CHAPTER 3

FIELD EXPLORATION

3-1. Scope

The field study is used to determine the presence, extent, and nature of expansive soil and groundwater conditions. The two major phases of field exploration are surface examination and subsurface exploration. The surface examination is conducted first since the results help to determine the extent of the subsurface exploration. In situ tests may also be helpful, particularly if a deep foundation, such as drilled shafts, is to be used.

3-2. Surface examination

a. Site history. A study of the site history may reveal considerable qualitative data on the probable future behavior of the foundation soils. Maps of the proposed construction site should be examined to obtain information on wooded areas, ponds and depressions, water-courses, and existence of earlier buildings. Surface features, such as wooded areas, bushes, and other deep-rooted vegetation in expansive soil areas, indicate potential heave from accumulation of moisture following elimination of these sources of evapotranspiration. The growth of mesquite trees, such as found in Texas, and other small trees may indicate subsurface soil with a high affinity for moisture, a characteristic of expansive soil. Ponds and depressions are often filled with clayey, expansive sediments accumulated from runoff. The existence of earlier structures on or near the construction site has probably modified the soil moisture profile and will influence the potential for future heave beneath new structures.

b. Field reconnaissance. A thorough visual examination of the site by the geotechnical engineer is necessary (table 3-1). More extensive subsurface exploration is indicated if a potential for swelling soil is evident from damages observed in nearby structures. The extent of desiccation cracks, plasticity, slickensides, and textures of the surface soil can provide a relative indication of the potential for damaging swell.

(1) *Cracking in nearby structures.* The appearance of cracking in nearby structures should be especially noted. The condition of on-site stucco facing, joints of brick and stone structures, and interior plaster walls can be a fair indication of the possible degree of swelling that has occurred. The differential heave that may occur in the foundation soil beneath the proposed structure. however, is not necessarily equal to the differential heave of earlier or nearby structures. Differential heave depends on conditions such as variation of soils beneath the structure, load distribution on the foundation, foundation depth, and changes in groundwater since construction of the earlier structures.

(2) *Soil gilgai.* The surface soil at the site should also be examined for gilgai. Soil gilgai are surface mounds that form at locations where the subsurface soil has a greater percentage of plastic fines and is thus more expansive than the surface soil. Gilgai begin to form at locations where vertical cracks penetrate into the subsurface soil. Surface water enters and swelling takes place around the cracks leaving fractured zones where plastic flow occurs. These mounds usually have a higher pH than the adjacent low areas or depressions and may indicate subsurface soil that had extruded up the fractures.

(3) *Site access and mobility.* Indicators of site access and mobility (table 3-1) may also influence behavior of the completed structure. For example, nearby water and sewer lines may alter the natural moisture environment. Flat land with poor surface drainage, as indicated by ponded water, may aggravate differential heave of the completed structure if drainage is not corrected during construction. Construction on land with slopes greater than 5 degrees may lead to structural damage from creep of expansive clay surface soils. Trees located within a distance of the proposed structure of 1 to 1.5 times the height of mature trees may lead to shrinkage beneath the structure, particularly during droughts.

c. Local design and construction experience. Local experience is very helpful in indicating possible design and construction problems and soil and groundwater conditions at the site. Past successful methods of design and construction and recent innovations should be examined to evaluate their usefulness for the proposed structure.

3-3. Subsurface exploration

Subsurface exploration provides representative samples for visual classification and laboratory tests. Classification tests are used to determine the lateral and vertical distribution and types of foundation soils. Soil swell, consolidation, and strength tests are needed to evaluate the load/displacement behavior and bearing capacity of the foundation in swelling soil. The struc-

Table 3-1. Field Reconnaissance

Indicators of swelling soil	1.	Desiccation cracks	Cracks appear in the ground surface during dry periods. Larger and more frequent polygon arrangements of cracks indicate greater potential swell. Dry strength of exposed surfaces is high.
	2.	Plasticity	Relative ease to roll into a small thread indicates greater potential swell.
	3.	Slickensides	Slickensides and fissures are abundant in freshly exposed surfaces of many swelling soils.
	4.	Texture	Slick, cohesive soil tending to adhere to shoes or tires of vehicles when wet indicates swelling soil.
	5.	Structure distortion	Relative size and frequency of cracks and distortion in nearby structures indicates the relative potential swell. Potential swell is approximately the sum of the crack widths. Appearance of power lines, fences, or trees often gives an indication of creep behavior.
	6.	Gilgai	Surface mounds of rounded or long, narrow shape.
Indicators of site access and mobility	1.	Restrictions on access.	
	2.	Locations of utilities and restrictions concerning removal of relocation.	
	3.	Locations of existing structures on site and adjacent to the site. Description of foundation types. Obtain photographs if it can be reasonably expected that existing structures may be affected by construction operations.	
	4.	Locations of trees and other major surface vegetation and restrictions concerning removal or disposition.	
	5.	Surface drainage including presence of ponded water.	
	6.	Examination of contour maps of the site: fill areas, slopes, rock outcrops, or other topographic features.	
	7.	Possible condition of ground at time of construction in relation to trafficability of equipment.	

ture interaction effects in swelling soil are complicated by the foundation differential movement caused by soil heave. Sufficient samples should be available to allow determination of the representative mean of the swell and strength parameters of each distinctive soil stratum. The lower limit of the scatter in strength parameters should also be noted.

a. Sampling requirements. The design of lightly loaded structures and residences can often be made with minimal additional subsurface investigations and soil testing if the site is developed, if subsurface features are generally known, and if the local practice has consistently provided successful and economical designs of comparable structures. Additional subsurface investigation is required for new undeveloped sites, multistory or heavy buildings, structures with previously untested or new types of foundations, and special structures that require unusually limited differential movements of the foundation such as deflection/length ratios less than 1/1000. Where the local practice has not consistently provided satisfactory designs, a careful review of the local practice is necessary. Corrections to improve performance compared with earlier structures may prove difficult to devise and implement and may require evaluation of the behavior of the subsurface foundation soils and groundwater conditions.

b. Distribution and depth of borings. The distribution and depth of borings are chosen to determine the soil profile and to obtain undisturbed samples required to evaluate the potential total and differential heave of the foundation soils from laboratory swell tests, as well as to determine the bearing capacity and settlement. Consequently, greater quantities of undisturbed samples may be required in swelling soils than normally needed for strength tests.

(1) Borings should be spaced to define the geology and soil nonconformities. Spacings of 50 or 25 feet and occasionally to even less distance may be required when erratic subsurface conditions (e.g., soils of different swelling potential, bearing capacity, or settlement) are encountered. Initial borings should be located close to the corners of the foundation, and the number should not be less than three unless subsurface condi-

tions are known to be uniform. Additional borings should be made as required by the extent of the area, the location of deep foundations such as drilled shafts, and the encountered soil conditions.

(2) The depth of sampling should be at least as deep as the probable depth to which moisture changes and heave may occur. This depth is called the depth of the active zone X_a. The active depth usually extends down about 10 to 20 feet below the base of the foundation or to the depth of shallow water tables, but it may be deeper (para 5-4c). A shallow water table is defined as less than 20 feet below the ground surface or below the base of the proposed foundation. The entire thickness of intensely jointed or fissured clays and shales should be sampled until the groundwater level is encountered because the entire zone could swell, provided swelling pressures are sufficiently high, when given access to moisture. Continuous sampling is required for the depth range within the active zone for heave.

(3) Sampling should extend well below the anticipated base of the foundation and into strata of adequate bearing capacity. In general, sampling should continue down to depths of 1.5 times the minimum width of slab foundations to a maximum of 100 feet and a minimum of three base diameters beneath the base of shaft foundations. The presence of a weak, compressible, or expansive stratum within the stress field exerted by the entire foundation should be detected and analyzed to avoid unexpected differential movement caused by long-term volume changes in this stratum. Sampling should continue at least 20 feet beneath the base of the proposed foundation. Determination of the shear strength and stress/strain behavior of each soil stratum down to depths of approximately 100 feet below the foundation is useful if numerical analysis by the finite element method is considered.

c. Time of sampling. Sampling may be done when soil moisture is expected to be similar to that during construction. However, a design that must be adequate for severe changes in climate, such as exposure to periods of drought and heavy rainfall, should be based on maximum levels of potential soil heave. Maximum potential heaves are determined from swell tests using soils sampled near the end of the dry season, which often occurs toward the end of summer or early fall. Heave of the foundation soil tends to be less if samples are taken or the foundation is placed following the wet season, which often occurs during spring.

d. Sampling techniques. The disturbed samples and the relatively undisturbed samples that provide minimal disturbance suitable for certain laboratory soil tests may be obtained by the methods described in table 3-2. Drilling equipment should be well maintained during sampling to avoid equipment failures, which cause delays and can contribute to sample disturbance. Personnel should be well trained to expedite proper sampling, sealing, and storage in sample containers.

(1) *Disturbed sampling.* Disturbed auger, pit, or split spoon samplers may be useful to roughly identify the soil for qualitative estimates of the potential for soil volume change (para 4-1). The water content of these samples should not be altered artificially during boring, for example, by pouring water down the hole during augering.

(2) *Undisturbed sampling.* Minimization of sample disturbance during and after drilling is important to the usefulness of undisturbed samples. This fact is particularly true for expansive soils since small changes in water content or soil structure will significantly affect the measured swelling properties.

(a) The sample should be taken as soon as possible, after advancing the hole to the proper depth and cleaning out the hole, to minimize swelling or plastic deformation of the soil to be sampled.

(b) The samples should be obtained using a push tube sampler without drilling fluid, if possible, to minimize changes in the sample water content. Drilling fluids tend to increase the natural water content near the perimeter of the soil sample, particularly for fissured soil.

(c) A piston Denisen or other sampler with a cutting edge that precedes the rotating outer tube into the formation is preferred, if drilling fluid is necessary, to minimize contamination of the soil sample by the fluid.

e. Storage of samples. Samples should be immediately processed and sealed following removal from the boring hole to minimize changes in water content. Each container should be clearly labeled and stored under conditions that minimize large temperature and humidity variations. A humid room with relative humidity greater than 95 percent is recommended for storage since the relative humidity of most natural soils exceeds 95 percent.

(1) *Disturbed samples.* Auger, pit, or other disturbed samples should be thoroughly sealed in waterproof containers so that the natural water content can be accurately measured.

(2) *Undisturbed samples.* Undisturbed samples may be stored in the sampling tubes or extruded and preserved, then stored. Storage in the sampling tube is not recommended for swelling soils even though stress relief may be minimal, The influence of rust and penetration of drilling fluid or free water into the sample during sampling may adversely influence the laboratory test results and reduce the indicated potential heave. Iron diffusing from steel tubes into the soil sample will combine with oxygen and water to form rust. Slight changes in Atterberg limits, erosion resistance, water content, and other physical properties may occur. In addition, the outer perimeter of a soil sample

Table 3-2. Soil Sampling Methods

Type of Sample	Purpose	Sampler	Description	Application
Disturbed	Profile classification: Specific gravity, Grain-size distribution	Auger	Bucket	All soils where wall can be maintained without caving. Continuous flight augers not recommended as the location in the profile cannot be approximated.
		Split spoon	Tube sampler split lengthwise	
	Atterberg limits, Water content, Physicochemical[a], Lime treatment[b]	Pit	Shallow trench or large borehole	Capable of providing large quantities of soil for special tests such as compaction or chemical stabilization.
Undisturbed	In situ classification:	Pit	Shallow trench or large borehole	Capable of providing large quantites of soil for special tests such as compaction or chemical stabilization.
	Swell behavior, Shear strength	Push tube	Pistonless: driving head fixed to sampling tube with ball pressure release valve to bleed off compressed air and form vacuum during sampler withdrawal	Medium to stiff clays free of gravel or small rocks that could damage the leading edge of the tube sampler.
			Free piston: piston locked at lower end of sampler during insertion into hole and resting on top of sample during push. Vacuum assisted sampler withdrawal	Medium to stiff clays free of gravel or small rocks that could damage the leading edge of the tube sampler.
			Fixed piston: piston fixed to drill rig during the push causing vacuum to assist during the push and sampler withdrawal	Medium to stiff clays free of gravel or small rocks that could damage the leading edge of the tube sampler.
		Rotary core barrel	Double-barrel or Denison Sampler: outer barrel with cutter shoe to advance the sampler and inner barrel with cutter edge to fine trim and contain the sample	Hard soils and soils containing gravel.
			Single barrel: with cutter shoe, usually diamond head, to advance and contain the sample	Rock.

[a] Discussed in paragraph 4-1d.

[b] Discussed in paragraph 7-3d.

stored in the sampling tube cannot be scraped to remove soil contaminated by water that may have penetrated into the perimeter of the sample during sampling. The sample may also later adhere to the tube wall because of rust. If samples are stored in tubes, the tubes should be brass or lacquered inside to inhibit corrosion. An expanding packer with a rubber O-ring in both ends of the tube should be used to minimize moisture loss. The following procedures should be followed in the care and storage of extruded samples.

(a) Expansive soil samples that are to be extrubed and stored should be removed from the sampling tubes immediately after sampling and thoroughly sealed to minimize further stress relief and moisture loss. The sample should be extruded from the sampling tube in the same direction when sampled to minimize further sample disturbance.

(b) Samples extruded from tubes that were obtained with slurry drilling techniques should be wiped clean to remove drilling fluid adhering to the surface of the sample prior to sealing in the storage containers. An outer layer of 1/8 to 1/4 inch should be trimmed from the cylindrical surface of the samples so that moisture from the slurry will not penetrate into the sample and alter the soil swelling potential and strength. Trimming will also remove some disturbance at the perimeter due to sidewall friction. The outer perimeter of the soil sample should also be trimmed away during preparation of specimens for laboratory tests.

(c) Containers for storage of extruded samples may be either cardboard or metal and should be approximately 1 inch greater in diameter and 1.5 to 2 inches greater in length than the sample to be encased. Three-ply, wax-coated cardboard tubes with metal bottoms are available in various diameters and lengths and may be cut to desired lengths.

(d) Soil samples preserved in cardboard tubes should be completely sealed in wax. The wax and cardboard containers provide an excellent seal against moisture loss and give sufficient confinement to minimize stress relief and particle reorientation. A good wax for sealing expansive soils consists of a 1 to 1 mixture of paraffin and microcrystalline wax or 100 percent beeswax. These mixtures adequately seal the sample and do not become brittle when cold. The temperature of the wax should be approximately 20 degrees Fahrenheit above the melting point when applied to the soil sample, since wax that is too hot will penetrate pores and cracks in the sample and render it useless, as well as dry the sample. Aluminum foil or plastic wrap may be placed around the sample to prevent penetration of molten wax into open fissures. A small amount of wax (about 0.5-inch thickness) should be placed in the bottom of the tube and allowed to partly congeal. The sample should subsequently be placed in the tube, completely immersed and covered with the molten wax, and then allowed to cool before moving.

(e) When the samples are being transported, they should be protected from rough rides and bumps to minimize further sample disturbance.

f. Inspection. A competent inspector or engineer should accurately and visually classify materials as they are recovered from the boring. Adequate classification ensures the proper selection of samples for laboratory tests. A qualified engineering geologist or foundation engineer should closely monitor the drill crew so that timely adjustments can be made during drilling to obtain the best and most representative samples. The inspector should also see that all open borehoes are filled and sealed with a proper grout, such as a mixture of 12 percent bentonite and 88 percent cement, to minimize penetration of surface water or water from a perched water table into deeper strata that might include moisture deficient expansive clays.

3-4. Groundwater

Meaningful groundwater conditions and engineering properties of subsurface materials can often best be determined from in situ tests. In situ tests, however, are not always amenable to simple interpretation. The pore water conditions at the time of the test may differ appreciably from those existing at the time of construction. A knowledge of groundwater and the negative pore water pressure are important in evaluating the behavior of a foundation, particularly in expansive soil. Every effort should be made to determine the position of the groundwater level, its seasonal variation, and the effect of tides, adjacent rivers, or canals on it.

a. Measurement of groundwater level. The most reliable and frequently the only satisfactory method for determining groundwater levels and positive pore water pressures is by piezometers with tips installed at different depths. Ceramic porous tube piezometers with small diameters (3/8-inch) risers are usually adequate, and they are relatively simple, inexpensive, and sufficient for soils of low permeability.

b. Measurement of in situ negative pore water pressure, Successful in situ measurements of negative pore water pressure and soil suction have been performed by such devices as tensiometers, negative pore pressure piezometers, gypsum blocks, and thermocouple psychrometer. However, each of these devices has certain limitations, The range of tensiometers and negative pore pressure piezometers has been limited to the cavitation stress of water under normal conditions, which is near one atmosphere of negative pressure. The fluid-filled tensiometer is restricted to shallow soils less than 6 feet in depth. The useable range of the tensiometer is reduced in proportion to the pressure exerted by the column of fluid in the tensiometer. Gypsum blocks require tedious calibration of electrical resistivity for each soil and dissolved salts greatly influence the results. Thermocouple psychrometer cannot measure soil suctions reliably at negative pressures that are less than one atmosphere and require a constant temperature environment. Psychrometer also measure the total suction that includes an osmotic component caused by soluble salts in the pore water, as well as the matrix suction that is comparable with the negative pore water pressure. Tensiometers require constant maintenance, while gypsum blocks and psychrometer tend to deteriorate with time and may become inoperable within one year. A routine field measurement of soil suction is not presently recommended because of the limitations associated with these devices. Alternatively, laboratory measurements of soil suction can be easily performed (para 4-2a).