CHAPTER 3

SUBSURFACE INVESTIGATION

This chapter provides information to use when characterizing the *unconsolidated stratigraphic units* (*soil units*) beneath a proposed or existing *waste containment facility* in Ohio. This chapter also includes the recommended format for submitting the results of a subsurface investigation to Ohio EPA for review.

The purpose of characterizing subsurface conditions is to determine if the soils beneath a facility exhibit properties that ensure the facility will remain stable under static and seismic conditions during construction and operation and after it is closed. A complete comprehensive *soil stratigraphy* should be developed that will adequately characterize the lateral and vertical extent of all *soil units* beneath the proposed facility. Characteristics to be measured include, but are not limited to, shear strength, liquefaction potential, compressibility, *phreatic surface* elevations, *piezometric surface* elevations, and the water content of the soil materials. Any *piezometric surfaces* associated with *bedrock* that may affect the facility during excavation, construction, operations, or closure must also be identified. Part of this investigation involves identifying all *critcal layers* beneath the facility . A *critical layer* is any thickness of soil material that has a *drained* or *undrained shear strength* suspected of being capable of causing a failure if all or part of the mass of a facility were suddenly put in place. *Critical layers* may be only a few inches thick to tens of feet thick. *Critical layers* may include parts of one or more *soil units*. Any layer that is potentially liquefiable must also be identified as a *critical layer*.

In addition, the subsurface investigation must be used to identify and characterize all *compressible layers*. *Compressible layers* are soil or fill materials that may settle after establishing a facility, and may continue to settle after a facility has closed. *Compressible layers* must be identified and characterized to determine the bearing capacity and settlement potential of the in situ soils, fill, and stabilized materials that exist on the site. Analysis must show that bearing failure will not occur. Analysis must also show that the engineered components of the facility will meet minimum design requirements during construction, operation, closure, and post-closure of the facility after settlement is complete (at least 100% of *primary settlement*, and the *secondary settlement* expected using a time-frame of 100 years or another time-frame acceptable to Ohio EPA).

A subsurface investigation is typically performed in distinct stages, although some activities of one stage may overlap with other stages. First, a preliminary investigation is conducted to gather and review all available regional and site-specific information. Second, a site-specific investigation is conducted to identify and characterize the *soil stratigraphy* of the site and identify those *soil units* that need further investigation. The *phreatic* and *piezometric surfaces* that exist at the facility are also determined. Finally, *samples* are gathered to be used to produce *higher quality data* from the *critical* and *compressible layers*.

REPORTING SUBSURFACE INVESTIGATION RESULTS

> Any drawings or cross sections referred to in this policy that are already present in another part of the geotechnical and stability analyses report can be referenced rather than duplicated in each section. It is helpful if the *responsible* party ensures the referenced items are easy to locate and marked to show the appropriate information.

Ohio EPA recommends that all of the information be organized and presented so the conclusions are clear and have been justified. The location, extent, and characteristics of all *soil units*, including the *critical layers* and the *compressible layers*, and the elevations of the temporal high *phreatic surfaces* and the temporal high *piezometric surfaces* should also be included (see Table 2 on page 3-8). Laboratory test reports should include all intermediate data gathered during the test along with the results. Reporting should be performed according to the ASTM reporting requirements for the methods being used when reporting requirements exist. Rejected and failed test results should also be reported to Ohio EPA. A brief narrative describing the reasons each test was rejected or considered failed should be included. Ohio EPA recommends that all data be organized and tabbed so that they can be easily located.

To expedite the review process, present the results and conclusions of the investigation with the following sections in the order described. Specific recommendations for each section of the subsurface investigation report are discussed below.

Summary Narrative

The summary narrative should describe the rationale behind the site investigation, the assumptions and methodologies used, the *critical layers* and *compressible layers* selected, the temporal high *phreatic surfaces* and temporal high *piezometric surfaces* defined, and the characteristics of each item identified. The summary narrative should also include recommendations for the values for the characteristics of each material and interface tested to use during modeling, design, and construction.

Summary Table

A summary of all field test data and laboratory test data obtained from all *borings* conducted and *samples* collected at the facility should be presented in one or more tables. The data in these tables that represent the *critical layers* and *compressible layers* should be identified as such. Each record in the table should be referenced to the laboratory testing data sheets, *boring* logs, or other appropriate source.

Topographic Maps

The summary and conclusions section should include one or more topographic maps of the facility that show the location and identification of each *boring* and *sample* collection point at the facility. The limits of the *waste containment unit(s)* should also be shown. These maps can be used to identify the cross sections provided in the report, to show the lateral extent of each *critical layer* and each *compressible layer* that exists at the facility, and to show the elevations of the temporal high *phreatic surfaces*, and the elevations of the temporal high *piezometric surfaces*.

Cross Sections

Cross sections should be included for each length and width of the grid created by the site characterization *borings*. All *borings* that intersect each cross section should be shown in two cross sections oriented roughly perpendicular to each other. Any additional *borings* that intercept the *critical layers* or the *compressible layers* should also be included on appropriate cross sections.

The cross sections should show the vertical and lateral limits of each *soil unit* using the Unified Soil Classification System (USCS) or the American Association of State Highway and Transportation Officials (AASHTO) *unconsolidated material* classification. The vertical and lateral limits of *soil units* should be grouped together or further divided based on the characteristics that affect the geotechnical and stability analyses. These characteristics include, but are not limited to, shear strength, compressibility, liquefaction potential, Atterberg limits (including liquidity index), corrected blow counts, cone penetrometer data, and permeability. When *samples* have been taken from a *boring*, the classification and characterization data obtained from the *samples* should be shown with the *boring* at the *sample* elevation in each cross section that it appears. The *critical layers* and *compressible layers* should be noted as such on the cross section, along with the temporal high *phreatic* and *piezometric surfaces* that exist at the facility. The cross sections should show the proposed and/or existing vertical and lateral limits of the facility excavation and engineered components as encountered by each cross section.

Preliminary Investigation Results

This section of the report should include a discussion of the findings of the preliminary investigation and the sources of information used. The information included in this section should describe evidence that was found, if any, that indicates *critical layers* or *compressible layers* may exist in the area. It should also include a summary of the evidence, if any, of historical mass movements of soil or *bedrock* materials or settlement sufficient to cause damage at the facility or in the region. If *critical layers*, *compressible layers*, occurrences of mass movements of soil or *bedrock* materials, or landslides exist in the region, then a discussion must be included to describe the steps taken to incorporate these findings into the site characterization.

Site Characterization Results

A summary of the activities, methods, and findings that resulted from the site characterization should be included at the front of this section. A description of the information used to identify the possible *critical layers* and the *compressible layers* designated for further investigation should be included in this section. Also included in this section should be the information used to determine the temporal high *phreatic* and *piezometric surfaces.* All data gathered during the site characterization and field testing should be organized, tabbed, and included in this section. This includes all *boring* logs for the subsurface investigation, blow counts, field test results, and any other information used for defining the potentially *critical layers* and the potentially *compressible layers*.

Results of the Investigation of Critical Layers and Compressible Layers

A summary of the activities, methods, and findings that resulted from the investigation of potentially *critical layers* and *compressible layers* should be included in the front of this section. This section should also include a detailed description of data that were relied upon and why they were used to determine the lateral and vertical extent and characteristics of the *critical layers* and the *compressible layers*. This section should include the methodologies used for laboratory testing, and a discussion that identifies the criteria used to determine the meaning of each test. The laboratory sheets and field data sheets created during sampling and analyses of the *critical layers* and the *compressible layers* should be organized, tabbed, and included in this section.

CONDUCTING THE INVESTIGATION

Preliminary Investigation

The purpose of a preliminary investigation is to gather existing information regarding in situ soils and *bedrock* material strengths, liquefaction potential, and compressibility of the soils from the facility and the surrounding region. All potential sources of information should be checked for evidence of landslides, mass movements of soil material or *bedrock*, strength data, and stratigraphy. Many potential sources for this information exist, such as:

- Field reconnaissance, including a site walkover and field mapping,
- Existing site information such as *boring* logs, open excavations, and utilities installations,
- Local sources such as the health department, soil and water conservation districts, building inspection departments, the county auditor's office, and local newspaper articles,
- State sources such as the Ohio Department of Natural Resources' (ODNR's), Division of Geological Survey and Division of Mineral Resources Management, the Department of Transportation (ODOT), Ohio EPA,
- Federal sources such as the United States Department of Agriculture (USDA), the Natural Resources Conservation Service under USDA, and the United States Geological Survey (USGS).

> Site topography can reveal evidence of historic slope failures and the potential for failures occurring. For example, some indications that downslope movement has occurred or is occurring include:
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> - Leaning trees, telephone poles, and fence lines,
> - Sections of roads, fences, or telephone lines that are displaced relative to others on either side,
> - Hummocks of grass and vegetation that look like rumpled carpet at the toe of slopes,
> - Surface springs or artesian wells,
> - Flood plain (alluvium) or erosion deposits (colluvium),
> - Cracks near the shoulder of a slope running roughly parallel to the toe of the slope,
> - Cracks that when viewed from a distance create an inverted arc,
> - The existence of near vertical escarpments, and
> - Aerial photographs that show what appears to be a flow of material down and away from an elevated area.

These and other sources can provide information such as aerial photographs, *boring* logs, and reported incidences of mass movements of *bedrock* and soil material that may have occurred in the area. Information about the *soil stratigraphy* in the area can also be gained from these types of sources.

During the preliminary investigation, existing field and laboratory test data from the site might be obtained. When this happens, the data must be evaluated to determine if they were appropriately validated and are thus still usable. This evaluation can be done by applying many of the same procedures to the data as they are discussed later in this chapter and in Chapter 4. If the data are valid and applicable, they can be used, as appropriate, along with newly acquired data. However, any data that cannot be verified to be valid and reliable must be excluded for use.

Site Characterization and Screening

The purpose of site characterization and screening is to identify the temporal high *phreatic surfaces*, the temporal high *piezometric surfaces*, and the vertical and lateral extent of all potentially *critical layers*, and all potentially *compressible layers*. Site characterization and screening are generally performed using investigation and sampling methods that produce *lower quality data*. The data obtained are often well-suited for comparing relative characteristics of different soils, but are unreliable for determining the best obtainable definitive measurement of any given characteristic.

Besides gravity, water is one of the most important factors in stability. Water can affect stability in at least five ways:

1. Reduces shear strength,
2. Changes the mineral constituents through chemical alteration and solution,
3. Changes the bulk density,
4. Generates pore pressures, and
5. Causes erosion.

The areas to be investigated should include the *soil units* from the original ground surface to at least 50 feet below the depth of the deepest excavation proposed at the facility. Extending the investigation deeper to ensure the facility will remain stable may be necessary, especially when evidence exists of *critical layers* or *compressible layers* more than 50 feet below the deepest excavation. All *phreatic surfaces* and *piezometric surfaces* that are likely to affect the stability of the facility must be identified, regardless of the depth or materials associated with the surfaces.

Critical layers may be relatively thin. The site characterization should be planned and conducted so that all *critical layers* will be found, even if they are only a few inches thick. *Critical layers* may be only part of a single broader stratigraphic or hydrogeologic *soil unit*. Averaging of strength values across part or all of a *soil unit* is unacceptable because it may mask the lower strength values of the *critical layer*(s) within a *soil unit*.

Averaging the characteristics of *compressible layers* should also be avoided so that *differential* and *total settlement* can be properly estimated. Enough valid data must be provided to ensure the identification of all *critical layers* and *compressible layers* and all temporal high *phreatic* and *piezometric surfaces* that may affect the stability of the facility. To accomplish this, initial exploratory *borings* should be performed at a minimum frequency of one (1) *boring* for every four (4) acres on a fairly uniform grid across the facility. This is to help ensure the data gathered are representative and increase the likelihood that local geological discontinuities are discovered. *Borings* may be moved laterally from the grid to accommodate site topography and features. Site-specific knowledge should always be used to enhance the site investigation. Some *borings* must be conducted near areas of a site where engineered components will be placed that may be especially sensitive to settlement (e.g., landfill sumps, shallow grade piping, waste water outlet structures, or dikes having relatively little freeboard).

Figure 3-1 Drill rig and operator conducting a standard penetration test (SPT).

A lower frequency of *borings* may be acceptable to Ohio EPA at facilities that have comprehensive and reliable information from the preliminary investigation and information from existing or confirmatory site *borings* that demonstrate that soil materials at the facility are uniform in liquefaction potential, shear strength, and compressibility. Sites that have little preliminary investigation data available, exist in areas where landslides or mass movements of soil materials have occurred, or have evidence of variable soil characteristics will likely be required to increase the frequency of *borings*. Additional *borings* may also be necessary to define the lateral and vertical extent of potential *critical* and *compressible layers* adequately.

In some cases, it is necessary to stabilize a borehole due to heaving soils. The use of hollow-stem augers, or drilling mud has been proven effective for stabilizing a borehole without affecting the blow counts from a standard penetration test. Casing off the borehole as it is advanced has also been used, but it has been found that for non-cohesive soils, such as sands, it has an adverse effect on the standard penetration test results (Edil, 2002).

Except as modified in this policy or in the Ohio Administrative Code, the procedure for exploratory *borings* should follow ASTM D 420 "Guide to Site Characterization for Engineering, Design, and Construction Purposes." Standard penetration tests (SPTs) with corrected blow counts, CPTs, or another method should be conducted in each *boring*. To find thin *critical layers*, initial exploratory *borings* conducted on a grid pattern should be *sample*d and logged continuously for a minimum of 50 feet below the elevation of the deepest excavation (see Table 3 on page 3-9). *Borings* may need to be *sample*d and logged continuously even deeper if evidence exists indicating that deeper *critical layers* or *compressible layers* may affect the stability of the *waste containment facility*.

If CPTs are used, though blow counts will not be measured, the other physical testing discussed below will still need to be performed during the investigation of the *critical layers* and the *compressible layers*. If hydrological data are not otherwise available, temporal high *phreatic* and *piezometric surfaces* must be determined in relation to the local *soil stratigraphy* via piezometers, on-site groundwater monitoring wells, or other field methods.

Investigating Critical Layers and Compressible Layers

> Residual soil and weathered *bedrock* can be weakened by preexisting discontinuities such as faults, bedding surfaces, foliations, cleavages, sheared zones, relict joints, and soil dikes. Relict joints and structures in residual soils often lose shear strength when *saturated*. Slickensided seams or weak dikes may also preexist in residual soil and weathered rock slopes. Faults, bedding surfaces, cleavages, and foliations often have more influence on rock stability than soil stability.

Once the *critical layers* and *compressible layers* are located, additional *borings* may be needed to obtain *samples* of each layer, to determine the lateral and vertical extent of each layer, and to define the range of shear strengths and compressibility parameters, along with other characteristics that may affect the stability of a facility. To accomplish this, a representative number of *samples* of each *critical layer* and *compressible layer* must be collected and analyzed. When *borings*, in addition to those performed during the site characterization and screening, are being conducted specifically to obtain *samples* of *critical layers* or *compressible layers*, logging is not required beyond what is necessary to ensure that *samples* are being collected from the targeted *critical layers* and *compressible layers*.

Characterizing *critical layers* is generally accomplished using investigation and sampling methods that produce *higher quality data*. The data obtained are well-suited for determining the best obtainable definitive measurement of any given characteristic. To provide enough accurate and reliable *higher quality data* to characterize a facility adequately, undisturbed *samples* from each *critical layer* and each *compressible layer* encountered should be collected and laboratory tested from at least ten (10) percent of the *borings* passing through such layers, or a minimum of three (3) undisturbed *samples* from each *critical layer* and each *compressible layer* should be collected and laboratory tested, whichever is greater.

If CPT data or other valid definitive field shear strength data can be used to identify the *critical layer*(s), and if for analytical purposes, it can be appropriately assumed that the weakest layer exists under the entire facility, then undisturbed *samples* from only the weakest *critical layer* need be collected and analyzed, unless evidence suggests doing otherwise. However, consolidation parameters must be obtained from all *compressible layers* to analyze *differential settlement* properly. The lateral and vertical extent of each *critical layer* and each *compressible layer* are to be defined based on results of testing and the location of *borings*.

Laboratory testing and analyses should include, but are not limited to, determining Atterberg limits (including liquidity index), grain size distribution, natural moisture content, dry density, soil classification, consolidation parameters, and shear strength testing. The stress history and existing overburden stresses experienced by each *sample* while in situ must be taken into account during shear testing. Consolidation testing must be conducted to provide information for estimating immediate settlement, *primary settlement*, and *secondary settlement* associated with the facility and its underlying soils (see Chapter 4 for more details about testing methods).

In addition to testing *critical layers* and *compressible layers*, it is recommended that any soils that are identified for use as structural fill or recompacted soil layers be tested during the site investigation. The testing should be conducted at the lowest density and the highest moisture content that is likely to be specified for use during construction. Care should be taken to ensure that soils expected to exhibit the weakest shear strengths are included in the testing. This will allow the use of appropriate values for the shear strength of structural fill and recompacted soil components during stability analyses.

Table 2. An example subsurface investigation report table of contents.

Section No.	**Section Title**
1.0	Summary and Conclusions
1.1	Site Description
1.2	Rationale of Investigation
1.3	Assumptions
1.4	Methodologies
1.5	Description of Critical Layers due to Shear Strength
1.6	Description of Critical Layers due to Liquefaction Potential
1.7	Description Compressible Layers
1.8	Tables
1.9	Figures
1.10	Topographical Maps
1.11	Cross sections
2.0	Preliminary Investigation Results
2.1	Results and Conclusions of the Preliminary Investigation
2.2	Description of the Preliminary Investigation
3.0	Site Characterization
3.1	Results and Conclusions of the Site Characterization and Screening
3.2	Description of Site Characterization and Screening
3.3	Field Test Results
Tab FT1	Field Test Type 1
	Results
	Methods
Tab FT #...	Field Test Type #...
	Results
	Methods
4.0	Investigation of Critical and Compressible Layers
4.1	Laboratory Test Results
Tab LT1	Laboratory Test Type 1
	Results
	Methods, QA/QC, Data Validation, etc.
Tab LT #...	Test Type #...
	Results
	Methods, Laboratory QA/QC, Data Validation, etc.

Table 3. An example *boring* log**.**

OHIO LANDFILL
LOG OF BORING NO. SPT-3

COORDINATES
N 2418.60 E 4159.13
SURFACE EL: 681.08

Elev. (ft MSL)	Depth (Ft)	*Sample #*	Type	Blows / 6 in.				N	Recovery (in)	USCS	Description
680		1	SPT	2	2	2	3	4	19	ML	Top soil soft orange-brown, moist to wet, no laminations, silt and clay w/ trace fine sand
		2	SPT	3	7	11	14	18	23	CL	stiff to very stiff, orange-brown and gray, moist, mottling no laminations, silt some clay trace fine sand and gravel
	5	3	SPT	5	9	12	18	29	20	ML	same as above less clay
		4	SPT	4	6	8	13	18	20	CL	same as above more clay
	10	5	SPT	5	6	8	11	17	23	CL	same as above more clay
670		6	SPT	4	4	4	4	9	24	CL	stiff, orange-brown and yellow-brown, wet, no mottling laminations, silt and very fine sand trace clay
		7	SPT	2	4	7	15	12	24	CL	stiff, orange-brown and yellow-brown, wet, mottled, silt some clay trace fine sand and gravel
	15	8	SPT	9	10	11	18	22	24	CL	same as above
		9	SPT	4	6	7	9	13	24	CH	stiff, red-brown, laminated, moist, clay trace silt, highly plastic
		10	SPT	2	3	3	3	6	24	SC	loose, yellow brown sand, wet
660	20	11	SPT	2	2	3	2	5	24	SC	same as above
		12	SPT	2	2	2	2	4	24	CH	soft, yellow brown silt, laminated with red brown clay, moist to wet, highly plastic.
	25	13	SPT	50	-	-	-	-	-		refusal

Date Project Began: 12- 3-97	ground water elev: 662	Date: 12- 7-97	notes: (*boring* continues)
Date Project Ended: 12-12-97	ground water elev:	Date:	Below 5' N has been normalized
Field Geologist: CLW	Drilling method: 4 1/4" I.D. H.S. Auger with continuous		using a method recommended in
Checked By: FTR	standard split spoon sampling w/liner, w/standard safety hammer.		Peck Hansen and Thornburn, 1974
	$N = N_{60} 0.77 \log_{10}(20 / \textit{overburden pressure})$		

Note: Shelby tube *samples* should be taken from the layers with relatively lower blow counts at the site and from layers with compressible materials present.

Note: Though Shelby tube *samples* of the loose sand at 20' are not necessary, the sand layer would be considered a compressible material to be taken into account during settlement analysis. In this instance, immediate settlement of the sand would be the primary concern.

Note: If a nonstandard sampler or nonstandard hammer was used, the characteristics of the nonstandard equipment must be described.

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