseepage conditions at the structure. In borrow areas, the depth of exploration should extend several feet below the practicable or allowable borrow depth or to the ground-water table. If borrow is to be obtained from below the groundwater table by dredging or other means, borings should be at least 3 m (nominally 10 ft) below the bottom of the proposed excavation.

2-10. Geophysical Exploration

a. It is important to understand the capabilities of the different geophysical methods, so that they may be used to full advantage for subsurface investigations. Table 2-5 summarizes those geophysical methods most appropriate to levee exploration. These methods are a fairly inexpensive means of exploration and are very useful for correlating information between borings which, for reasons of economy, are spaced at fairly wide intervals. Geophysical data must be interpreted in conjunction with borings and by qualified, experienced personnel. Because there have been significant improvements in geophysical instrumentation and interpretation techniques in recent years, more consideration should be given to their use.

b. Currently available geophysical methods can be broadly subdivided into two classes: those accomplished entirely from the ground surface and those which are accomplished from subsurface borings. Applicable geophysical ground surface exploration methods include: (1) seismic methods, (2) electrical resistivity, (3) natural potential (SP) methods, (4) electromagnetic induction methods, and (5) ground penetrating radar. Information obtained from seismic surveys includes material velocities, delineation of interfaces between zones of differing velocities, and the depths to these interfaces. The electrical resistivity survey is used to locate and define zones of different electrical properties such as pervious and impervious zones or zones of low resistivity such as clayey strata. Both methods require differences in properties of levee and/or foundation materials in order to be effective. The resistivity method requires a resistivity contrast between materials being located, while the seismic method requires contrast in wave transmission velocities. Furthermore, the seismic refraction method requires that any underlying stratum transmit waves

Table 2-5
Applicable Geophysical Methods of Exploration[a]

	Top of Bedrock	Fault Detection	Suspected Voids or Cavity Detection	In Situ Elastic Moduli (Velocities)	Material Boundaries, Dip, ...	Subsurface Conduits and Vessels	Landfill Boundaries
Seismic Refraction	W	S		W	S		
Seismic Reflection	S	S	S		W		
Natural Potential (SP)						S	
DC Resistivity	S	S	S		S	S	W
Electro-Magnetics		S			S	W	W
Ground Penetrating Radar	S	S	S		S	S	S
Gravity		S	S		S		
Magnetics		S					S

W - works well in most materials and natural configurations.
S - works under special circumstances of favorable materials or configurations.
Blank - not recommended.
[a] After EM 1110-1-1802.

at a higher velocity than the overlying stratum. Difficulties arise in the use of the seismic method if the surface terrain and/or layer interfaces are steeply sloping or irregular instead of relatively horizontal and smooth. Therefore, in order to use these methods, one must be fully aware of what they can and cannot do. EM 1110-1-1802 describes the use of both seismic refraction and electrical resistivity. Telford et al. (1990) is a valuable, general text on geophysical exploration. Applicable geophysical exploration methods based on operation from the ground surface are summarized in Table 2-5. A resistivity survey measures variations in potential of an electrical field within the earth by a surface applied current. Variation of resistivity with depth is studied by changing electrode spacing. The data is then interpreted as electrical resistivity expressed as a function of depth. (Telford et al. 1990; EM 1110-1-1802)

c. Downhole geophysical logging can be used with success in correlating subsurface soil and rock stratification and in providing quantitative engineering parameters such as porosity, density, water content, and moduli. They also provide valuable data for interpreting surface geophysical data. The purpose in using these methods is not only to allow cost savings, but the speed, efficiency and often much more reliable information without lessening the quality of the information obtained. Electromagnetic (EM) induction surveys use EM transmitters that generate currents in subsurface materials. These currents produce secondary magnetic fields detectable at the surface. Simple interpretation techniques are advantages of these methods, making EM induction techniques particularly suitable for horizontal profiling. EM horizontal profiling surveys are useful for detecting anomalous conditions along the centerline of proposed levee construction or along existing levees. Self potential (SP) methods are based on change of potential of ground by human action or alteration of original condition. Four electric potentials due to fluid flow, electrokinetic or streaming, liquid junction or diffusion, mineralizaion, and solution differing concentration, are known.

The qualitative application of this method is relatively simple and serves best for detection of anomalous seepage through, under, or around levees (Butler and Llopis, 19909; EM 1110-1-1802).

Section III
Field Testing

2-11. Preliminary Strength Estimates

It is often desirable to estimate foundation strengths during Phase 1 of the exploration program. Various methods of preliminary appraisal are listed in Table 2-6.

Table 2-6
Preliminary Appraisal of Foundation Strengths

Method	Remarks
1. Split-spoon penetration resistance	1-a. Unconfined compressive strength in hundreds kPa (or tons per square foot), of clay is about 1/8 of number of blows per 0.3 m (1 ft), or N/8, but considerable scatter must be expected. Generally not helpful where N is low
	1-b. In sands, N values less than about 15 indicate low relative densities. N values should not be used to estimate relative densities for earthquake design
2. Natural water content of disturbed or general type samples	2. Useful when considered with soil classification, and previous experience is available
3. Hand examination of disturbed samples	3. Useful where experienced personnel are available who are skilled in estimating soil shear strengths
4. Position of natural water contents relative to liquid and plastic limits	4-a. Useful where previous experience is available
	4-b. If natural water content is close to plastic limit foundation shear strength should be high
	4-c. Natural water contents near liquid limit indicate sensitive soil usually with low shear strengths
5. Torvane or pocket penetrometer tests on intact portions of general samples or on walls of test trenches	5. Easily performed and inexpensive but may underestimate actual values ; useful only for preliminary strength classifications

2-12. Vane Shear Tests

Where undisturbed samples are not being obtained or where samples of acceptable quality are difficult to obtain, in situ vane shear tests may be utilized as a means of obtaining undrained shear strength. The apparatus and procedure for performing this test are described in ASTM D 2573. The results from this test may be greatly in error where shells or fibrous organic material are present. Also, test results in high plasticity clays must be corrected using empirical correction factors as given by Bjerrum (1972) (but these are not always conservative).

2-13. Groundwater and Pore Pressure Observations

Piezometers to observe groundwater fluctuations are rarely installed solely for design purposes but should always be installed in areas of potential underseepage problems. The use and installation of piezometers are described in EM 1110-2-1908. Permeability tests should always be made after installation of the piezometers; these tests provide information on foundation permeability and show if piezometers are functioning. Testing and interpretation procedures are described in EM 1110-2-1908.

2-14. Field Pumping Tests

The permeability of pervious foundation materials can often be estimated with sufficient accuracy by using existing correlations with grain-size determination; see TM 5-818-5. However, field pumping tests are the most accurate means of determining permeabilities of stratified in situ deposits. Field pumping tests are expensive and usually justified only at sites of important structures and where extensive pressure relief well installations are planned. The general procedure is to install a well and piezometers at various distances from the well to monitor the resulting drawdown during pumping of the well. Appendix III of TM 5-818-5 gives procedures for performing field pumping tests.