CHAPTER 3

Site Exploration and Characterization

QUESTIONS AND PRACTICE PROBLEMS

Introduction

3.1 Define site exploration and site characterization.

Solution

Site exploration is the exploration of the subsurface using borings and other techniques to identify the materials in the subsurface. Site characterization is to characterize the properties of the subsurface materials by testing recovered samples in the laboratory or performing in situ tests.

3.2 List in chronological order the steps involved in performing a site exploration and characterization program.

Solution

1. Project assessment
2. Literature search
3. Field reconnaissance
4. Subsurface exploration: drilling and sampling, groundwater exploration and monitoring, and in situ testing
5. Ex situ or laboratory testing
6. Synthesis and interpretation

Section 3.1 Project Assessment

3.3 What information should be gathered for the planning of a site exploration and characterization program?

Solution

1. The types, locations, and approximate dimensions of the proposed improvements.
2. The type of construction, structural loads, and allowable settlements.
3. The existing topography and any proposed grading.
4. The presence of previous development on the site, if any.

Section 3.2 Literature Search

3.4 What information can be obtained from geologic maps?

Solution

Geologic maps show the extents of various geologic formations, alignments of faults, major landslides, and other geologic features. They also may include cross-sections showing subsurface conditions.

Section 3.5 Subsurface Exploration

3.5 Describe the following drilling methods and give advantages and disadvantages of each: solid stem auger, hollow stem auger, rotary wash, and coring.

Solution

- Solid stem auger: The auger is lowered into the hole and rotated to dig into the soil. Then, it is removed, the soil is discharged onto the ground, and the process is repeated. The hole is free of equipment between these cycles, which allows the driller to insert sampling equipment at desired depths and obtain undisturbed samples.
    - Advantages: relatively cost effective; suitable for firm and dense soils or soft rocks; allows samplers to obtain relatively undisturbed samples.
    - Disadvantages: unsuitable for loose sands and gravels; ineffective below the groundwater table; prone to squeezing and caving.
- Hollow stem auger: Each auger section has a pipe core known as a stem, with a temporary plug on the bottom of the first section. The driller screws these augers into the ground, adding sections as needed. Unlike conventional augers, it is not necessary to remove them to obtain samples. Instead, the driller removes the temporary plug and inserts the sampler through the stem and into the soils below the bottom auger section.
    - Advantages: cost effective; suitable for all coarse- and fine-grained soils; allows relatively undisturbed samples to be obtained through the hollow stem; suitable below the groundwater table.
    - Disadvantages: cost and size of the equipment required to operate the auger.
- Rotary wash: The boring is filled with drilling mud, a mixture of bentonite or attapulgite clay and water. This drilling mud exerts a hydrostatic pressure on the walls of the boring, thus preventing caving or squeezing. During drilling, the cuttings are circulated to the ground surface by a pump. When sampling is performed, the drilling tools are removed from the hole and the sampling tools are lowered through the mud to the bottom, to retrieve relatively undisturbed samples.
    - Advantages: cost effective; suitable for coarse-grained soils; allows sampling of relatively undisturbed samples; suitable below the groundwater table.
    - Disadvantages: cost and size of the equipment required to operate the system.
- Coring: It consists of grinding away an annular zone with a rotary diamond drill bit, leaving a cylindrical core which is captured by a *core barrel* and removed from the ground, obtaining a nearly continuous undisturbed rock sample.

- Advantages: suitable for rock sampling; allows a continuous sample to be obtained.
- Disadvantages: cost and size of the equipment required to operate the system; suitable only for rock sampling.

3.6 Describe the advantages and disadvantages of using an exploratory trench in site exploration.

Solution

Advantages

- Provides more subsurface information than a boring of comparable depth.
- Often is less expensive than a standard boring.

Disadvantages

- Limited to shallow exploration.
- Must be adequately shored or have trench side walls laid back to a sufficiently flat slope before anyone enters.
- Must be properly backfilled to avoid creating an artificial, soft zone.

Section 3.6 Soil and Rock Sampling

3.7 Describe the concept of sample disturbance and explain the relationship between sampler type and disturbance.

Solution

Soil sample disturbance occurs when the soil is not recovered completely intact and its in-place structure and stresses are modified in any way. Most disturbances occur in the form of shearing and compression that occurs during the process of inserting the sampling tool or sampler. During normal sampling, the relative amount of disturbance can be quantified by the area ratio of the sampler, which is the ratio of the annular cross-sectional area of the sampler tube to the circular cross-sectional area of the sampler itself. For example, the heavy-wall sampler would create more sample disturbance than a Shelby tube sampler due to its thicker wall.

3.8 Describe the Shelby tube sampler and the heavy-wall sampler and state the advantages and disadvantages of each.

Solution

Shelby tube

Advantages:

- Provides soil samples.
- Provides very good results in soft soils.
- Provides minimal sample disturbance.

Disadvantages

- Difficult to use in hard soils
- The tube may bend or collapse due to the heavy loads required to drive through dense soils.
- It may become jammed into the ground and impossible to retrieve.

Heavy-wall Sampler

Advantages:

- Provides soil samples.
- Provides sufficient strength under heavy loading.
- Provide good results in medium dense and fine-grained soils.

Disadvantages

- Provides a larger amount of sample disturbance due to its thickness.
- Difficult to use in coarse soils.

3.9 A one-story, 50-m wide × 90-m long manufacturing building is to be built on a site underlain by medium dense to dense silty sand with occasional gravel. This soil probably has better-than-average engineering properties and average uniformity. There are no indications of previous grading or fill at this site, and the groundwater table is believed to be about 30 m below the ground surface. We anticipate supporting this building on spread footing foundations located about 0.5 m below the ground surface. There are no accessibility problems at this site.

(a) How many exploratory borings will be required, and to what depths should they be drilled?
(b) What type of drilling and sampling equipment would you recommend for this project?

Solution

a.

$$A = (50\text{ m})(90\text{ m}) = 4500\text{ m}^2$$

Per Table 3.1 – one boring per 200-400 m^2 - $\therefore$ Use 15 borings

$$\text{Min Depth } = 5S^{0.7} + D = 5(1)^{0.7} + 0.5 = 5.5\text{ m}$$

Note: There is no single "correct" answer to this problem. A range of answers would be acceptable.

b. Some caving might occur in these soils, so a hollow stem auger would be a good choice for this project. Alternatively, we might use a rotary wash rig or even a conventional flight auger with casing as needed.

3.10 A one-story, 20-m wide × 50-m long concrete tilt-up office building is to be built at a site near a wetlands. Previous exploratory borings at nearby sites encountered about 1 m of moderately stiff clayey fill underlain by about 4 m of very soft organic silts and clays, then 15 m of progressively stiffer sandy clays and clayey sands. Limestone bedrock is located about 20 m below the ground surface. The groundwater table is thought to be at a depth of about 0.5 m. Because of the soft soils, we will probably need to support this building on deep foundations that extend at least into the stiffer soils, and possibly to bedrock. There are no accessibility problems at this site.

(a) How many exploratory borings will be required, and to what depth should they be drilled?
(b) What type of drilling and sampling equipment would you recommend for this project, and what kinds of problems should the field crew be prepared to solve?

Solution

a.

$$A = (20\ \mathrm{m})(50\ \mathrm{m}) = 1000\ \mathrm{m}^2$$

Per Table 3.1 – one boring per 100-300 m^2 - ∴ Use 6 borings

Boring Plan

3 Borings to 18 m depth

3 boring 2 m into bedrock (approx. 22 m depth)

Note: There is no single "correct" answer to this problem. A range of answers would be acceptable.

b. The very soft organic silts and clays will almost certainly have squeezing and caving problems. In addition, some of the borings need to penetrate into the limestone bedrock. The drilling method will need to be selected to accommodate both of these requirements. For this project we would probably use a rotary wash rig, which can drill through the soil without caving problems, then add rotary rock drilling bits when reaching the limestone.

Other kinds of drilling equipment also could be used.

Shelby tube samples would be obtained in the soil strata. It may be possible to use a heavy-wall sampler in the limestone.

The field crew should be prepared to encounter caving, difficulties in sampling, and possible difficulties in drilling through the limestone.

3.11 A ten-story steel-frame office building with a 200 ft × 200 ft footprint is to be built on a site underlain by alluvial sands and silts. These soils are fairly uniform and probably have good engineering properties. The building will have one 12-ft deep basement and will probably be supported on either a mat foundation located 5 ft below the bottom of the basement, or a deep foundation extending about 60 ft below the bottom of the basement. The groundwater table is about 30 ft below the ground surface and bedrock is several 100 ft below the ground surface. There are no accessibility problems at this site.

(a) How many exploratory borings will be required, and to what depth should they be drilled?
(b) What type of drilling and sampling equipment would you recommend for this project?

Solution

a.

$$A = (200\text{ ft})(200\text{ ft}) = 40{,}000\text{ m}^2$$

Per Table 3.1 – one boring per 3,000 – 10,000 ft^2 – $\therefore$ Use 8 borings

$$\text{Min depth} = 10S^{0.7} + D = 10(10)^{0.7} + 17 = 67\text{ ft}$$

Since deep foundations are a possibility, at least some of the borings should extend below the toe of these piles, which are estimated to be 12 + 60 = 72 ft below the ground surface. This produces a boring depth of about 90 ft.

Boring Plan

5 borings to 70 ft depth

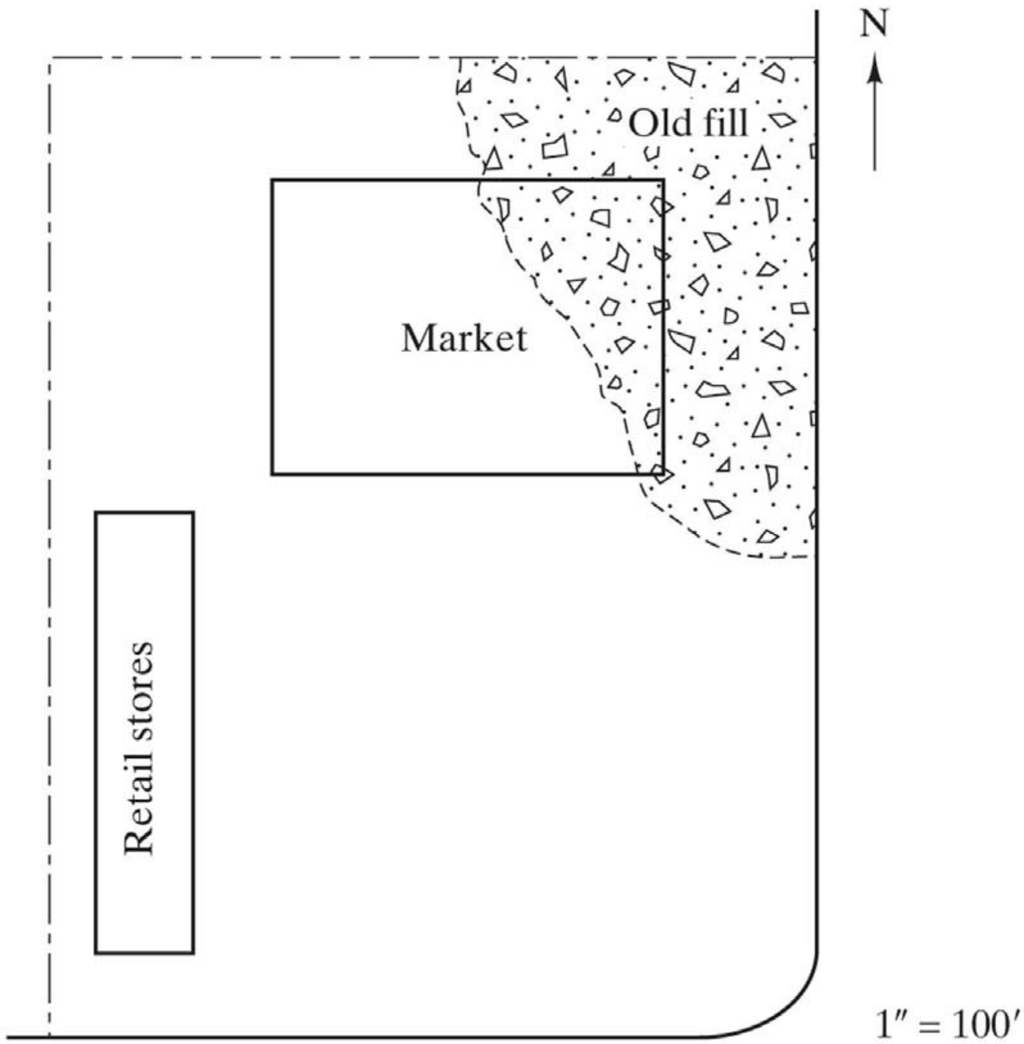
3 borings to 90 ft depth

Note: There is no single “correct” answer to this problem. A range of answers would be acceptable.

b. Alluvial sand and silt below the groundwater table might experience some caving. We probably would use a hollow stem auger for this project. Alternatively, we might use a rotary wash rig.

3.12 A small commercial development consisting of a one-story supermarket and a one-story retail store building is to be built on the site shown in Figure 3.40. The proposed spread footing foundations will be located at a depth of 2 ft below the ground surface. The site has never been developed before, but a study of old aerial photographs indicates a fill was placed in the northeast section. This fill appears to be up to 5-ft thick, probably was not compacted, and most likely will need to be removed during construction. However, we may be able to reuse this material as fill, so long as it does not contain trash or other deleterious substances. The remainder of the soils are probably stiff clayey silts and sandy silts. The groundwater table is believed to be about 20 ft below the ground surface. There are no accessibility problems at this site.

Develop a subsurface exploration program and present it as a 250–350 word memo to your field crew instructing them what to do. Be sure to include a copy of the site plan marked with the proposed location of each activity.



Solution

Market

$$A = (200\text{ ft})(150\text{ ft}) = 30{,}000\text{ ft}^2$$

Per Table 3.1 – one boring per 2000 – 4000 ft^2 – $\therefore$ Use 10 borings

$$\text{Min depth} = 15S^{0.7} + D = 15(1)^{0.7} + 2 = 17\text{ ft}$$

Retail stores

$$A = (50\text{ ft})(235\text{ ft}) = 12{,}000\text{ ft}^2$$

Per Table 3.1 – one boring per 2000 – 4000 ft^2 – $\therefore$ Use 4 borings

$$\text{Min depth} = 15S^{0.7} + D = 15(1)^{0.7} + 2 = 17 \text{ ft}$$

Commentary: The site exploration and characterization program needs to determine depth and lateral extent of the old fill. Since its maximum depth is probably about 5 ft, it would be best to explore it using backhoe trenches instead of borings. However, the evaluation of the natural soils for foundation design purposes is best done using borings. The locations of these trenches and borings should be shown on the plan view of the site.

Memorandum to Field Crew

Please schedule a backhoe and a hollow stem drill rig to trench and drill at the proposed shopping center site. The approximate locations and depths of these trenches and borings are shown on the attached drawing.

An old fill is located in the northeast corner of the site, as shown on the map. The lateral limits shown are approximate, and the depth is probably no more than 5 ft. The backhoe trenches need to penetrate through this fill, so we will know its exact depth. We also need to determine if any trash or other unsuitable materials are present to help us decide if the soils in the fill can be reused or if they need to be hauled away. Please obtain a few representative bulk samples of the old fill.

The borings are for foundation design purposes. I expect the natural soils will be primarily stiff clayey silts and sandy silts. Please use a heavy-wall sampler to obtain undisturbed samples of each stratum, with sampling intervals no greater than 5 ft.

Finally please obtain a few representative samples of the surface soils in the parking lot area.

Note: There is no single “correct” answer to this problem. A range of answers would be acceptable. No drawing showing the trenching and boring locations is provided here.

Section 3.7 Groundwater Exploration and Monitoring

3.13 Describe how to install an observation well and what it measures.

Solution

The installation of an observation well consists of drilling a borehole, inserting a slotted plastic pipe, and backfilling around the pipe with pervious soils and sealing the top of the backfill with an impervious cap. The slotted pipe allows water to flow freely into or out of this pipe, so the water level inside is the groundwater table. An observation well gives the depth to the groundwater table that can be measured, for example, with an electronic probe.

Section 3.9 In Situ Testing

3.14 The vertical effective stress at Sample 1 in Figure 3.14 is 405 lb/ft^2. Compute $N_{1,60}$.

Solution

$$N_{1,60} = N_{60}\sqrt{\frac{2000\ \text{lb/ft}^2}{\sigma_z'}} = 10\sqrt{\frac{2000\ \text{lb/ft}^2}{405\ \text{lb/ft}^2}} = 22$$

3.15 The vertical effective stress at Sample 3 in Figure 3.14 is 1270 lb/ft^2. Compute $N_{1,60}$.

Solution

$$N_{1,60} = N_{60}\sqrt{\frac{2000\ \text{lb/ft}^2}{\sigma_z'}} = 42\sqrt{\frac{2000\ \text{lb/ft}^2}{1270\ \text{lb/ft}^2}} = 52$$

3.16 A standard penetration test has been performed at a depth of 6.5 m in a medium sand using a standard sampler and a USA-style donut hammer. The N-value recorded in the field was 16. The boring diameter was about 100 mm, and the vertical effective stress at the test location was 85 kPa. Compute $N_{1,60}$.

Solution

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60} = \frac{(0.45)(1.00)(1.00)(0.95)(16)}{0.60} = 11.4$$

$$N_{1,60} = N_{60}\sqrt{\frac{100\ \text{kPa}}{\sigma_z'}} = 11.4\sqrt{\frac{100\ \text{kPa}}{85\ \text{kPa}}} = 12$$

3.17 Using Figure 3.29, classify the soils between depths of 23 and 48 ft in the CPT results presented in Figure 3.28. Why are there spikes in the q_c, f_{sc}, and R_f curves between these depths?

Solution

Per figure 3.28, most of the soil between 23 and 48 ft has the following characteristics:

q_c = 17 tsf = 17 kg/cm

R_f = 2.6%.

Per Figure 3.29, The soil is a clayey silt or silty clay, the spikes indicate a higher amounts of sand content.

3.18 Using Figure 3.29, classify the soils between depths of 66 and 80 ft in the CPT results presented in Figure 3.29. Why are there spikes in the q_c, f_{sc}, and R_f curves between depths of 76 and 78 ft?

Solution

Per figure 3.29, most of the soil between 66 and 80 ft has the following characteristics:

$q_c = 17$ tsf $= 17$ kg/cm^2

$R_f = 2.6\%$

Per Figure 3.30, the soil is a clayey silt or silty clay, the spikes between 76 and 78 ft indicate a sand seam.

3.19 A cone penetration test on a sandy soil with mean particle size of 0.5 mm produced a q_c of 80 kg/cm^2. Estimate the equivalent SPT N_{60}-value.

Solution

Per Figure 3.32 – $q_c/N_{60} = 4.5$ (Kulhawy & Manye, 1990):

$$N_{60} = \frac{80}{4.5} = 18$$

3.20 Compare the standard penetration test and the Becker penetration test.

Solution

The Standard Penetration Test (SPT) is used mostly for medium dense and fine-grained soils. The Becker penetration test is used for very dense and coarse soils. For both, the hammer blow-count is monitored to advance the casing 1 ft, recorded, and used for correlation with in situ soil properties. But the major difference is the ability of the SPT sampler to retrieve a relatively undisturbed sample for the purpose of soil classification.

3.21 Describe how to perform a pressuremeter test and what it measures.

Solution

The pressuremeter test (PMT) produces direct measurements of soil compressibility and lateral stresses. The test entails placement of a cylindrical balloon that is inserted into a carefully drilled boring in the ground and inflated. The PMT measures the volume of the void produced by the balloon and pressure applied to the surrounding soil. These measurements can be used to evaluate the in situ stress, the compressibility and strength of the adjacent soil.

3.22 Describe how to perform a dilatometer test and what it measures.

Solution

The dilatometer test (DMT) entails measuring the pressure applied by the surrounding soil at three different moments. The primary benefit of the DMT is that it measures the lateral stress condition and compressibility of the soil. The dilatometer is embedded into the soil and pressurized by nitrogen gas. The "A pressure" is recorded when the center of the membrane has moved 0.05 mm into the soil. The "B pressure" is recorded when the center of the membrane has moved 1.10 mm into the soil. The "C pressure" is recorded when the once the membrane has returned to its original position once deflated. Once these values are determined and corrected using equipment calibration factors, they are expressed as the DMT indices.

Comprehensive

3.23 An engineer is planning to use a 24-inch diameter bucket auger similar to the one in Figure 3.7 to drill several exploratory borings at a site adjacent to a lake. The underlying soils are probably soft clays and silts with *N*-values of less than 5. Is this a wise choice? Why or why not?

Solution

This would be very poor choice, and is almost certainly doomed to failure. Soft clays and silts are prone to caving and squeezing, especially in such a large diameter boring. It would be much better to use a rotary wash rig or a hollow stem rig.

3.24 What type of soil sampling equipment would be most appropriate for the soils described in Problem 3.23? Why?

Solution

Shelby tube samples would be ideal in these soils because they are so soft. This type of sampler induces much less disturbance than heavy-wall samplers.

3.25 A large compacted fill is to be placed on a site underlain by a 15 m thick layer of saturated clay. The weight of this fill will cause the clay layer to consolidate, which will result in large settlements at the ground surface. Since these settlements would have an adverse effect on buildings and other improvements planned for this site, a settlement rate analysis, similar to those we will discuss in Chapter 11, is to be performed to estimate the time required for a certain percentage of the settlement to be completed.

A series of exploratory borings have already been drilled at this site, samples have been recovered, and laboratory tests have been performed to evaluate the consolidation properties of the clay. However, to complete the settlement rate analysis, we need to know if thin horizontal sand seams are present in the clay, and the approximate spacing between these seams. If they exist at all, these seams are probably less than 100 mm thick. Although some of the undisturbed samples contained sand seams, more information is needed.

What kind of additional exploration would you do to determine whether or not more sand seams are present? Be sure to consider both technical feasibility and cost, and explain the reason for your choice.

Solution

One method would be to perform a series of cone penetration tests. Sand seams would have a greater q_c, and a lower R_f than the surrounding clay, and thus would show up as "spikes" on the test results. Seams 100 mm thick would most likely show up in the test results, but very thin seams might not.

An alternative method would be to take nearly "continuous" Shelby tube samples in a boring. This involves taking a Shelby tube sample, drilling the boring to the depth where the bottom of the sampler was, then taking another sample. Thus, the top of the second sample is, in theory, at the same depth as the bottom of the first sample. This process continues with additional samples as necessary. The Shelby tube samples would then be extracted in the laboratory and examined. This method would be much more expensive than performing CPTs, but we would be nearly assured of finding sandy seams if they truly exist at the boring location.

3.26 A level building pad is to be built at the site shown in Figure 3.41 by cutting and filling as shown. The final pad elevation is to be 215 ft. Then, a three-story steel-frame office building is to be built.

Five exploratory borings have been drilled to determine the subsurface conditions. The logs from these borings were summarized as follows:

Boring 1

Groundwater table depth = 44 ft

Depth (ft)	Soil or Rock Conditions
0 - 18	Sandy clay
18 - 35	Clayey sand
35 - 52	Silty sand
52 - 55	Sandstone bedrock

Boring 2

Groundwater table depth = 31 ft

Depth (ft)	Soil or Rock Conditions
0 - 28	Clayey sand
28 - 36	Silty sand
36 - 39	Sandstone bedrock

Boring 3

Groundwater table depth = 41 ft

Depth (ft)	Soil or Rock Conditions
0 - 34	Clayey sand
34 - 48	Silty sand
48 - 52	Sandstone bedrock

Boring 4

Groundwater table depth = 40 ft

Depth (ft)	Soil or Rock Conditions
0 - 33	Clayey sand
33 - 45	Silty sand
45 - 47	Sandstone bedrock

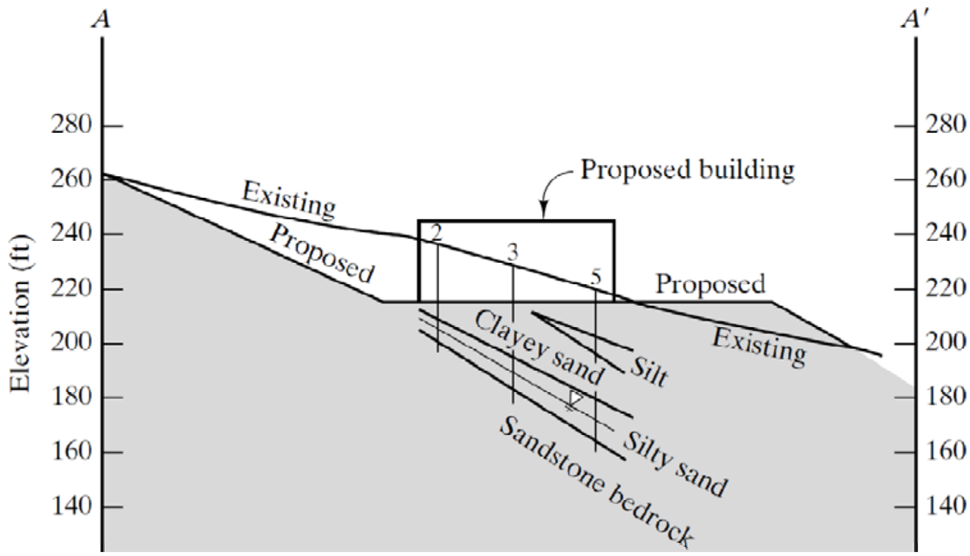
Boring 5

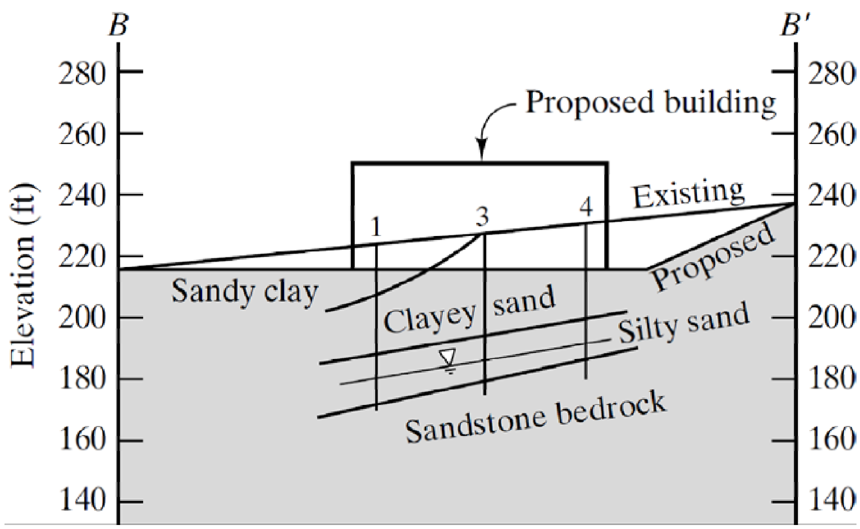
Groundwater table depth = 49 ft

Depth (ft)	Soil or Rock Conditions
0 - 17	Clayey sand
17 - 25	Silt
25 - 42	Clayey sand
42 - 57	Silty sand
57 - 60	Sandstone bedrock

Develop cross-sections A-A′ and B-B′ and show the soil profiles beneath the proposed building. The profiles should be similar to the one in Figure 3.36 and should include the existing and proposed grades, the proposed building, strata boundaries, and the groundwater table. Do not use an exaggerated vertical scale.

Solution


A
A′
Elevation (ft)
280
260
240
220
200
180
160
140
Proposed building
Existing
Proposed
2
3
5
Proposed
Existing
Clayey sand
Silt
Silty sand
Sandstone bedrock


B
B′
Elevation (ft)
280
260
240
220
200
180
160
140
Proposed building
Existing
1
3
4
Proposed
Sandy clay
Clayey sand
Silty sand
Sandstone bedrock