CHAPTER 6

Site Investigation, Drilling, and Sampling

6.1 GENERAL

Site investigation is the first step in solving most geotechnical engineering problems (Figure 6.1). Indeed, when a geotechnical engineer is asked to solve a problem at a site, the first reflex is to go to the site, drill borings, take samples, and/or run in situ tests. Back in the laboratory, additional soil properties are determined and the problem is studied on the basis of the site-specific information already obtained. Note that laboratory tests and in situ tests are not mutually exclusive. The best site investigation features a combination of in situ tests and laboratory tests. Indeed, the advantages of laboratory tests and the advantages of in situ tests complement each other, as shown in Table 6.1. Boring logs add a very important component to the site investigation. The first part of this chapter deals with onshore site investigations, the second part with offshore site investigations.

A site investigation takes place in two steps: the preliminary investigation and the main investigation. Once the site investigation is completed, the geotechnical engineer makes appropriate calculations and recommendations to the project owner or representative. Sometimes additional site investigation allows the geotechnical engineer to optimize the design and propose less expensive options. For most projects, the cost of the soil investigation is a very small fraction of the cost of the project; it can be 0.1% for buildings up to 3% for dams. Yet it is extremely important that it be well carried out, as a poor site investigation can have disastrous consequences, generate great expenses, delay the project, and lead to litigation. For geotechnically complicated projects, it is very desirable for the geotechnical engineer to act as inspector of the work being done at the site.

Note that under current practice, only an extremely small portion of the soil involved in the project is tested. In a typical soil investigation, 0.001% of the soil involved in providing the foundation support for the structure might be tested. The proportion of soil tested is much smaller than the amount of testing done for the structure itself (concrete cylinder testing, for example).

6.2 PRELIMINARY SITE INVESTIGATION

The preliminary site investigation takes place in two steps: a paper study and a site visit. The paper study consists of obtaining documents related to the site information and history. In addition to maps, previous records of site uses are very helpful. Maps include geologic maps (e.g., http://ngmdb.usgs.gov/), aerial photographs (www.terraserver.com/, http://maps.google.com/), flood maps (www.fema.gov/hazard/map/flood.shtm), and seismicity maps (http://earthquake.usgs.gov/earthquakes/world/seismicity/). The site visit consists of going to the site, taking notes and photos of the site conditions, including the behavior of other projects in the vicinity. The site conditions include general topography, rig access, geologic features, stream banks exposing the stratigraphy, land use, water-flow conditions, and possibility of flood. A good site visit requires a keen eye and keeping a detailed record of what is found and observed at the site. In the case of environmentally related problems, special guidelines exist for what is called environmental site assessments (ESAs). The rest of this chapter describes the main site investigation.

6.3 NUMBER AND DEPTH OF BORINGS AND IN SITU TESTS

The word *sounding* is used in this section to refer to both borings and in situ tests. The number, location, and depth of soundings on the one hand and the type of samples and in situ tests on the other depend on several factors, including the type of geotechnical project, the stratigraphy of the site, the soil type, and the water table conditions.

About 2 to 6 soundings are performed for average size buildings and bridges. A common rule for a building is to perform 1 sounding per 250 m^2 of foundation surface area. For major bridges, a sounding is performed at each pier. For extended projects such as runways and highways, soundings are located anywhere from every 50 m for major runways to

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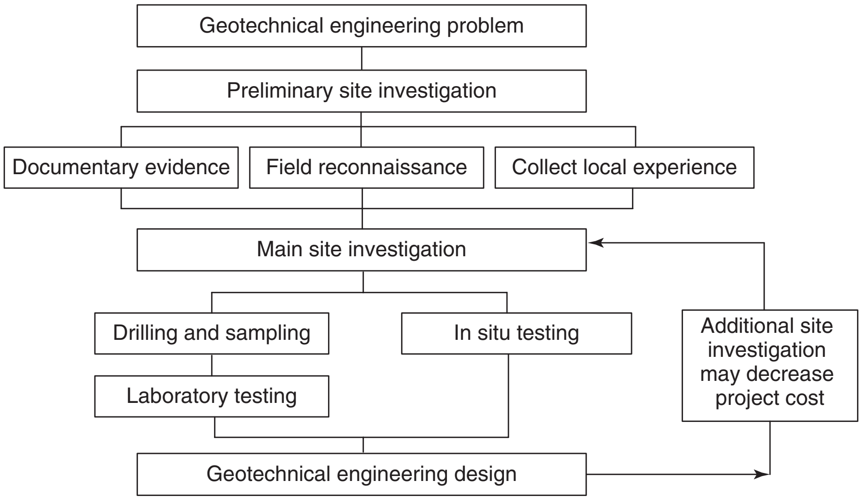

Figure 6.1 Flowchart for a geotechnical engineering project.

Table 6.1 Advantages and Drawbacks of Laboratory and In Situ Tests

Laboratory Testing		In Situ Testing	
Advantages	Drawbacks	Advantages	Drawbacks
Easier to analyze theoretically	Small-scale testing	Large-scale testing	Difficult to analyze theoretically
Drainage can be controlled	Time-consuming	Relatively fast to perform	Drainage difficult to control
Elementary parameters easier to obtain	Stresses must be simulated	Testing done under *in situ* stresses	Elementary paramaters harder to obtain
Soil identification possible	Some disturbance	Less disturbance for some tests	Soil identification rarely possible

every 500 m for secondary highways. For power lines and pipelines, soundings are performed for locations associated with difficult soil conditions and for special loading like corner towers. The depth of the soundings is typically equal to twice the foundation width below the foundation depth. Shallower borings may be accepted if a hard layer is found and confirmed to be thick enough for the project. Depths of soundings commonly vary from 5 m to 30 m.

It is critical to think about the zone of influence of the geotechnical project and ensure that the soil conditions are reasonably well known within that zone. For example, the zone of influence below the tip of a pile may be a few meters, but if 10,000 piles are driven with close spacing, the zone of influence of the foundation is related to the width of the pile group, not the width of a single pile. It is also critical to think about the cost-benefit ratio of the site investigation. The cost of an additional sounding is trivial compared to the cost of repair for most geotechnical projects.

6.4 DRILLING

The two most common methods of drilling for soil samples are the wet rotary method and the hollow stem auger.

6.4.1 Wet Rotary Drilling Method

The wet rotary method consists of drilling a borehole with a drill bit (Figure 6.2) while circulating drilling mud through the center of the rods. The drill bit is typically 75 to 150 mm in diameter and the rods 40 to 70 mm in diameter. The

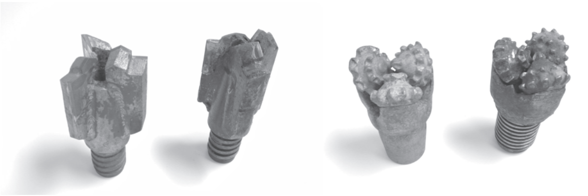

Figure 6.2 Drill bits.

Figure 6.3 Wet rotary drilling method including mud pit. (*Right*: Courtesy of Wikimedia. See also this video: http://cee.engr.ucdavis.edu/faculty/boulanger/video.html)

drilling mud flows down the center of the rods while they rotate and back to the surface on the outside of the rods between the wall of the borehole and the exterior wall of the rods. This return flow carries the soil cuttings back to the surface by entrainment. The drilling mud arrives in the mud pit (Figure 6.3), where it is sucked back up to the top of the drilling rods by a pump. The connection between the hose carrying the drilling mud back to the top of the rods and the rods themselves is called the *water swivel*; this connection allows the hose to remain stationary while the rods keep rotating. The drill bit at the bottom end of the drill rods is typically either a drag bit or a roller bit (Figure 6.2). Drag bits tend to carve the soil with finger-like protrusions and are used for fine-grained soils. Roller bits are made of three rollers that roll against the soil and erode it or push it aside; they are used for drilling in gravel because the larger particles could get stuck between the fingers of a drag bit, damage it, and create excessive disturbance. In sand, either bit can be used; the bit itself is not that critical because the drilling proceeds by washing or eroding the sand with the mud flow in front of the bit. When the rods progress smoothly downward, the soil is likely a fine-grained soil; when the rods go down in a more jerky fashion, the soil is likely a coarse-grained soil. The grinding sound associated with drilling in gravel, cobbles, or rock can be easily identified. Once the borehole is advanced to the required depth, the rods and bit are withdrawn, the bit is uncoupled, and a sampling tube or an in situ test device is connected at the bottom of the rods.

6.4.2 Hollow Stem Auger Drilling Method

The hollow stem auger method (Figure 6.4 and 6.5) sometimes also called the continuous flight auger method consists of

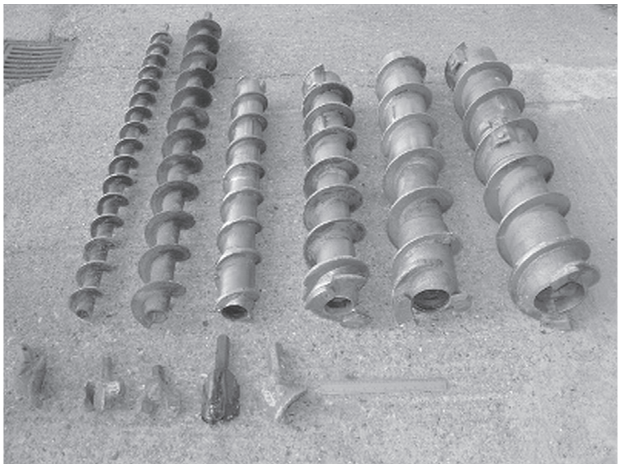

Figure 6.4 Hollow stem augers. (Courtesy of C. Jeffries, Environmental Sampling Ltd.)

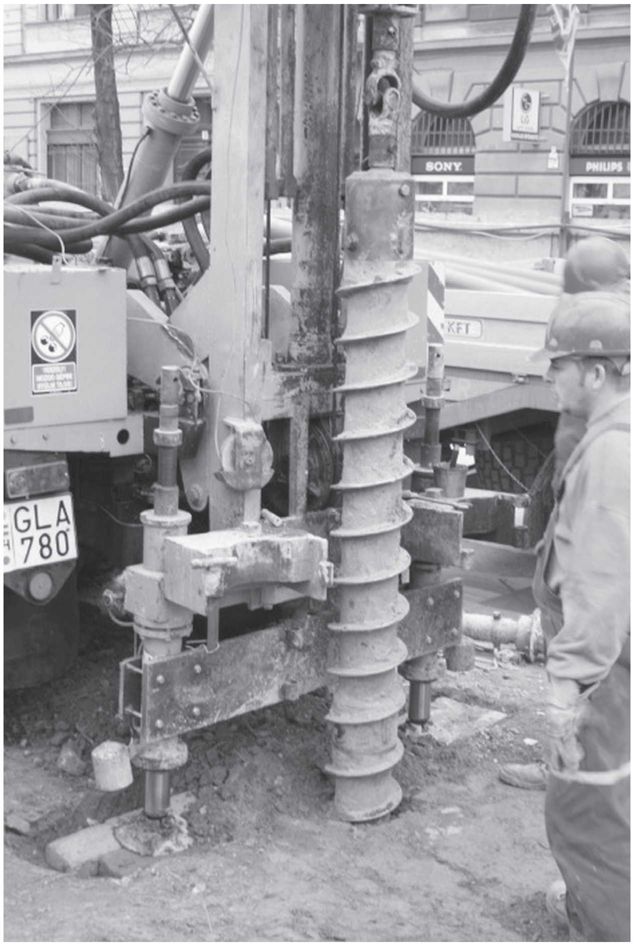

Figure 6.5 Hollow stem auger drilling method. (Courtesy of Geovil Ltd)

rotating hollow stem augers into the soil; these augers are 150 to 300 mm in diameter. The hollow center part of the augers gives access for sampling or any other testing device that can be lowered to the bottom of the hole. The hollow stem auger has the advantage of providing a casing against collapse of the side walls of the borehole, but is limited in penetration depth because it requires significant torque to advance the augers. The wet rotary method is much less limited by depth, but sometimes faces problems of borehole instability.

6.5 SAMPLING

6.5.1 Sample Disturbance

The objective in sampling a soil or rock deposit is to obtain samples that have the least amount of disturbance. This disturbance can come from:

1. Change in stress condition
2. Mechanical disturbance of the soil structure
3. Changes in water content and porosity
4. Chemical changes
5. Mixing and segregation of soil constituents

The goal is to minimize factors 1, 2, and 3, and to eliminate factors 4 and 5. Factor 1 recognizes that the sample follows a certain sequence of stress states as it goes from the intact field situation to testing in the laboratory. In the field, the sample exists under an at-rest effective vertical stress σ'_{ov} and an at-rest effective horizontal stress σ'_{oh}. During sampling, both stresses are likely to increase; σ'_{ov} because the friction between the sample wall and the inside of the sampler compresses the sample and σ'_{oh} because the thickness of the sampler creates horizontal displacement and associated compression. Upon extrusion of the sample from the sampling tube, both total stresses are decreased, but the effective stresses may or may not decrease as much as the total stresses. Indeed, as the sample tries to expand upon extrusion, the expansion may be limited by the inability of the air to get into the pores if the soil has a high degree of saturation and a low hydraulic conductivity. During transport, vibrations are likely and can affect the internal stress state. Figure 6.6 shows a possible scenario before and after testing the sample in the laboratory. It is important to remember this sequence to better understand sample behavior in the laboratory, especially at smaller strains. For one, it is clear that the sample does not start at a state of stress equal to the one it was at in the field. It is desirable to try to recreate this initial state of stress before starting the laboratory test. Similar observations can be made for in situ testing.

Factors 1 and 2 can be minimized by using samplers with a low area ratio. The area ratio, AR, is the ratio of the cross-sectional area of the tube wall over the cross-sectional area of the sample:

$$AR = \frac{\pi(D_0{}^2 - D_i{}^2)/4}{\pi D_i{}^2/4} = \frac{D_0{}^2}{D_i{}^2} - 1 \tag{6.1}$$

where D_o and D_i are the outside and inside diameter of the sampling tube, respectively.

Ratios less than 10% are desirable. Factor 3 in the preceding list can be minimized by sealing the samples as soon as they

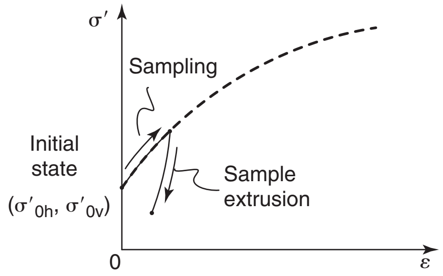

Figure 6.6 Sequence of stress strain behavior during sampling.

are extruded from the sampler. This can be done by pouring hot wax at each end or sealing them with a thin plastic film or foil wrap. Also, it is necessary to keep the vibrations during transport to a minimum, and store the samples in a humidity room as soon as possible. Note that humidity rooms are actually drying rooms, as the humidity level very rarely reaches 100%. Indeed, even at 95% humidity, significant suction exists that can draw water out of the soil into the air. Efforts should be made to seal the sample as well as possible for storage. Despite these best efforts, samples that have been in a humidity room for more than one month are likely to have been affected by drying.

The least disturbed samples of mineral soils are obtained when the sampler is pushed into the soil in one continuous motion. Driving creates much more disturbance. Repeated pushes are not acceptable either, as they create a series of compressions and extensions in the sample and disturbs it (Figure 6.7). There is one exception to this, for organic fibrous soils such as peats. In this case it is best to drive the sampler, because the driving action has a better chance of cutting the fibers rather than pushing them and simply compressing and disturbing the peat excessively. Further information on sample disturbance can be found in Hvorslev (1949).

6.5.2 Common Sampling Methods

The two most common samplers are the *Shelby tube sampler* for clays and silts, also called *thin-wall steel tube*, and the *split spoon sampler* for sands and gravels.[1] The Shelby tube (Figure 6.8) is a seamless, thin-wall steel tube (e.g., 76.2 mm outside diameter, 73 mm inside diameter, 0.9 m long). The area ratio for the Shelby tube is 9%. This is a very low area ratio, so samples taken with the Shelby tube are considered undisturbed. The tube is pushed into the silt or clay at a steady pace under one continuous push. The tube is then pulled out of the soil and the sample stays in the tube by friction. At the surface, the sample is extruded, wrapped and sealed to prevent moisture loss, and then shipped to the laboratory for testing.

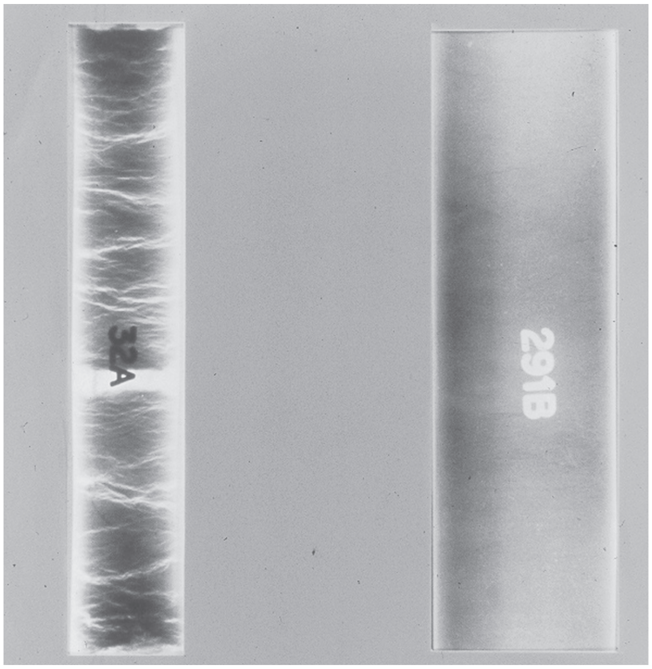

Figure 6.7 X-ray photographs of a driven sample (*left*) and pushed sample (*right*). (Courtesy of FUGRO Inc.)

Figure 6.8 Shelby tube sampling. (Courtesy of Leslie Kanat, 2010, http://kanat.jsc.vsc.edu/drh/.)

Note that the length of the sample recovered is rarely equal to the length pushed. One reason is that the friction that develops between the sample and the inner wall of the sampler increases as the sample enters the sampler. If the friction on the sample becomes larger than the ultimate bearing capacity of the silt or clay below the lower end of the sampler, the sampler becomes plugged and the soil ahead of the sampler experiences bearing-capacity failure, so no more soil enters the sampler. The length of sample required to plug

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[1] The name “Shelby” comes from the Shelby seamless steel tube company established in the late 1800s in Shelby, Ohio. The city of Shelby was named after General Isaac Shelby, a hero of the Revolutionary War and War of 1812 and first governor of Kentucky.

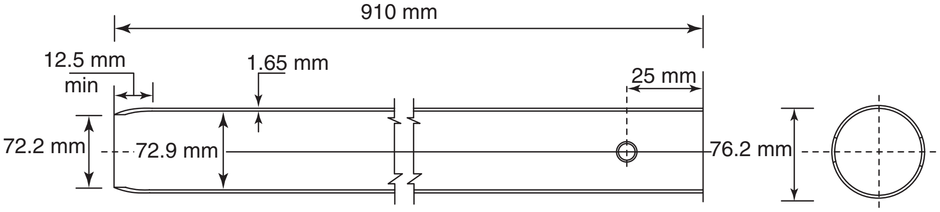


Figure 6.9 Shelby tube sampler cross section.

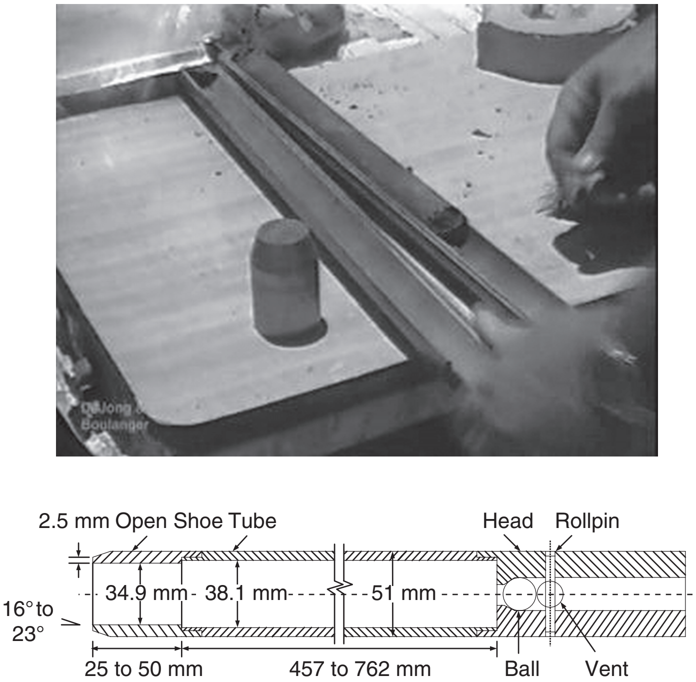


Figure 6.10 Split spoon sampler. (a: From DeJong and Boulanger 2000.)

the sampler depends on the soil and on the sampler, but a length equal to a few sampler diameters may be sufficient to plug the sampler. To minimize the friction between the sample and the inner wall of the sampler, Shelby tubes have an inward curl near the penetrating end (Figure 6.9).

The split spoon sampler (Figure 6.10) is a thick-wall steel tube (50.8 mm outside diameter, 34.9 mm inside diameter, about 0.6 m long) made of two half tubes kept together at the top and the bottom by rings. A core catcher in the bottom ring helps keep the sample in place upon retrieval. The area ratio of the split spoon sampler is 112%. This is a high area ratio, so the samples collected with a split spoon sampler are considered to be disturbed samples. The sampler is driven into the sand or gravel with a standard 623N hammer falling on an anvil at the top of the rods from a height of 0.76 m. This is called the standard penetration test (SPT). The driving process further contributes to the disturbance of the sample. The sampler is brought back to the surface, the tube is opened, and the sample is typically collected in glass jars.

The thin-wall steel tube sampler is used primarily with clays and silts and gives undisturbed samples well suited to many quality laboratory tests. By comparison, the split spoon sampler is used primarily with sands and gravels and gives disturbed samples well suited for soil identification and classification purposes. Other, more advanced samplers exist, such as the Osterberg piston sampler, Swedish foil sampler, Denison sampler, and Pitcher sampler (Hunt, 2005). Piston samplers have the advantage that they minimize part of the disturbance associated with open-tube samplers. Piston samplers have a piston blocking the opening at the bottom of the sampler (Figure 6.11). This piston is locked in place as the sampler is lowered to the desired depth. The piston is then held at that depth while the sampling tube is pushed past the piston into the soil. The vacuum that can develop at the top of the sample helps the soil enter the sampler and minimizes the plugging effect mentioned earlier.

6.6 GROUNDWATER LEVEL

The level of the groundwater at a site is a very important piece of information for any geotechnical investigation. This level can be found in a number of ways: existing information,

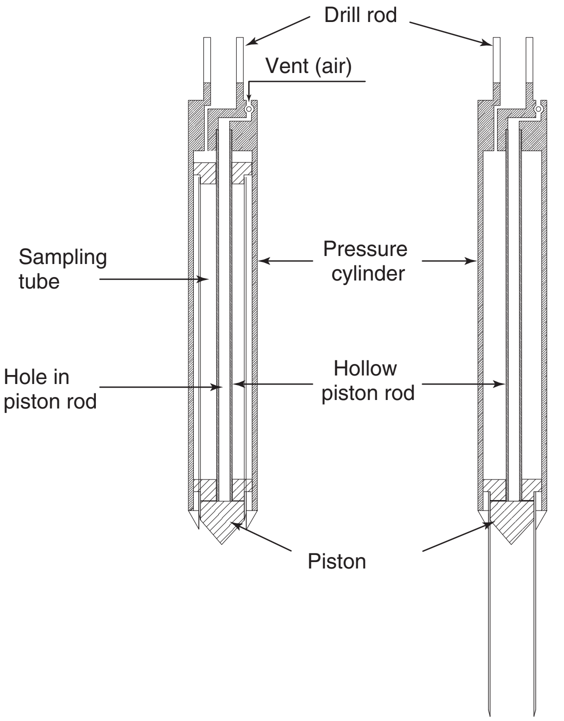


Figure 6.11 Piston sampler diagram.

water level in open borings, standpipe piezometer, and driven piezometers. Existing information can be found in records of water wells drilled in the area (Figure 6.12). These records are often kept by government agencies, such as those dealing with water resources, hydrology, natural resources, geology, and transportation. The well owners may have some very useful information on the seasonal fluctuation of the water level in the well.

Reading the water level in an open borehole is often done as part of a site investigation. At the end of the drilling process, the water or drilling mud is bailed out of the borehole and the water fills the borehole back up to the groundwater level. Water level readings are typically taken 24 hours after the boring is completed and recorded as such in the boring log. Note that 24 hours may not be long enough for the water level to come to equilibrium with the surrounding groundwater. Standpipe piezometers are made by preparing a special borehole (Figure 6.12). After the borehole is drilled, a plastic casing, slotted with holes at its bottom part and smaller in diameter than the borehole, is lowered to the bottom of the borehole. The annulus between the slotted casing and the borehole is filled with sand over the portion where the water pressure measurement is intended. The annulus above the sand-filled portion is filled with bentonite pellets to form an

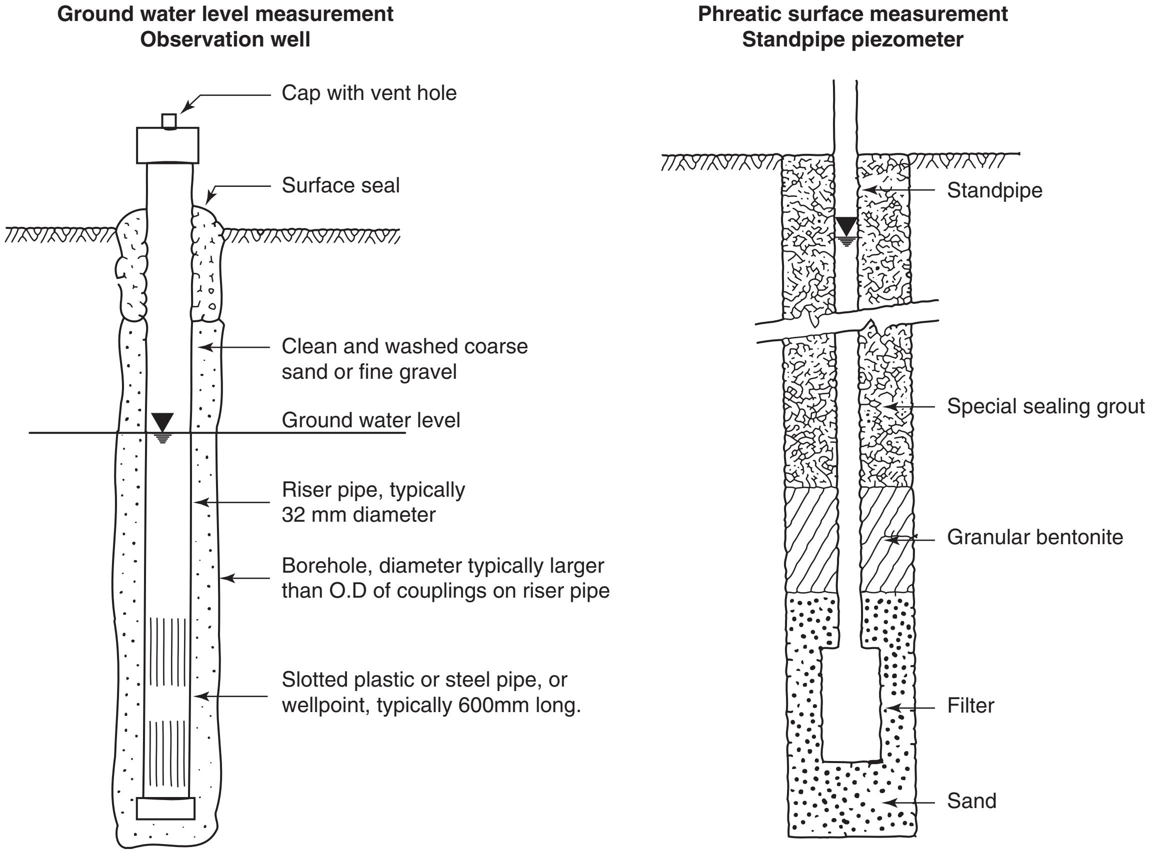


Figure 6.12 Measurement of groundwater level and phreatic surface: (a) groundwater level measurement; (b) phreatic surface measurement observation well. (Courtesy of FHWA.)

impervious plug and isolate the zone to be studied. Water is allowed to rise in the standpipe and the water level is measured when equilibrium is reached. This gives the pressure head at the depth of the slotted casing. Driven piezometers are pushed into the ground like a cone penetrometer and water-pressure measurements are made through pore-pressure transducers located at the bottom of the piezometer. After equilibrium is reached, the pressure measured is equal to the unit weight of water times the height to where the water level would rise in the pipe.

A distinction has to be made between the groundwater level and the phreatic surface. The *groundwater level* is the level to which the water rises in an open borehole. The *phreatic surface* is the line where the water would rise in a pipe (not an open borehole) connected to a point in the ground. These two definitions amount to the same thing unless there is a water pressure in the ground different from hydrostatic. This is the case with an artesian pressure, where the phreatic surface is higher than the groundwater level (Figure 2.14). Standpipe piezometers measure the phreatic surface, whereas open boreholes measure the groundwater level (Figure 6.12).

6.7 FIELD IDENTIFICATION AND BORING LOGS

The best way to identify the soil type is to classify the soil through proper laboratory tests, as described in Chapter 4 on soil classification. In the field, it is also possible to classify the soil through a series of simple tests (ASTM D2488).

Sands and gravels are easily identified, as the particle size is large enough to be seen with the naked eye. Sands will feel gritty when rubbed between your fingers. Dirty sands such as SM and SC tend to leave stains on your hands when wet, whereas SW and SP will have much less tendency to do so. If the sand is dry, taking a handful of sand and dropping it from a height of about 0.3 m will generate a cloud of fine particles for an SC or SM; very little dust will be observed for an SP or SW. Observations about obvious gradation gaps can help in deciding whether the sand is SP or SW.

The type of silt or clay is more difficult to identify. First, wet silts and clays will feel smooth when rubbed between your fingers. The tests described in this section help you decide whether the soil is an ML, MH, CL, or CH; this is the typical order from one extreme to another because in this sequence the soil particles become smaller and smaller and induce a progression in certain properties. The *wash hands test* simply refers to the fact that high-plasticity clays are very difficult to wash off your hands compared to low-plasticity clays and silts. High-plasticity clays tend to feel greasy and it requires quite a bit of rubbing to remove the soil from your skin. Also, when you wash your hands after handling a high-plasticity clay, the pores of your hands will tend to contract and your skin will feel tight after your hands dry. The *dry strength test* also helps you distinguish between high- and low-plasticity materials. Take a piece of soil and let it dry under the sun or in a field office. In a few hours, most soils will be dry enough that the dry strength test can be performed. High-plasticity clays will exhibit high dry strength: difficult to crush between your fingers, difficult to break a small piece by bending. Low-plasticity soils will crush easily or break easily by bending. Silts exhibit little cohesion. The *thread rolling test*, also called the *toughness test*, consists of taking the piece of soil used in the hand shaking test and trying to roll it into a thread as thin as 3 mm in diameter. If it is nearly impossible without the thread cracking, the soil is low plasticity; if it is possible, the soil is likely high plasticity.

The *hand shaking test*, also called the *dilatancy test*, can help in evaluating the hydraulic conductivity of a soil. Silts have a much higher hydraulic conductivity than clays because of the larger particles. The hand shaking test consists of taking a small piece of very wet soil, placing it in the bottom of your cupped hand such that it forms a mushroom-sized patty, and tapping your hand against your other hand to impart horizontal shaking blows to the soil. If the surface of the soil becomes glossy after a few blows, it means that water is coming to the surface and the soil has relatively high hydraulic conductivity (silt). If the soil surface stays matte after 10 blows, the soil has much lower hydraulic conductivity (clay). Organic soils have a distinct foul smell and dark color. Peat is fibrous when young and dark and smooth when decomposed.

Some simple tests can also be used to gauge the strength of the soil encountered. In clays and silts, the tests consist of taking a sample in your hand and trying to deform the sample with your thumb or fingernail. In sands and gravels, the tests consist of trying to push or drive a steel bar into the soil from the surface, as well as checking for footprints behind you. These tests and corresponding categories of strengths are presented in Table 6.2. Note that the tests for silts and clays can be performed on samples retrieved at depth, while the tests for sands and gravels are limited to the ground surface. The SPT blow count is used for evaluating the strength properties of sand and gravel at depth.

During drilling, the driller usually has a good idea what soil is being drilled through: the driller can hear the noise made by the drilling bit, the driller can observe the downward progress of the rods, and the driller can catch the cuttings coming back to the surface (in the mud pit, for example). Clays are carved by a drill bit without much noise and with smooth continuous penetration. Sands are washed by the mud flow and the downward movement of the rods is more erratic. Gravels make a grinding noise during drilling. The driller writes down the soil type that is encountered as the borehole advances; this is the field borehole log. (An example of a field log is shown in Figure 6.13.) While in the field the geotechnical engineer will take notes, collect samples, and perform simple tests. Back in the office, she or he will ask the lab technician to run classification tests and other engineering property tests best suited for the project. On the basis of the data collected, the engineer will prepare the final boring log corresponding to each borehole. Examples of boring logs are

Table 6.2 Simple Field Evaluation of Strength

Silts and Clays Strength

Description	S_u (kPa)	N (bpf)	Simple field test[1]
Very soft	<12	<2	Squeezes between your fingers.
Soft	12–25	2–4	Easily penetrated by light thumb pressure.
Medium or firm	25–50	4–8	Penetrated by strong thumb pressure.
Stiff	50–100	8–15	Indented by strong thumb pressure.
Very stiff	100–200	15–30	Slightly indented by strong thumb pressure.
Hard	200–400	30–50	Slightly indented by thumbnail.
Very hard	>400	>50	Not indented by thumbnail.

Gravels and Sands Strength

Description	Φ°	N (bpf)	Simple field test[2]
Very loose	$<28^\circ$	<4	12 mm diameter rebar pushed in 0.3 m by hand Shows definite marks of footsteps; hard to walk on
Loose	28°–30°	4–10	12 mm diameter rebar pushed in 0.1 m by hand Shows footsteps
Medium or compact	30°–36°	10–30	12 mm diameter rebar driven 0.3 m with carpenter hammer Footsteps barely noticeable
Dense	36°–41°	30–50	12 mm diameter rebar driven 0.1 m with carpenter hammer No marks or footsteps
Very dense	$>41^\circ$	>50	12 mm diameter rebar driven 0.03 m with carpenter hammer No marks of footsteps

[1] Note that these tests are performed on a sample of the soil.

[2] Note that these tests are performed at the ground surface of the gravel or sand deposit, not on a sample.

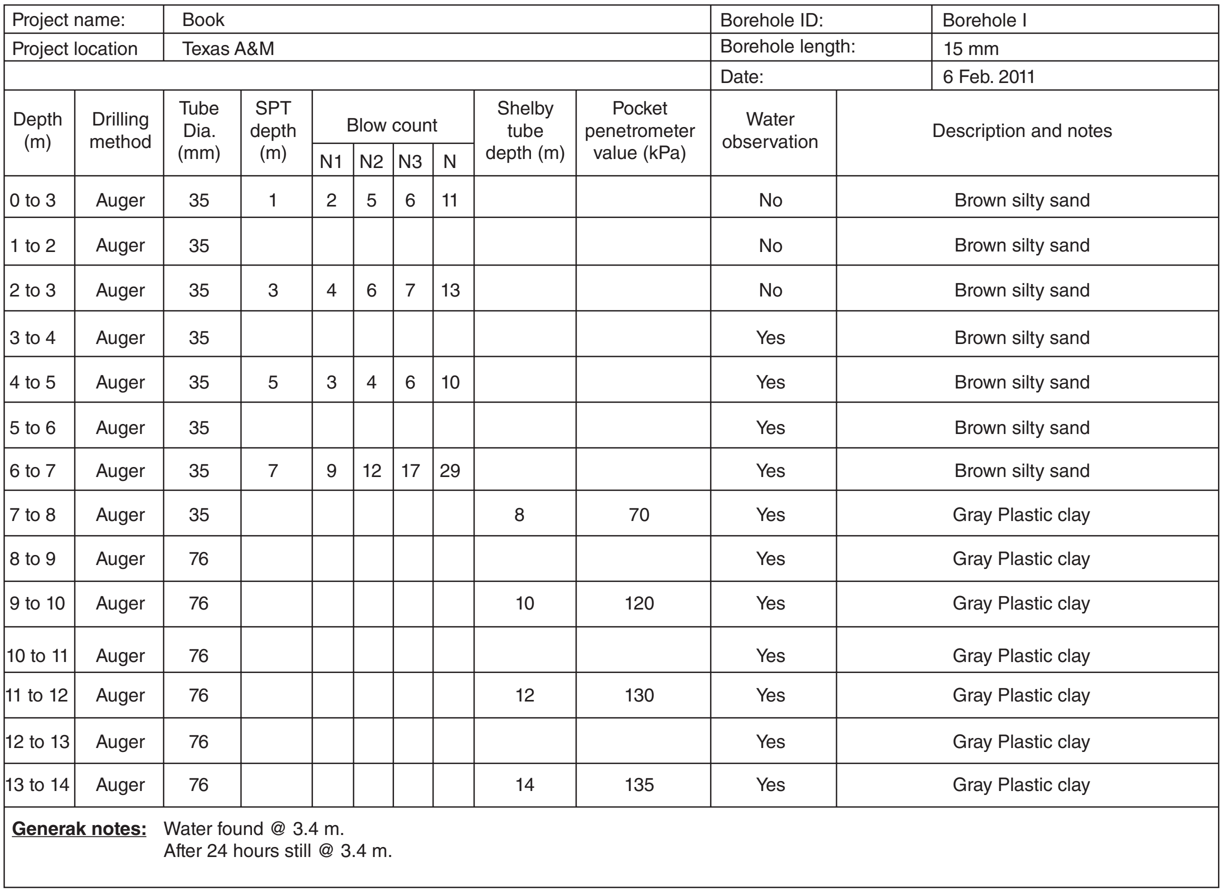
shown in Figure 6.14 and the key to soil type representation on boring logs is shown in Figure 6.15.

6.8 SOIL NAMES

In a natural soil, the four groups of particle sizes may exist side by side. A gravel will be a soil that has most of its particles in the gravel size range. A sand will be a soil that has most of its particles in the sand size range. Silts and clays are recognized according to their plasticity; that is, the ability of the soil to deform without breaking. Silts exhibit moderate plasticity, whereas clays can exhibit very high plasticity. Soils are classified as gravel, sand, silt, or clay according to a rigorous classification system described in Chapter 4.

Soils may also be given other names, such as those in the following list:

- *Adobe*: a local term describing silts and clays in semiarid regions
- *Aeolian soil*: soil deposited by wind such as loess
- *Alluvium*: soil carried by moving water and deposited when the water slows down
- *Bentonite*: a very fine clay with extreme swelling and shrinking properties; used with water as drilling mud
- *Calcareous sands*: sands formed by the shells of marine mollusks
- *Caliche*: soil cemented by calcium carbonate
- *Collapsible soils*: soils that exhibit sudden settlement (collapse of the structure) when placed under load and under water
- *Colluvium*: soil deposited by gravity at the bottom of a slope
- *Dispersive clays*: clays in which the particles separate from each other when exposed to water even when the water does not flow and the soil is not loaded
- *Expansive soils*: see shrink-swell soils
- *Lacustrine deposits*: soil deposited by settling in water under a low-energy environment such as a lake
- *Laterite*: soil rich in iron (red color) and found in hot and humid climates (tropics)



Project name:	Book	Borehole ID:	Borehole I
Project location	Texas A&M	Borehole length:	15 mm
		Date:	6 Feb. 2011

Depth (m)	Drilling method	Tube Dia. (mm)	SPT depth (m)	Blow count				Shelby tube depth (m)	Pocket penetrometer value (kPa)	Water observation	Description and notes
				N1	N2	N3	N				
0 to 3	Auger	35	1	2	5	6	11			No	Brown silty sand
1 to 2	Auger	35								No	Brown silty sand
2 to 3	Auger	35	3	4	6	7	13			No	Brown silty sand
3 to 4	Auger	35								Yes	Brown silty sand
4 to 5	Auger	35	5	3	4	6	10			Yes	Brown silty sand
5 to 6	Auger	35								Yes	Brown silty sand
6 to 7	Auger	35	7	9	12	17	29			Yes	Brown silty sand
7 to 8	Auger	35						8	70	Yes	Gray Plastic clay
8 to 9	Auger	76								Yes	Gray Plastic clay
9 to 10	Auger	76						10	120	Yes	Gray Plastic clay
10 to 11	Auger	76								Yes	Gray Plastic clay
11 to 12	Auger	76						12	130	Yes	Gray Plastic clay
12 to 13	Auger	76								Yes	Gray Plastic clay
13 to 14	Auger	76						14	135	Yes	Gray Plastic clay

Generak notes: Water found @ 3.4 m.
After 24 hours still @ 3.4 m.

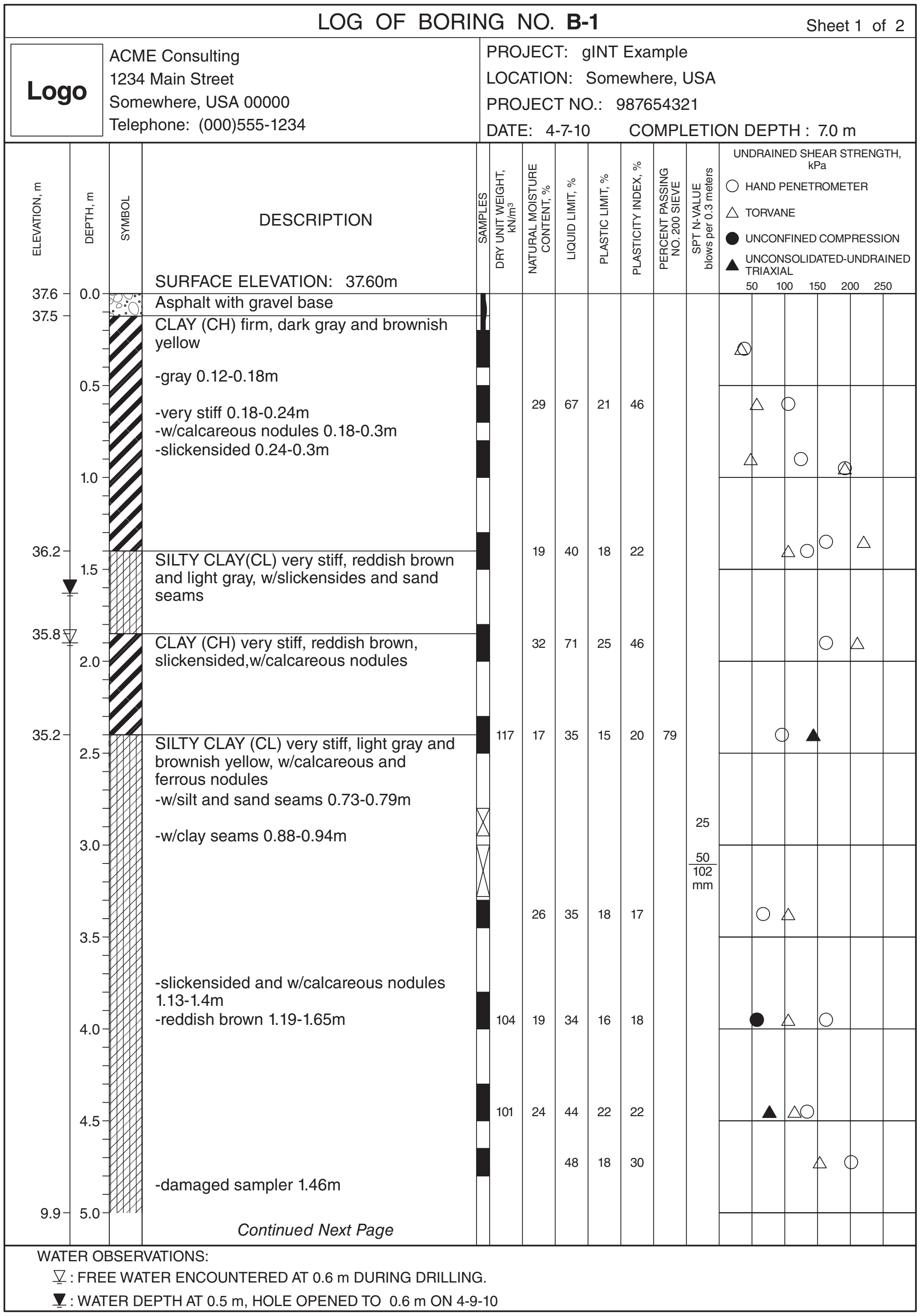
Figure 6.13 Example of a driller's field log.

- *Loam*: a mixture of sand, clay, and decaying organic materials
- *Loess*: lightly cemented soil made mostly of silt, and deposited by wind
- *Marl*: very stiff clay of marine origin and with calcareous content
- *Montmorillonite*: a very fine clay with extreme swelling and shrinking properties
- *Organic clay or silt*: a clay or a silt with a significant amount of organic constituents
- *Peat*: organic soil made of live or decayed plant fragments
- *Quick clay*: clay that can liquefy when sheared excessively
- *Quick sand*: sand that turns into a liquid when subjected to a sufficiently strong upward flow of water
- *Residual soils*: soils created by intense weathering of crystalline rock (tropical regions)
- *Shale*: a very hard soil or soft rock made of silt and clay particles; can slake when subjected to wet-dry cycles
- *Shrink-swell soils*: soils above the groundwater level that shrink and swell when exposed to the seasonal cycles; also but less appropriately called *expansive soils*
- *Slickensided clay*: clay with fissures, the surfaces of which have been smoothened by repeated movement
- *Till*: soil created by glaciers and containing many particle sizes well distributed across the range from very small to very large; typically very strong
- *Tuff*: soil deposited by a volcanic explosion, usually silt size
- *Varved clay*: a clay made of thin alternating layers of silt and clay.

6.9 OFFSHORE SITE INVESTIGATIONS

Offshore structures (Figure 6.16) are built primarily to drill for oil, to collect any oil found, and to send it to shore through pipelines. The depth of offshore platforms can reach several thousand meters of water depth, and the foundation of these enormous structures requires proper site investigations. Other types of offshore structures requiring site investigation include windmills, pipelines, and bridges.

The site investigation is performed from boats, ships, or sometimes jack-up rigs. The size of the ship used depends on the water depth. Figure 6.17 shows some of the vessels available for various water depths. In shallow waters, ships are simply anchored. In deep waters, the most sophisticated ships have dynamic global positioning systems (GPSs) where motors on the hull of the ship are able to maintain



LOG OF BORING NO. **B-1** Sheet 1 of 2

Logo

ACME Consulting
1234 Main Street
Somewhere, USA 00000
Telephone: (000)555-1234

PROJECT: gINT Example
LOCATION: Somewhere, USA
PROJECT NO.: 987654321
DATE: 4-7-10 COMPLETION DEPTH : 7.0 m

SURFACE ELEVATION: 37.60m

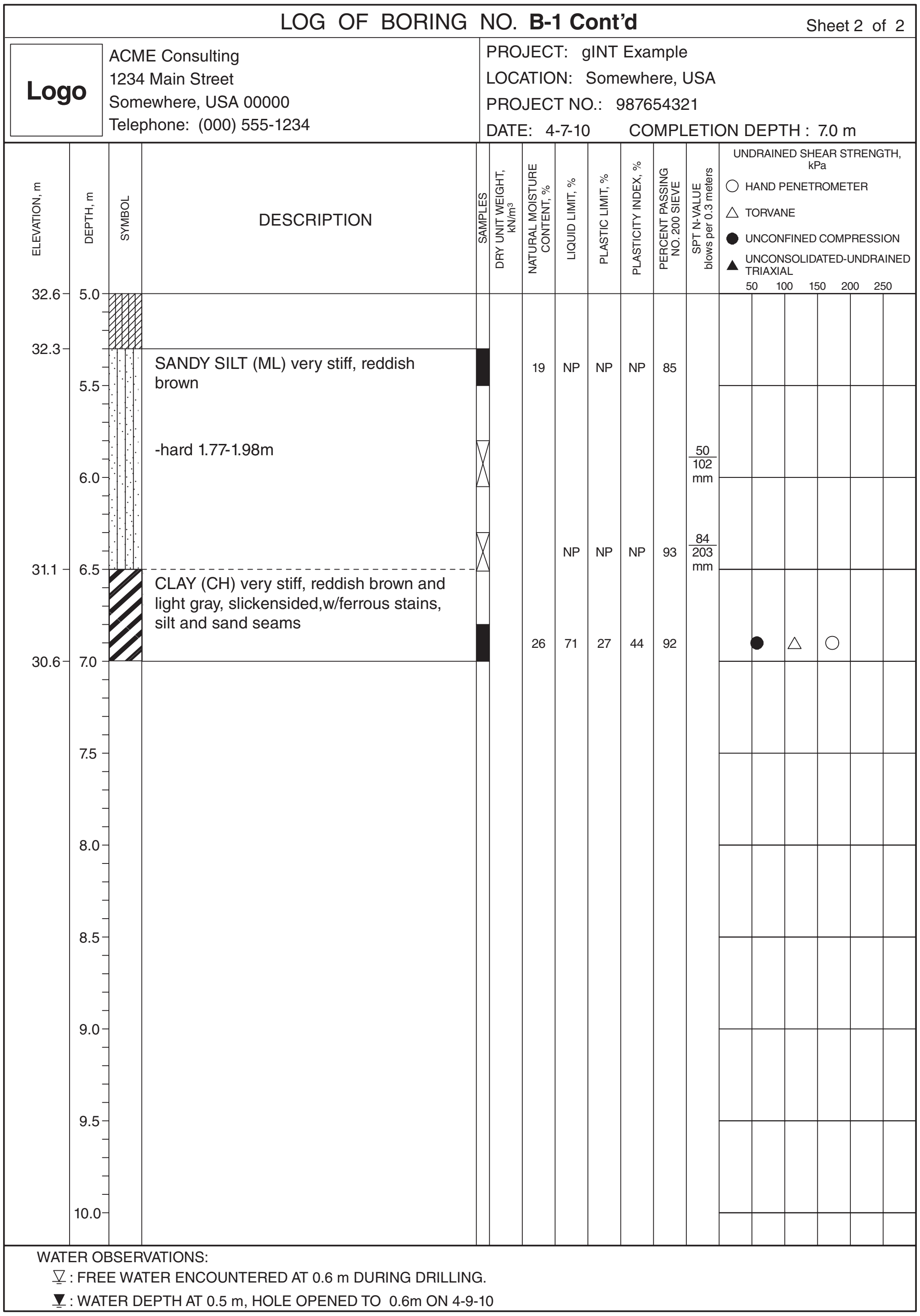
ELEVATION, m	DEPTH, m	SYMBOL	DESCRIPTION	SAMPLES	DRY UNIT WEIGHT, kN/m³	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	PERCENT PASSING NO. 200 SIEVE	SPT N-VALUE blows per 0.3 meters
37.6	0.0		Asphalt with gravel base								
37.5			CLAY (CH) firm, dark gray and brownish yellow								
			-gray 0.12-0.18m								
	0.5										
			-very stiff 0.18-0.24m -w/calcareous nodules 0.18-0.3m -slickensided 0.24-0.3m			29	67	21	46		
	1.0										
36.2			SILTY CLAY(CL) very stiff, reddish brown and light gray, w/slickensides and sand seams			19	40	18	22		
	1.5										
35.8			CLAY (CH) very stiff, reddish brown, slickensided,w/calcareous nodules			32	71	25	46		
	2.0										
35.2			SILTY CLAY (CL) very stiff, light gray and brownish yellow, w/calcareous and ferrous nodules		117	17	35	15	20	79	
	2.5										
			-w/silt and sand seams 0.73-0.79m								25
			-w/clay seams 0.88-0.94m								
	3.0										50 102 mm
						26	35	18	17		
	3.5										
			-slickensided and w/calcareous nodules 1.13-1.4m								
	4.0		-reddish brown 1.19-1.65m		104	19	34	16	18		
	4.5				101	24	44	22	22		
							48	18	30		
			-damaged sampler 1.46m								
9.9	5.0										

UNDRAINED SHEAR STRENGTH, kPa
○ HAND PENETROMETER
△ TORVANE
● UNCONFINED COMPRESSION
▲ UNCONSOLIDATED-UNDRAINED TRIAXIAL

Continued Next Page

WATER OBSERVATIONS:
▽ : FREE WATER ENCOUNTERED AT 0.6 m DURING DRILLING.
▼ : WATER DEPTH AT 0.5 m, HOLE OPENED TO 0.6 m ON 4-9-10

Figure 6.14 Examples of final borehole logs. (Copyright © 2011 Bentley Systems, Incorporated. All Rights Reserved.)



LOG OF BORING NO. **B-1 Cont'd** Sheet 2 of 2

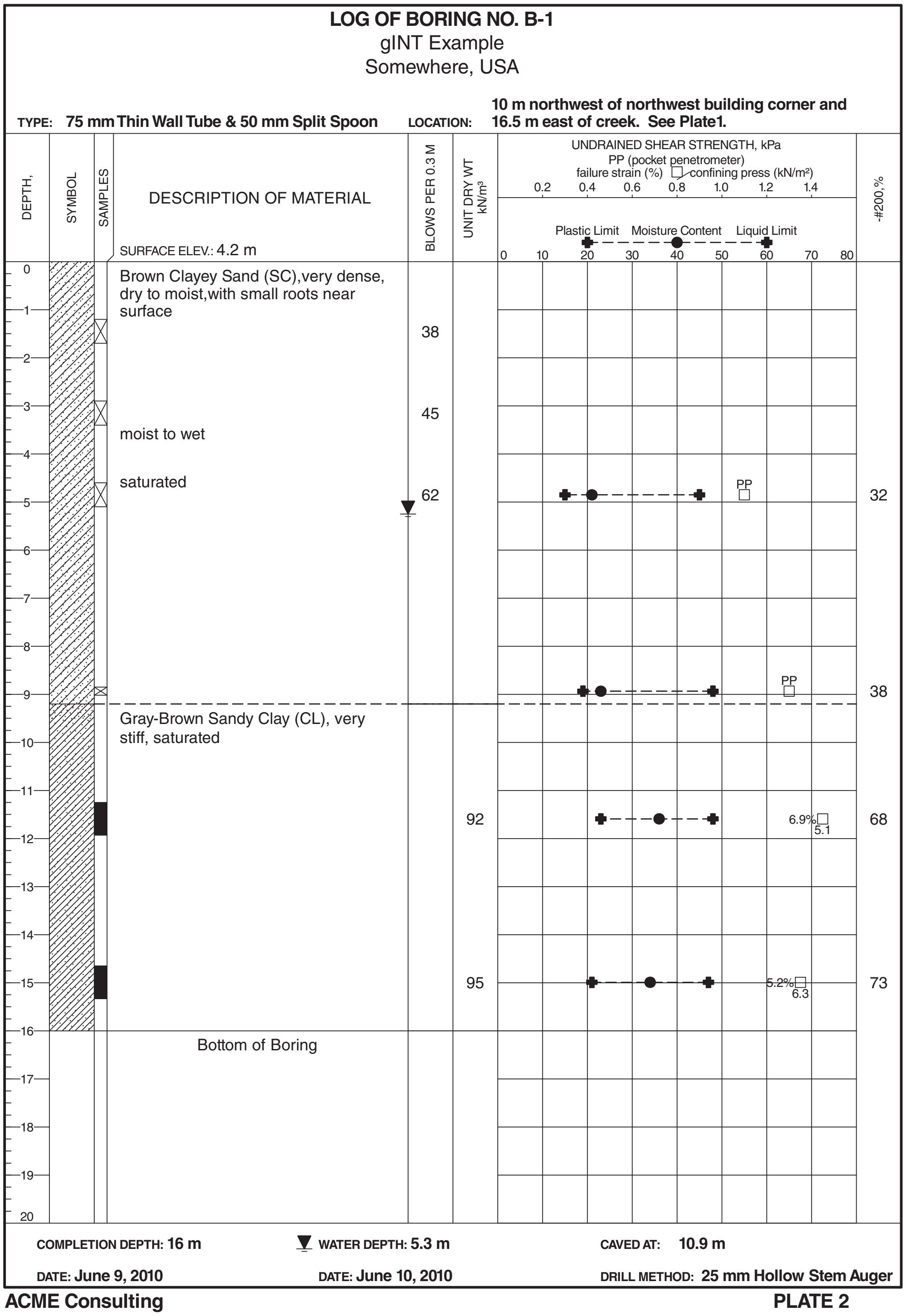
Logo
ACME Consulting
1234 Main Street
Somewhere, USA 00000
Telephone: (000) 555-1234

PROJECT: gINT Example
LOCATION: Somewhere, USA
PROJECT NO.: 987654321
DATE: 4-7-10 COMPLETION DEPTH : 7.0 m

ELEVATION, m	DEPTH, m	DESCRIPTION	DRY UNIT WEIGHT, kN/m³	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	PERCENT PASSING NO. 200 SIEVE	SPT N-VALUE blows per 0.3 meters	UNDRAINED SHEAR STRENGTH, kPa (50 100 150 200 250)
32.6	5.0									
32.3		SANDY SILT (ML) very stiff, reddish brown		19	NP	NP	NP	85		
	5.5									
		-hard 1.77-1.98m							50/102 mm	
	6.0									
					NP	NP	NP	93	84/203 mm	
31.1	6.5	CLAY (CH) very stiff, reddish brown and light gray, slickensided,w/ferrous stains, silt and sand seams								
				26	71	27	44	92		● △ ○
30.6	7.0									
	7.5									
	8.0									
	8.5									
	9.0									
	9.5									
	10.0									

WATER OBSERVATIONS:
▽ : FREE WATER ENCOUNTERED AT 0.6 m DURING DRILLING.
▼ : WATER DEPTH AT 0.5 m, HOLE OPENED TO 0.6m ON 4-9-10

Figure 6.14 (*Continued*)



LOG OF BORING NO. B-1
gINT Example
Somewhere, USA

TYPE: **75 mm Thin Wall Tube & 50 mm Split Spoon** **LOCATION:** **10 m northwest of northwest building corner and 16.5 m east of creek. See Plate1.**

DEPTH,
SYMBOL
SAMPLES
DESCRIPTION OF MATERIAL
SURFACE ELEV.: 4.2 m
BLOWS PER 0.3 M
UNIT DRY WT kN/m³
UNDRAINED SHEAR STRENGTH, kPa
PP (pocket penetrometer)
failure strain (%) ☐ confining press (kN/m²)
0.2 0.4 0.6 0.8 1.0 1.2 1.4
Plastic Limit Moisture Content Liquid Limit
0 10 20 30 40 50 60 70 80
-#200,%

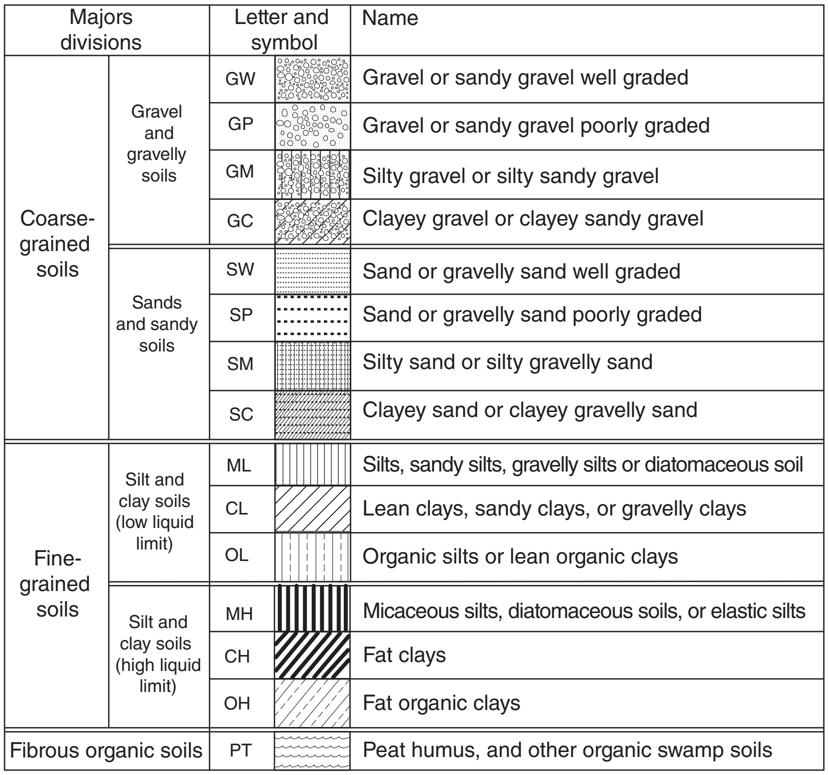
Depth	Description of material	Blows per 0.3 M	Unit dry wt kN/m³	Undrained shear strength	-#200,%
0	Brown Clayey Sand (SC),very dense, dry to moist,with small roots near surface				
1.5		38			
3.2	moist to wet	45			
4.9	saturated	62		PP	32
9				PP	38
9.2	Gray-Brown Sandy Clay (CL), very stiff, saturated				
11.6			92	6.9% 5.1	68
15			95	5.2% 6.3	73
16	Bottom of Boring				

COMPLETION DEPTH: **16 m** **WATER DEPTH:** **5.3 m** **CAVED AT:** **10.9 m**

DATE: **June 9, 2010** **DATE:** **June 10, 2010** **DRILL METHOD:** **25 mm Hollow Stem Auger**

ACME Consulting **PLATE 2**

Figure 6.14 (*Continued*)



Majors divisions		Letter and symbol		Name
Coarse-grained soils	Gravel and gravelly soils	GW		Gravel or sandy gravel well graded
		GP		Gravel or sandy gravel poorly graded
		GM		Silty gravel or silty sandy gravel
		GC		Clayey gravel or clayey sandy gravel
	Sands and sandy soils	SW		Sand or gravelly sand well graded
		SP		Sand or gravelly sand poorly graded
		SM		Silty sand or silty gravelly sand
		SC		Clayey sand or clayey gravelly sand
Fine-grained soils	Silt and clay soils (low liquid limit)	ML		Silts, sandy silts, gravelly silts or diatomaceous soil
		CL		Lean clays, sandy clays, or gravelly clays
		OL		Organic silts or lean organic clays
	Silt and clay soils (high liquid limit)	MH		Micaceous silts, diatomaceous soils, or elastic silts
		CH		Fat clays
		OH		Fat organic clays
Fibrous organic soils		PT		Peat humus, and other organic swamp soils

Figure 6.15 Key to soil type representation.

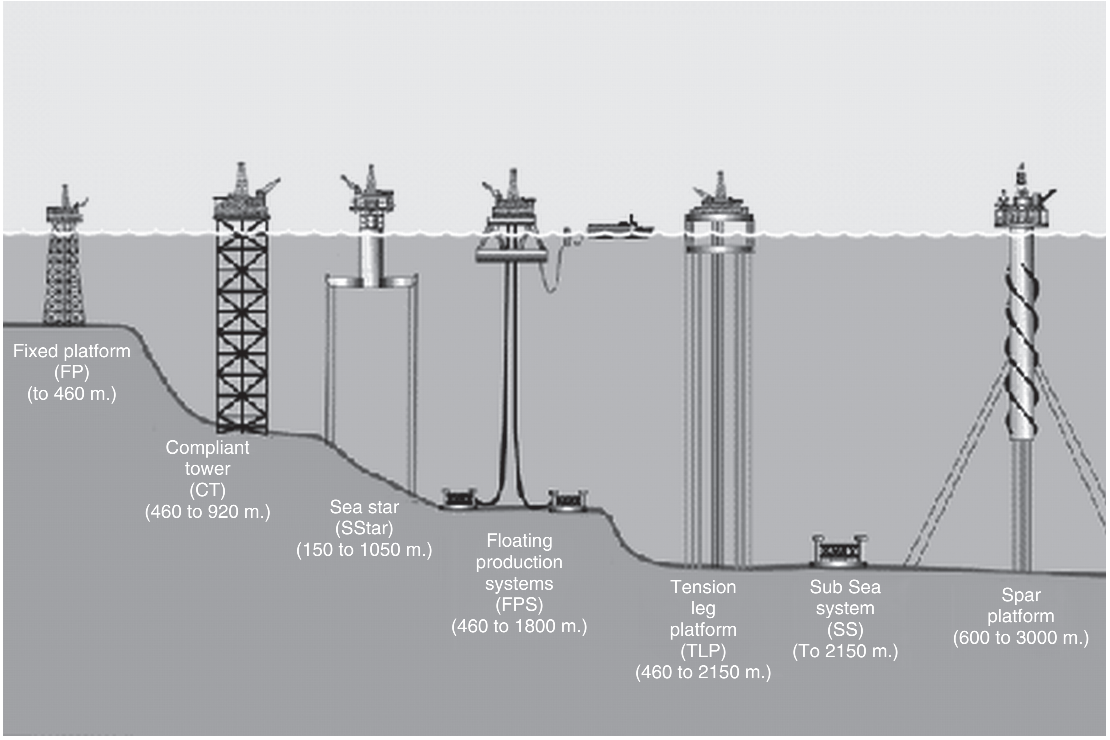


Figure 6.16 Types of offshore oil platforms. (Courtesy of Otis Armstrong and Greg Overton.)

Figure 6.17 Ships, jack-up rig, and remotely operated vehicle (ROV) for offshore investigations. (a, and c: Courtesy of FUGROSeacore., b and d: Courtesy of the ISSMGE Technical Committee on Offshore Geotechnics)

the ship in the same position (x and y) with respect to known satellite positions. Minimizing the movement of the drilling tool in the z direction due to ship movement is also important and is done through the use of heave compensators, described later in this chapter. Offshore geotechnical investigations include drilling, sampling, and in situ testing much like onshore investigations. The difference is a matter of scale, complexity, and cost. Another difference is the increased use of geophysical investigations for offshore work.

6.9.1 Offshore Geophysical Investigations

Offshore investigations rely on geophysics in addition to geotechnical investigations. The geophysics techniques most commonly used are seismic reflection and seismic refraction. Electrical resistivity methods are also used, but less frequently.

Seismic reflection systems use sound propagation energy generated by a device towed behind a ship. The device measures the travel time required for the acoustic energy or wave to travel to the seabed or an interface between two distinct soil layers below the seabed and be reflected to the same device or to a receiving array (Figure 6.18). The *seismic refraction* systems also use sound propagation energy, in this case generated by a device including an acoustic pulse generator and a line of hydrophones dragged on the sea bottom by a ship. The device measures the travel time required for the acoustic energy or wave to travel to an interface between two distinct soil layers below the seabed, refract critically along that interface, and send the wave back to the line of receivers or hydrophones. Seismic refraction is more often used for shallow penetration below the seafloor (pipelines, cables) and gives the thickness and the shear wave velocity of the material.

Precision of the measurement and penetration into the soil depend on the frequency and amplitude of the acoustic wave. A wave with a high frequency and low amplitude will give high resolution (good precision on the distance measured) but low penetration into the soil. A wave with a low frequency and high amplitude will give deeper penetration but lower resolution. Measurements of water depth or *bathymetry* (bathos

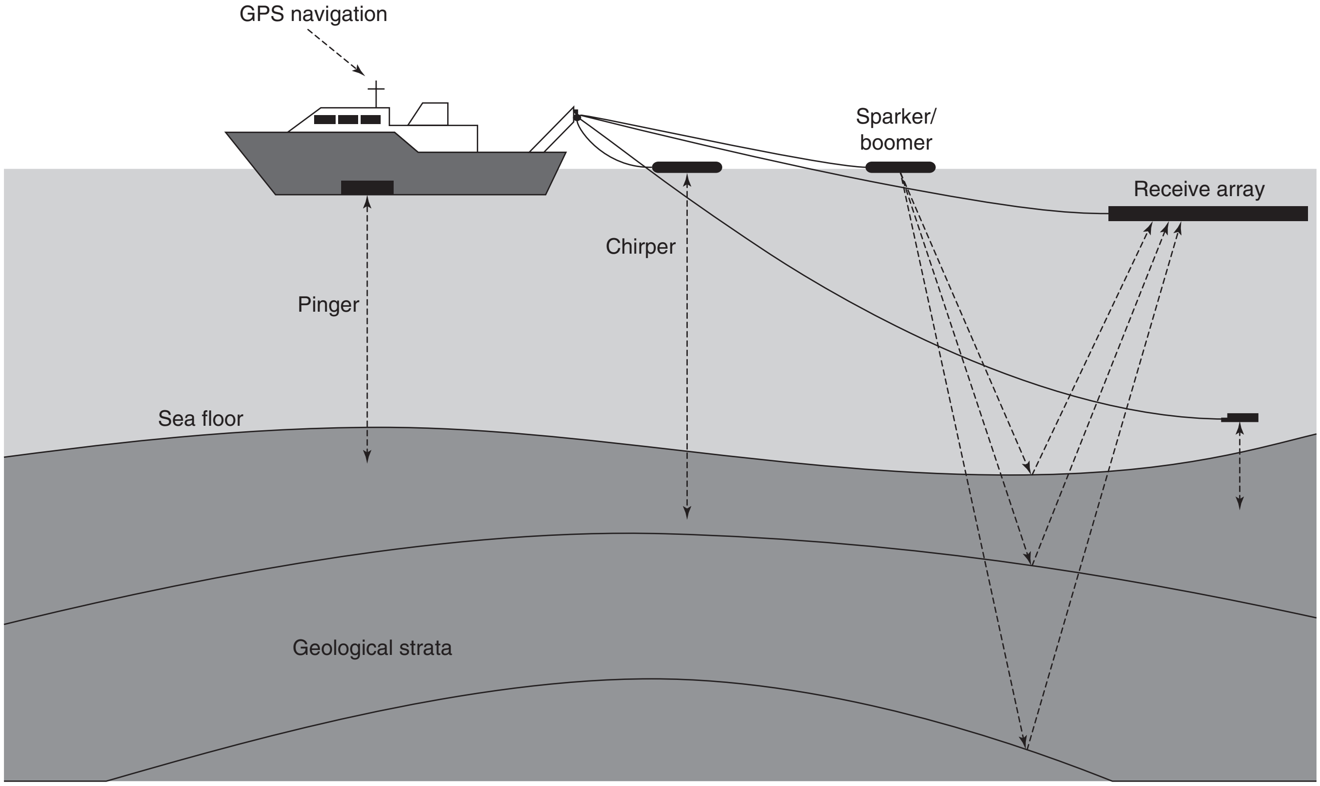


Figure 6.18 Offshore geophysics investigations: seismic reflection. (Courtesy of Ozcoast.)

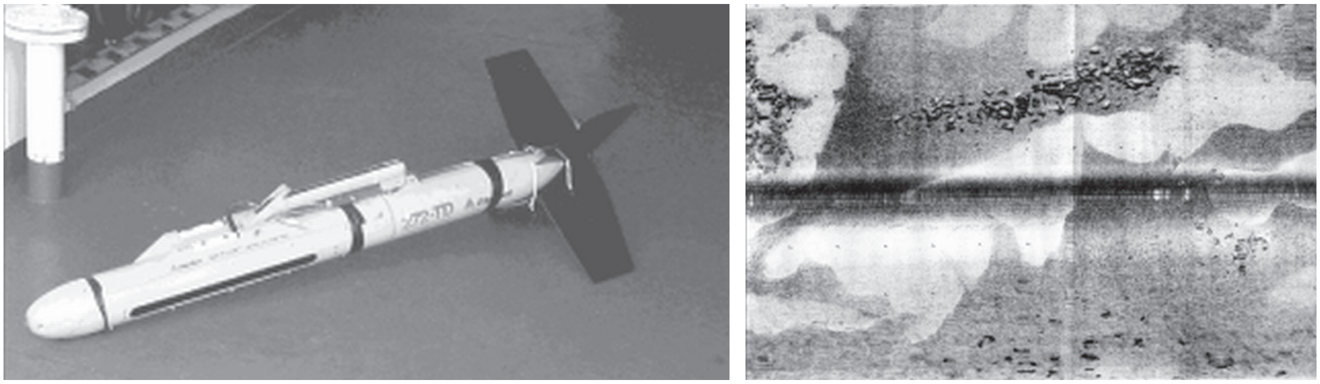


Figure 6.19 Sidescan sonar and sea-bottom image generated therefrom. (Courtesy of the ISSMGE Technical Committee on Offshore Geotechnics.)

means "depth" in Greek) are made using echosounders towed in the water column behind a boat. Pictures of the sea floor are obtained with *sidescan sonars* (Figure 6.19). These sonars aim sideways to capture a wide image of the sea floor. Images of the soil layers below the sea bottom are generated by using *sub-bottom profilers* such as pingers, chirpers, boomers, and sparkers (Figure 6.18). The frequencies generated by these devices vary from 0.5 kHz to 40 kHz and give penetration of the soil from 1 to 100 m with about a 1 to 10% resolution. Examples of the results obtained through geophysics tests are shown in Figure 6.20.

6.9.2 Offshore Geotechnical Drilling

Compared to onshore drilling, offshore drilling adds at least two complexities: larger depths, which can reach thousands of meters of combined water depth and penetration depth;

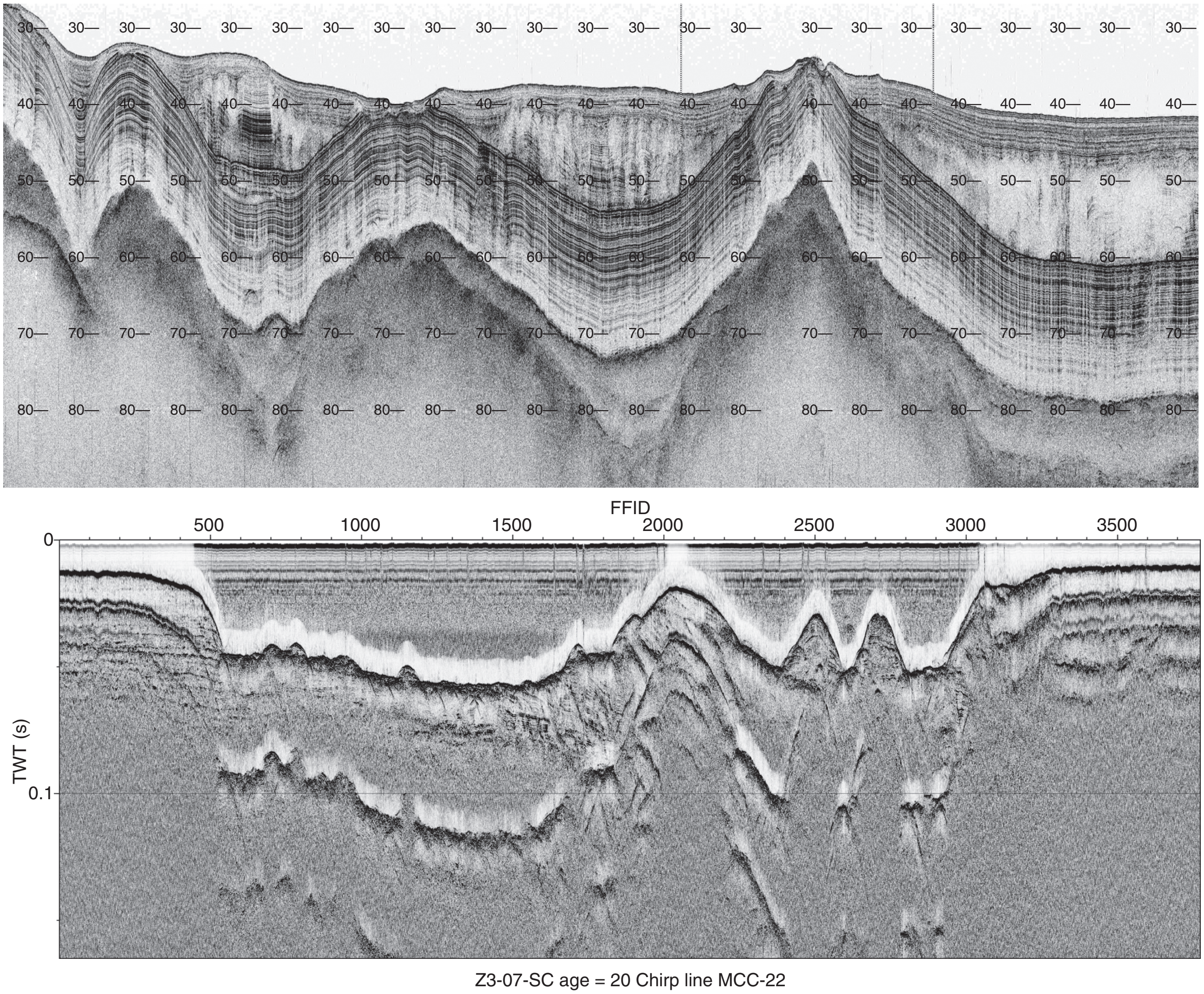


Figure 6.20 Examples of sub-bottom profiler results. (a: Courtesy of EdgeTech; image captured by EdgeTech 3100 Portable sub-bottom profiling system, b: Courtesy of United States Geological Survey, USA)

and vertical motion of the drill rig due to waves. The wet rotary drilling method is always used for offshore work, but it is very difficult to recirculate the drilling mud; this would require injecting the drilling mud from the ship down the drill pipes, and bringing it back to the ship. It would be necessary to have a double set of concentric drill pipes and would complicate the process dramatically while increasing the weight significantly. Instead, a single string of drill pipes is used and the biodegradable drilling mud is expended as waste on the sea floor. Many offshore sediments are very soft near the sea floor, so a casing is necessary to prevent collapse of the borehole. Furthermore, access to the borehole after drilling is necessary to take a sample or run an in situ test. For these reasons offshore drilling is done by rotating casing-size drill pipes, typically 127 mm outside diameter and 102 mm inside diameter. The drill bit at the end of the pipes is about 220 mm in outside diameter (Figure 6.21) and allows free access to the soil for various tools through the center of the pipes and the bit. Often the drill pipes will go through a support bottom platform (Figure 6.22) to guide the pipes and provide bottom support.

The ship movement must not be transmitted to the drill pipes or the drill bit would go up and down with the ship. This would lead to very poor borehole quality and could plug the bit. Heave compensators or motion compensators are instruments that minimize this problem (Figure 6.23). They can be passive (spring-and-dashpot system from which the top of the rods is hanging) or active (computer-controlled hydraulic jacks acting on the rods to compensate for measured motion).

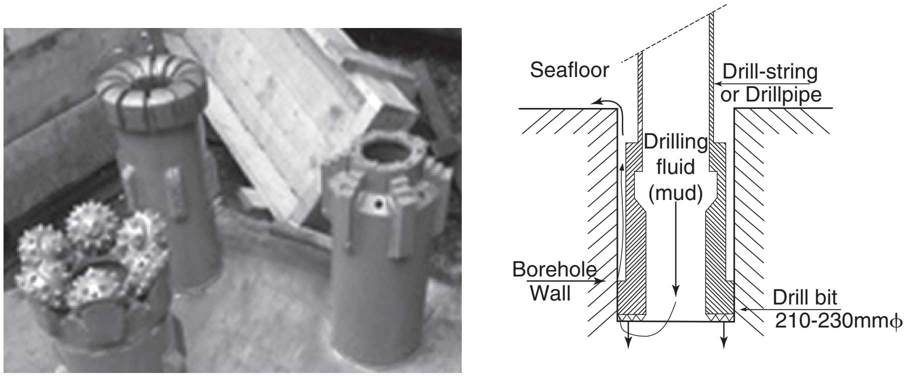


Figure 6.21 Bottom of drill pipes with drill bit. (*Left*: Courtesy of Rok Max Drilling Tools, Ltd.; *Right*: After Richards and Zuidberg 1985.)

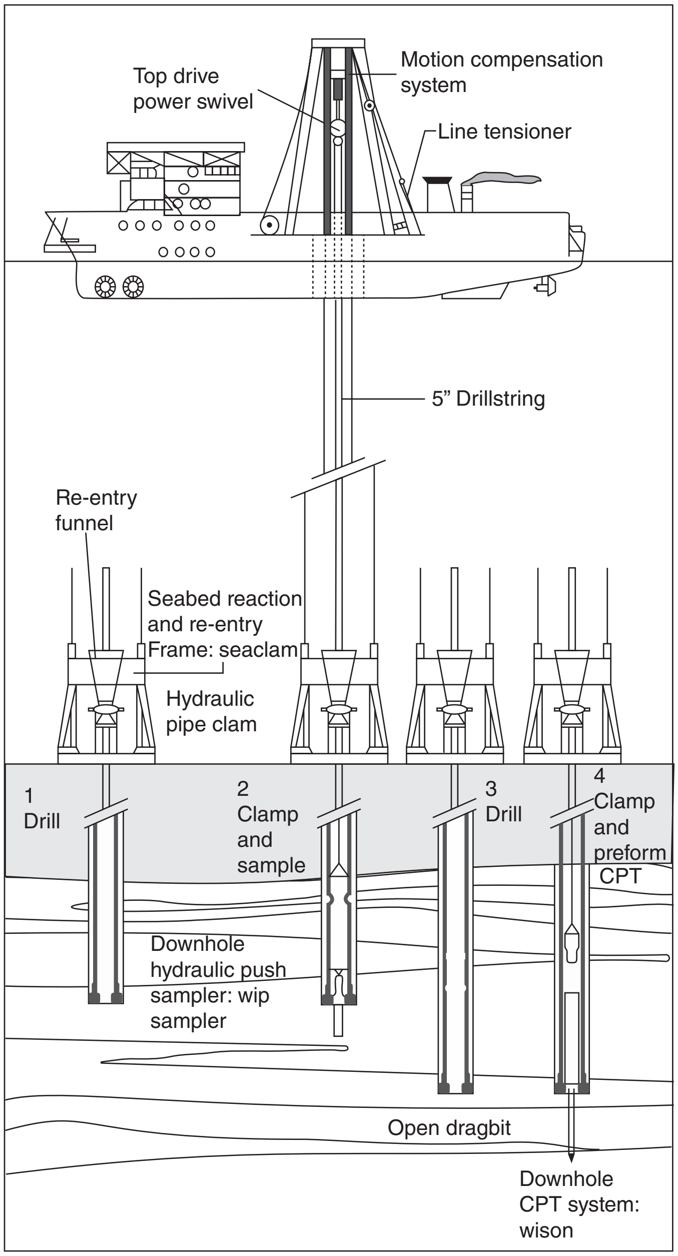


Figure 6.22 Drilling, sampling, and in situ testing through the drill string. (Courtesy of the ISSMGE Technical Committee on Offshore Geotechnics.)

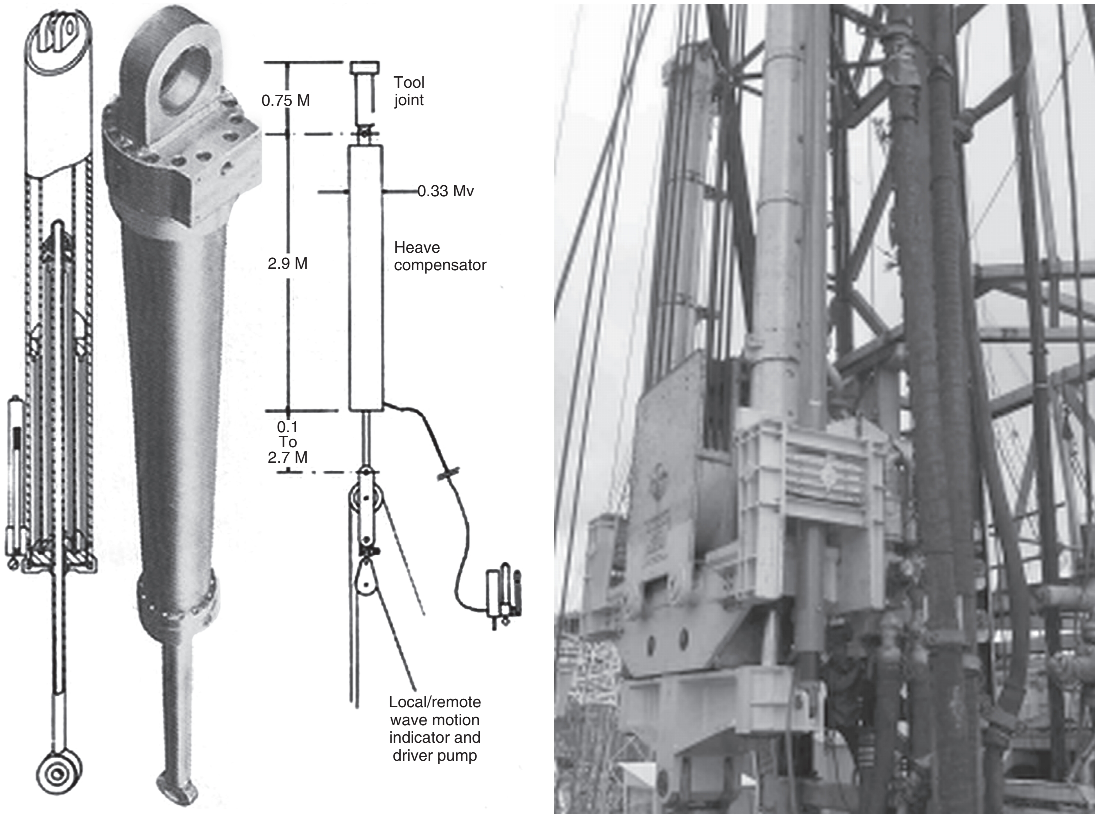


Figure 6.23 Drill derrick with heave compensator. (a: Courtesy of Pulse Guard; b: Courtesy of Integrated Ocean Drilling Program.)

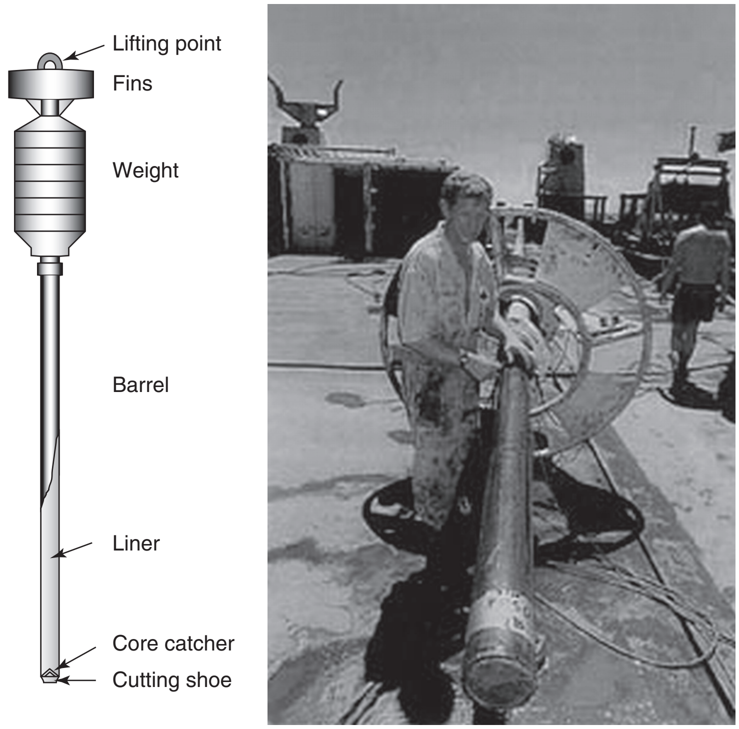


Figure 6.24 Drop core samplers. (a: After ISSMGE Technical Committee on Offshore Geotechnics, b: Courtesy of Offshore Magazine//PennWell Corp.)

6.9.3 Offshore Geotechnical Sampling

Sampling can be done remotely from a platform placed on the seabed (seabed mode) or through a drill pipe controlled from the ship deck (drilling mode). In the seabed mode, samples or in situ tests can be performed to a depth of 20 to 60 m below the sea floor, depending on the soil strength and the weight of the bottom platform. In the drilling mode, larger depths below the sea floor can be reached.

The simplest way to obtain soil samples offshore is by drop core sampling (Figure 6.24). These samples are taken by dropping a long, hollow tube (75 to 150 mm diameter) from a limited height above the sea floor. The length of these gravity samplers can reach tens of meters. Sometimes the process is aided by vibrating the sampler. In the seabed mode, the sampler is pushed hydraulically from a sea-bottom platform (Figure 6.25). In the drilling mode, the sampler is lowered through the drill pipes, locked in the bottom of the drill pipes by latches, and then pushed hydraulically out of the drill pipe into the soil by reaction against the weight of the drill pipes (Figure 6.22).

A piston sampler is preferred for softer, fine-grained soils. Otherwise, open tubes are used. In all cases, pushing is preferred to driving, although it may be necessary to drive the sampler into denser, coarse-grained soils to ensure penetration.

Further details on onshore site investigations can be found in Clayton, Simons, and Matthews (1982) and Hunt (2005). Further details on offshore investigations can be found in Poulos (1988) and a ISSMGE Technical Committee report (2010).

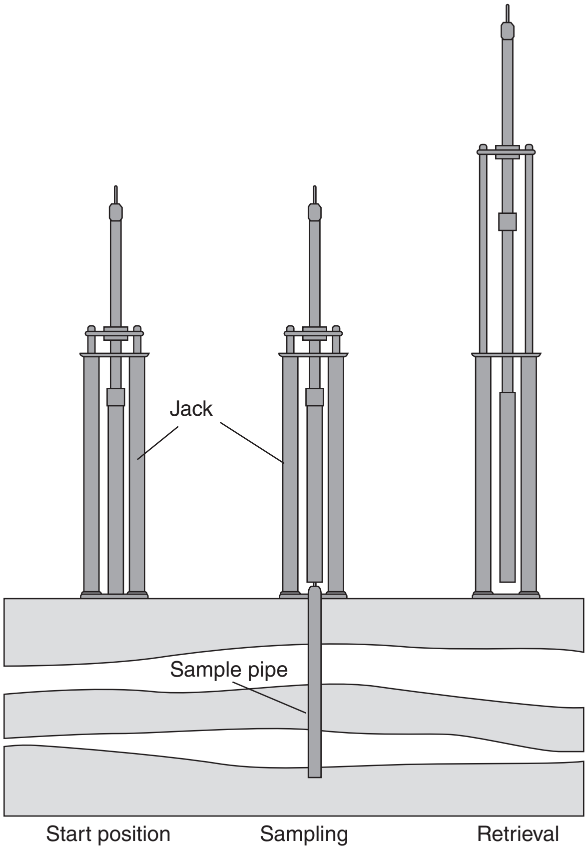


Figure 6.25 Push sampling from a seabed platform. (Courtesy of the ISSMGE Technical Committee on Offshore Geotechnics.)

PROBLEMS

6.1 A 70-story building has an imprint of 35 m by 25 m and will be supported on a mat foundation located at a depth of 10 m. How many borings would you propose and to what depth? Where would you place the borings on the building plan view?

6.2 For problem 6.1, estimate the ratio between the volume of soil that is tested over the volume of soil involved in supporting the building. Comment on the result.

6.3 What drill bit would you use for drilling in clay and which one would you use for drilling in gravel? Explain your choice.

6.4 Discuss and compare the wet rotary method and the hollow stem auger method. Make recommendations as to when to use one and when to use the other.

6.5 Give three sources of sample disturbance and calculate the area ratio for the Shelby tube sampler and the split spoon sampler.

6.6 Discuss when a sampler should be pushed and when it should be driven.

6.7 Calculate the length of clay sample necessary to plug a Shelby tube. (*Plugging* means that the friction between the sample and the inner wall of the sampler becomes equal to the ultimate bearing capacity of the soil below the sampler.) Give a parametric answer and do a few sample calculations to gauge the problem.

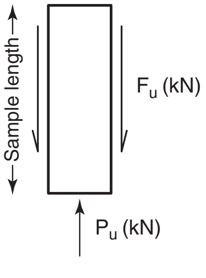


Figure 6.2s Free-body diagram of clay sample.

6.8 Describe the simple tests that would allow you to identify a soil in the field.
6.9 Explain the differences between drilling onshore and drilling offshore.
6.10 Explain the difference between the seismic reflection and the seismic refraction methods used for offshore investigations.
6.11 What is a piston sampler?

Problems and Solutions

Problem 6.1

A 70-story building has an imprint of 35 m by 25 m and will be supported on a mat foundation located at a depth of 10 m. How many borings would you propose and to what depth? Where would you place the borings on the building plan view?

Solution 6.1

A boring is required roughly every 250 m^2, so the minimum number of boreholes is

$$\frac{35 \times 25}{250} = 3.5$$

So, 4 or 5 borings are reasonable. The depth of the borings is usually one to two times the width of the foundation, with at least one boring extending to two times the width of the foundation below the foundation level. The depth of borings should be: $2B = 2 \times 25 = 50$ m.

For a rectangular mat, it is desirable to have a boring near each corner of the mat and one in the center. Therefore, a possible layout of the boring plan is shown in Figure 6.1s. Particular site specific soil conditions may affect this solution.

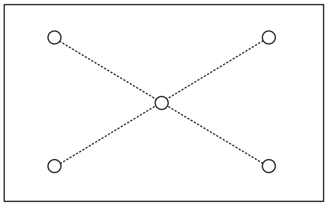


Figure 6.1s Borehole locations.

Problem 6.2

For problem 6.1, estimate the ratio between the volume of soil that is tested over the volume of soil involved in supporting the building. Comment on the result.

Solution 6.2

The depth of influence for the mat foundation can be considered to be $2B = 2 \times 25 = 50$ m. The volume of soil affected by the mat foundation of the building can be estimated as:

$$V_{Soil} = 35 \times 25 \times 50 = 43{,}750 \text{ m}^3$$

The volume of soil drilled (given a boring diameter of 100 mm) is:

$$V_{boreholes} = 5 \times \frac{\pi \times 0.1^2}{4} \times 50 = 1.96 \text{ m}^3$$

If it is assumed that the volume of soil tested is one-third of the volume of soil drilled, then:

$$V_{tested} = 0.33 \times 1.96 = 0.65 \text{ m}^3$$

The ratio of the volume of soil that is tested over the volume of soil involved in supporting the building is:

$$\frac{V_{tested}}{V_{soil}} = 1.48 \times 10^{-5} = 0.00148\,\%$$

This shows that the volume of soil tested in a typical soil investigation is extremely small. Add to this the fact that soils are known to be heterogeneous, and it is obvious that one must accept a significant degree of imprecision in geotechnical prediction.

Problem 6.3

What drill bit would you use for drilling in clay and which one would you use for drilling in gravel? Explain your choice.

Solution 6.3

A drag bit or finger bit is recommended for drilling in clay because it carves the soil with finger-like protrusions. This reduces the disturbance of the clay. Roller bits are used for drilling in gravel because it is made of three rollers that roll against the soil and erode it or push it aside. Finger bits are not used for drilling in gravel because the larger particles could get stuck between the fingers of the drag bit, damage it, and create excessive disturbance.

Problem 6.4

Discuss and compare the wet rotary method and the hollow stem auger method. Make recommendations as to when to use one and when to use the other.

Solution 6.4

The wet rotary method consists of drilling a borehole with a drill bit while circulating drilling mud through the center of the rods. The drill bit is typically 75 to 150 mm in diameter and the rods 40 to 70 mm in diameter. The drilling mud flows down the center of the rods while they rotate and back to the surface on the outside of the rods between the wall of the borehole and the exterior wall of the rods. This return flow carries the soil cuttings back to the surface by entrainment. The drilling mud arrives in the mud pit where it is sucked back up to the top of the drilling rods by a pump. The water swivel, which connects the hose carrying the drilling mud back to the top of the rods and the rods themselves, allows the hose to remain stationary while the rods keep rotating. The drill bit at the bottom end of the drill rods is typically either a drag bit or a roller bit.

The hollow stem auger method consists of rotating hollow stem augers into the soil; these augers are 150 to 300 mm in diameter. The hollow center part of the augers gives access for sampling or any other testing device that is to be lowered to the bottom of the hole. The hollow stem auger has the advantage of providing a casing against collapse of the side walls of the borehole, but is limited in penetration depth because it requires a significant torque to advance the augers. The wet rotary method has the advantage of being much less limited by depth, but sometimes faces problems of borehole instability.

Problem 6.5

(a) Give three sources of sample disturbance and (b) calculate the area ratio for the Shelby tube sampler and the split spoon sampler.

Solution 6.5

a. Three sources of sample disturbance:
   - Change in stress condition
   - Mechanical disturbance of the soil structure
   - Changes in water content and porosity
b. The equation to calculate the area ratio is:

$$AR = (\pi(D_o^2 - D_i^2)/4)/(\pi D_i^2/4)$$

where D_o is the outside diameter of the sampling tube, and D_i is the inside diameter of the sampling tube.

- For the Shelby tube sampler, $D_o = 76.2$ mm and $D_i = 72.9$ mm; therefore:

$$AR = (\pi(D_o^2 - D_i^2)/4)/(\pi D_i^2/4) = (D_o/D_i)^2 - 1 = (76.2/72.9)^2 - 1 = 0.092$$

  The area ratio for the Shelby tube sampler is 9.2%.
- For the split spoon sampler, $D_o = 50.8$ mm and $D_i = 34.9$ mm; therefore:

$$AR = (\pi(D_o^2 - D_i^2)/4)/(\pi D_i^2/4) = (D_o/D_i)^2 - 1 = (50.8/34.9)^2 - 1 = 1.13$$

  The area ratio for the split spoon sampler is 113%.

Problem 6.6

Discuss when a sampler should be pushed and when it should be driven.

Solution 6.6

Samplers should usually be pushed in clays or silts to minimize soil disturbance and yield samples well suited for quality laboratory tests. Samplers are usually driven in sands or gravels because it is very difficult to push them into these soils without damaging the tube and therefore the sample. Driven samples are disturbed and only well suited for soil identification and classification purposes. For organic fibrous soils such as peats, it is best to drive the sampler, because the driving action has a better chance to cut the fibers rather than pushing them and simply compressing and disturbing the peat excessively.

Problem 6.7

Calculate the length of clay sample necessary to plug a Shelby tube. (*Plugging* means that the friction between the sample and the inner wall of the sampler becomes equal to the ultimate bearing capacity of the soil below the sampler.) Give a parametric answer and do a few sample calculations to gauge the problem.

Solution 6.7

The free-body diagram of the clay sample is shown in Figure 6.2s.

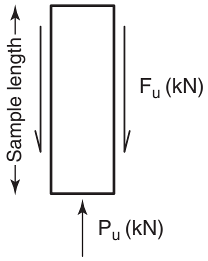


Figure 6.2s Free-body diagram of clay sample.

f_u: Unit side friction between Shelby tube and the soil
D: Diameter of the sample
L: Length of clay sample
S_u: Undrained shear strength
α: Friction coefficient
γ: Unit weight of the soil
Z: Depth of clay sample
N_c: Bearing capacity factor

$$F_u = f_u \pi DL = \alpha S_u \pi DL$$

$$P_u = (N_c S_u + \gamma z)\pi \frac{D^2}{4}$$

$$\text{Plugging occurs when: } \frac{P_u}{F_u} < 1 \rightarrow \frac{(N_c S_u + \gamma z)\pi \frac{D^2}{4}}{\alpha S_u \pi DL} < 1$$

$$\rightarrow \frac{(N_c S_u + \gamma z)D}{4\alpha S_u L} < 1$$

Sample calculations:

if z = 0, α = 1, $N_c = 9$

$$\frac{9S_u D}{4S_u L} < 1 \rightarrow \frac{9D}{4L} < 1$$

$$L > 2.25D$$

if z = 0, $\alpha = 0.5$, $N_c = 9$

$$\frac{9S_u D}{4 \times 0.5 S_u L} < 1$$

$$L > 4.5D$$

if $\gamma z = N_c S_u$, $\alpha = 0.5$, $N_c = 9$

$$\frac{2 \times 9 S_u D}{4 \times 0.5 S_u L} < 1$$

$$L > 9D$$

Problem 6.8

Describe the simple tests that would allow you to identify a soil in the field.

Solution 6.8

On cuttings:

1. Visual inspection
2. Feel the graininess or smoothness of the soil
3. Wash hands test
4. Dilatancy test (hand shaking test)
5. Dry strength test
6. Thread rolling test (toughness test)

On samples:

1. On clays and silts, the thumb or nail test for undrained shear strength
2. On the ground surface of a sand or gravel deposit, the 12 mm diameter steel bar test for strength

ASTM D2488, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)," describes some of these tests.

Problem 6.9

Explain the differences between drilling onshore and drilling offshore.

Solution 6.9

Offshore geotechnical investigations include drilling, sampling, and in situ testing, much like onshore investigations. The difference is a matter of scale, complexity, and cost. Compared to onshore drilling, offshore drilling has at least two complexities: larger depths, which can reach thousands of meters of combined water depth and penetration depth; and vertical motion of the drill rig due to waves. Another difference is the increased use of geophysical investigations for offshore work.

Problem 6.10

Explain the difference between the seismic reflection and the seismic refraction methods used for offshore investigations.

Solution 6.10

Seismic reflection systems use sound propagation energy generated by a device towed behind a ship. The device measures the travel time required for the acoustic energy or wave to travel to the seabed or an interface between two distinct soil layers below the sea bed and be reflected to the same device or to a receiving array. Seismic refraction systems use sound propagation energy generated by a device including an acoustic pulse generator and a line of hydrophones dragged on the sea bottom by a ship. The device measures the travel time required for the acoustic energy or wave to travel to an interface between two distinct soil layers below the seabed, refract critically along that interface, and send the wave back to the line of receivers or hydrophones. Seismic refraction is more often used for shallow penetration below the seafloor (pipelines, cables) and gives the thickness and the shear wave velocity of the material.

Precision of the measurement and penetration into the soil depend on the frequency and amplitude of the acoustic wave. A wave with a high frequency and low amplitude will give high resolution (good precision on the distance measured) but low penetration into the soil while a wave with a low frequency and high amplitude will give deeper penetration but lower resolution.

Problem 6.11

What is a piston sampler?

Solution 6.11

A piston sampler has a piston blocking the opening at the bottom of the sampler (see Figure 6.10). This piston is locked in place as the sampler is lowered to the desired depth. The piston is then held at that depth while the sampling tube is pushed past the piston into the soil. The vacuum that can develop at the top of the sample helps the soil enter the sampler and minimizes the plugging effect.