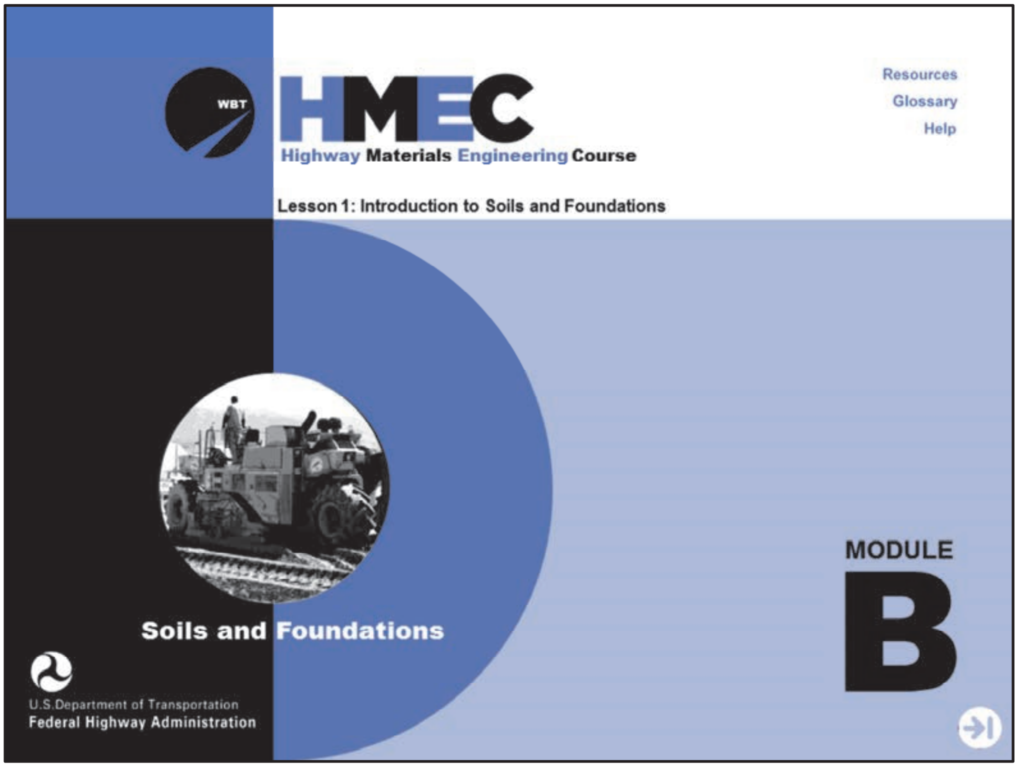
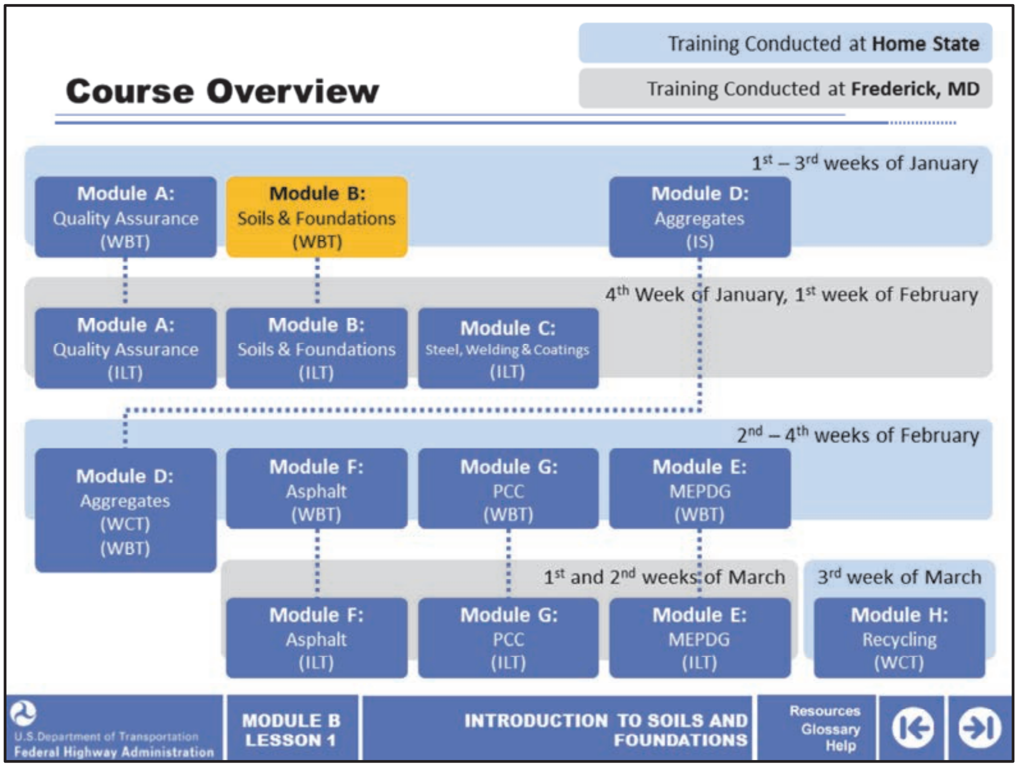


Welcome to the Highway Materials Engineering Course (HMEC) Module B, Lesson 1: Introduction to Soils and Foundations. This module is designed to focus on the group process required for geotechnical issues in the real world, with an emphasis on the role of the materials engineer. Materials engineers should be asking questions, collaborating, and viewing other perspectives in all aspects of geotechnical work. They should be familiar enough with the geotechnical aspects on projects to understand when to ask for technical expert guidance and to do so.

A printer-friendly version of the lesson materials can be downloaded by selecting the paperclip icon. Only the slides for the this lesson are available.

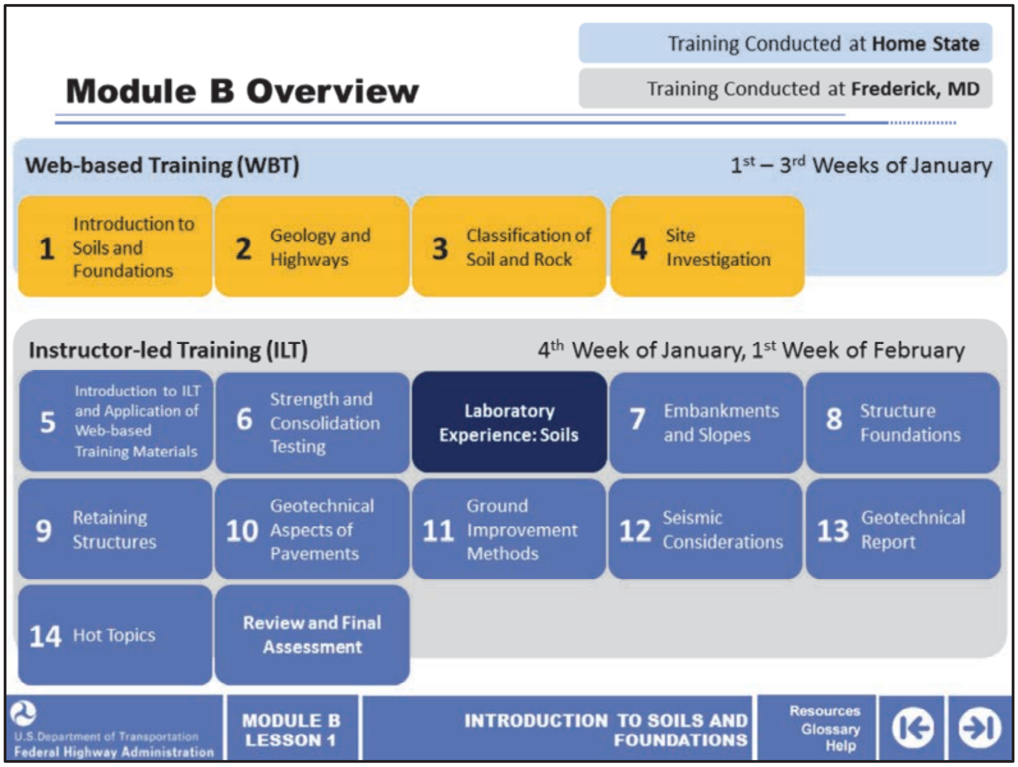
If you need technical assistance during the training, please select the Help link in the upper right-hand corner of the screen.



The FHWA Highway Materials Engineering Course is a comprehensive, six-week training event. Module B: Soils and Foundations is the second module in the HMEC. Module B follows a blended approach that is used in modules throughout the HMEC. The introductory material in Module B is delivered as a Web-based training (WBT) that participants complete in early January. The remainder of Module B is delivered as an instructor-led training (ILT) during the fourth week of January. Note that participants complete the independent study (IS) for Module D, and both the ILT and WBT portions of Module A before completing the ILT portion of Module B.

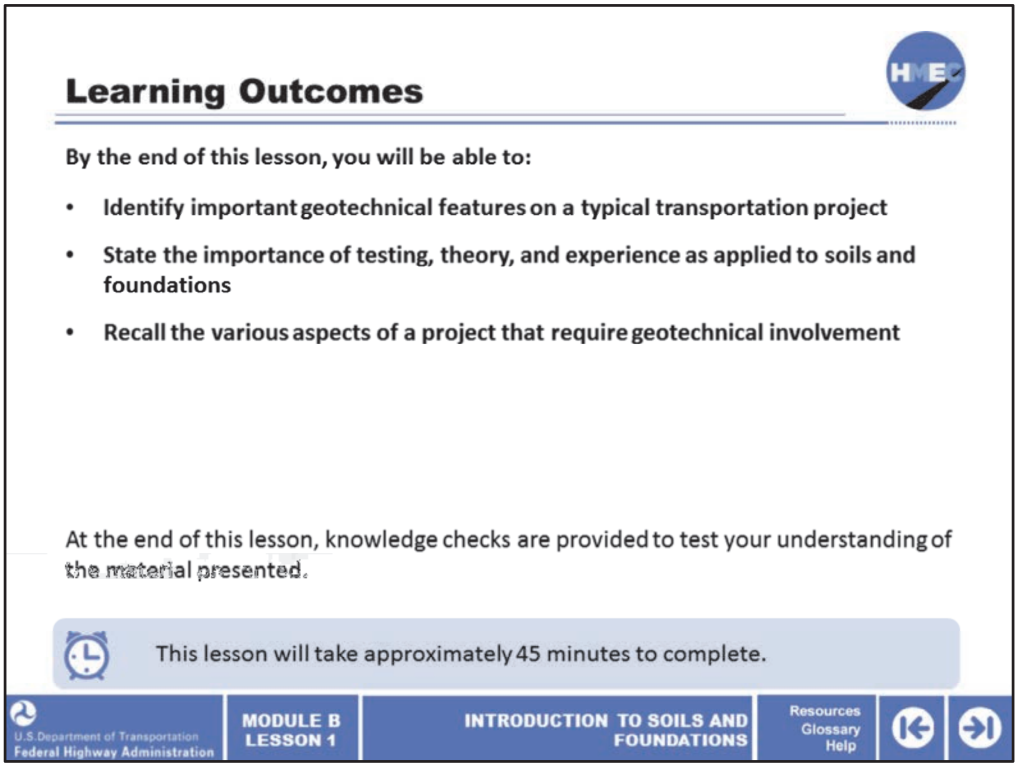
On the next screen, we'll review the lesson structure of this module.

Image description: Graphic of course overview.



Module B consists of 14 lessons. Lessons 1–4 are completed in the WBT portion of the module. Lessons 5 and 6 are completed before the soils lab experience. Then, the remainder of the lessons, Lessons 7–14, are completed before the review and final assessment.

Image description: Graphic of Module B overview.

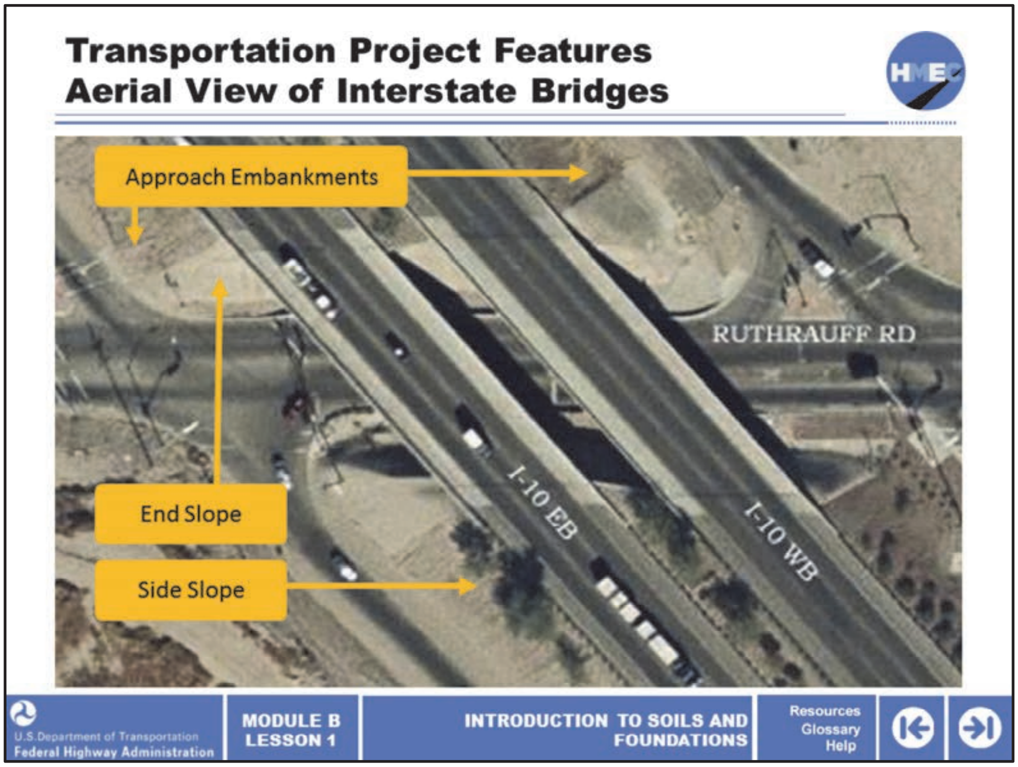


Welcome to Module B, Lesson 1: Introduction to Soils and Foundations. By the end of this lesson, you will be able to:

- Identify important geotechnical features on a typical transportation project;
- State the importance of testing, theory, and experience as applied to soils and foundations; and
- Recall the various aspects of a project that require geotechnical involvement.

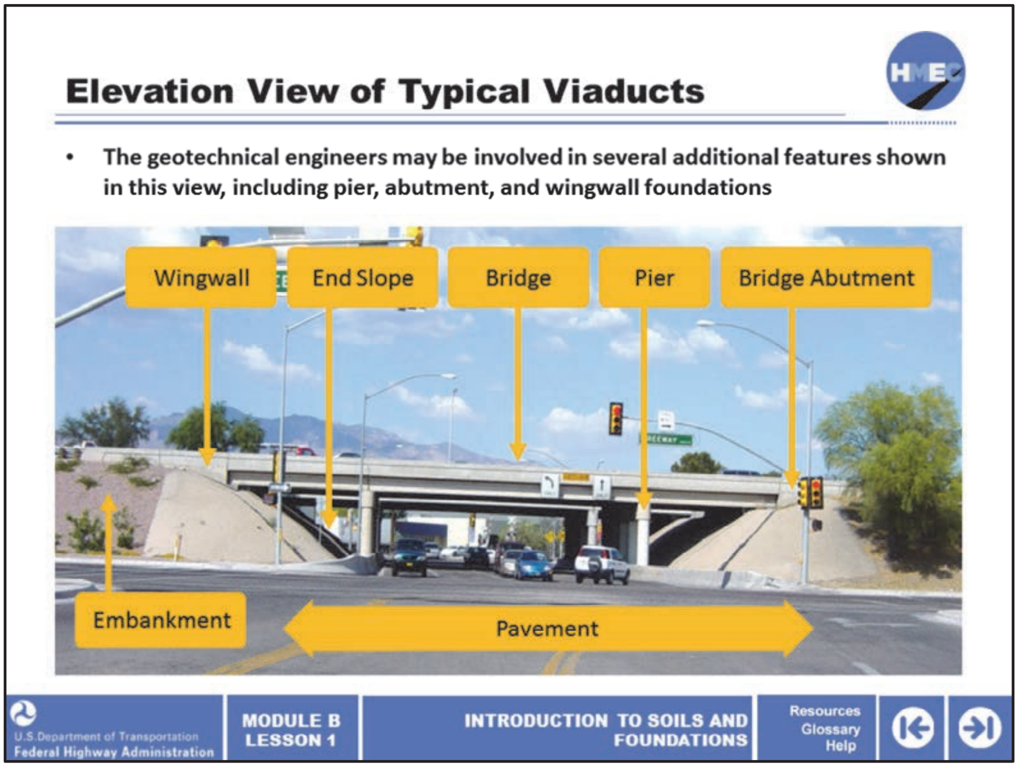
At the end of this lesson, knowledge checks are provided to test your understanding of the material presented.

This lesson will take approximately 45 minutes to complete.



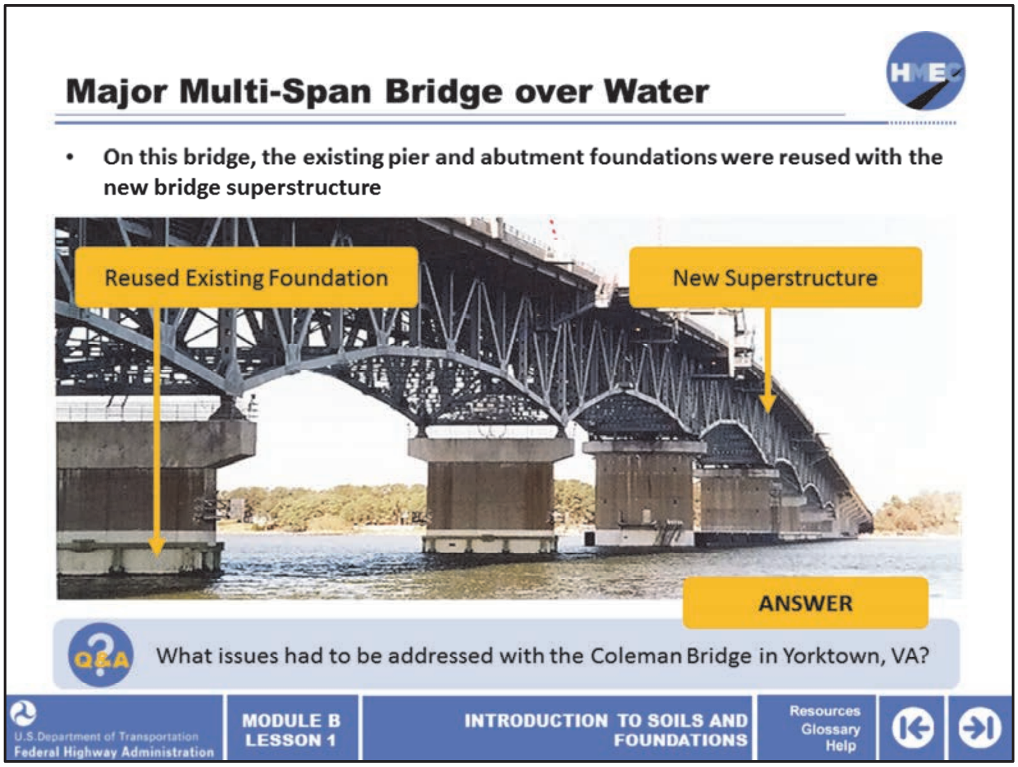
Let's review some of the typical geotechnical features on a transportation project. This is an aerial view of typical interstate bridges. The geotechnical engineer will be involved in several features shown in this view, including approach embankments, side slopes, and end slopes. Issues may include compaction of fill soils, consolidation of underlying foundation soils, embankment and/or abutment settlement, slope stability, soil reinforcement, ground improvement, and/or construction-monitoring techniques.

Image description: Photo of an aerial view of typical interstate bridges.



Additional geotechnical features of interstate bridges are identified on this screen. This is a typical viaduct (bridge) over a city street. The geotechnical engineers may be involved in several additional features shown in this view, including pier, abutment, and wingwall foundations. Issues may include soil and rock bearing capacities, material capacity of foundation types, selection of foundation types, and pavement subgrade.

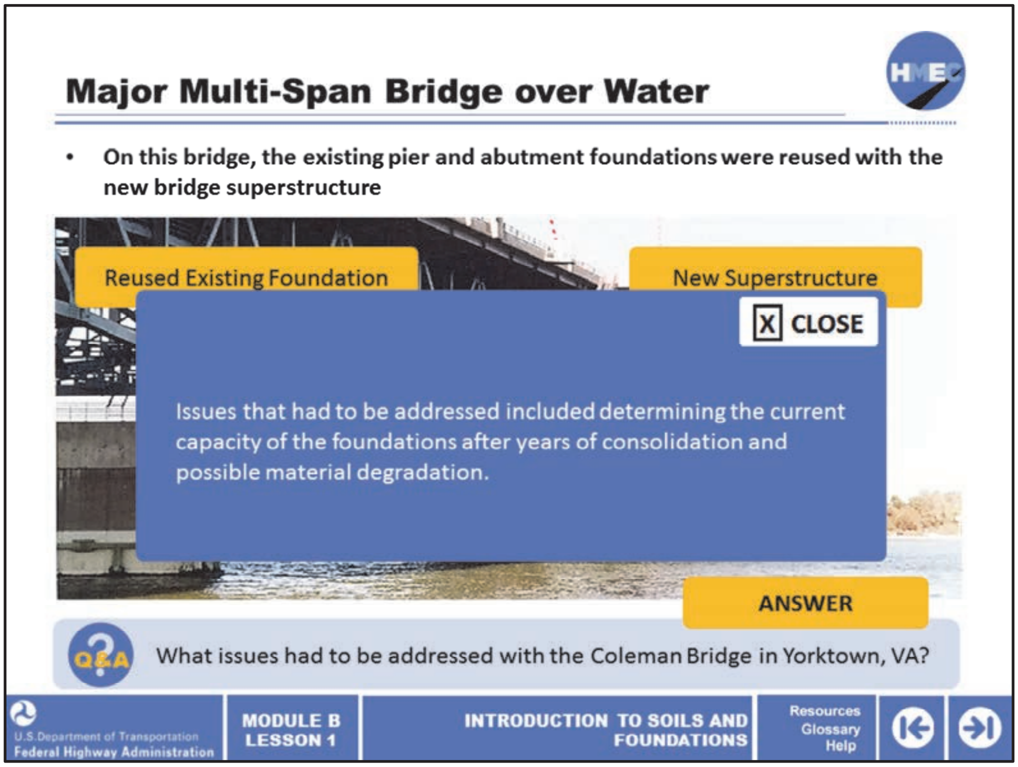
Image description: Photo of a typical viaduct (bridge) over a city street.



This is the Coleman Bridge in Yorktown, Virginia. On this bridge, the existing pier and abutment foundations were reused with the new bridge superstructure. The geotechnical engineer would be involved in the design and construction monitoring of those foundations.

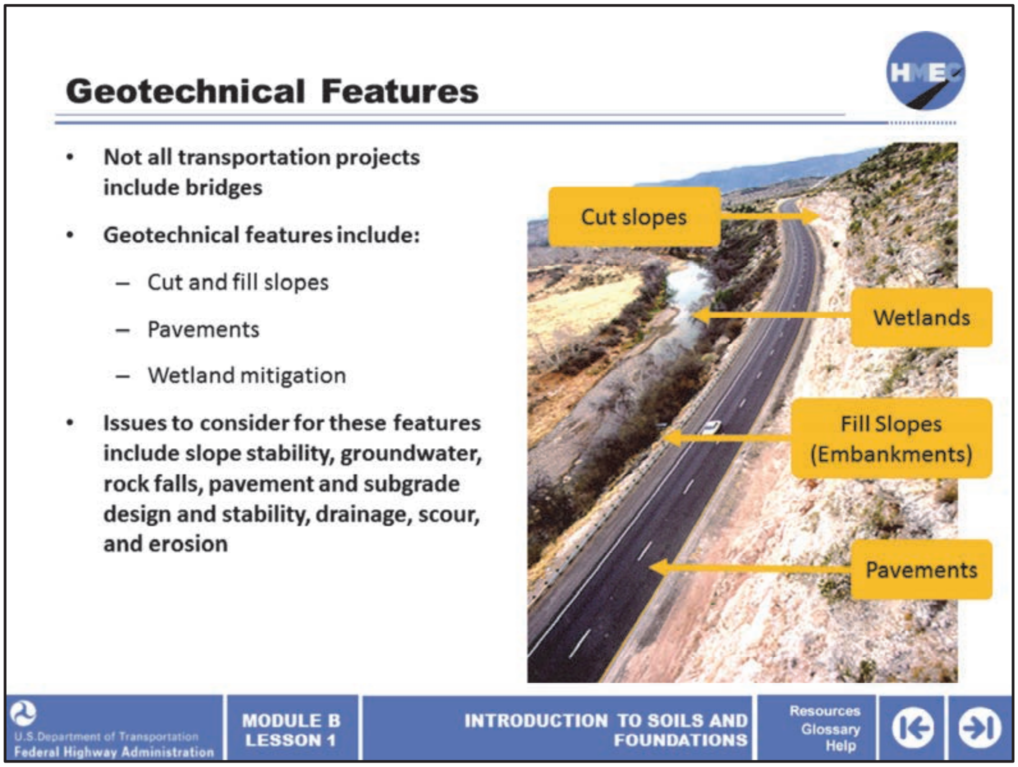
Select the box to answer the question: What issues had to be addressed with the Coleman Bridge in Yorktown, VA?

Image description: Photo of the Coleman Bridge in Yorktown, Virginia.



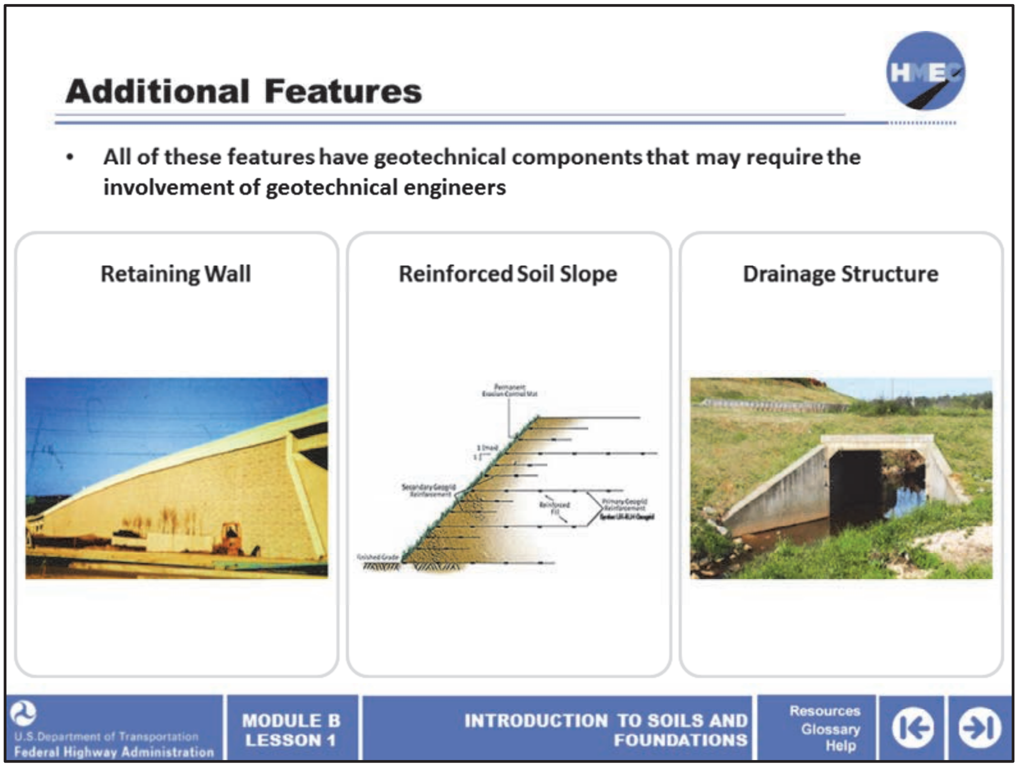
Issues that had to be addressed included determining the current capacity of the foundations after years of consolidation and possible material degradation.

Image description: Photo of the Coleman Bridge in Yorktown, Virginia.



Not all transportation projects include bridges. This is a transportation corridor through an environmentally sensitive area where the corridor design is influenced by the presence of wetlands and flowing water. Geotechnical features include cut and fill slopes, pavements, and wetland mitigation. Issues to consider for these features include slope stability, groundwater, rock falls, pavement and subgrade design and stability, drainage, scour, and erosion.

Image description: Photo of a transportation corridor through an environmentally sensitive area where the corridor design is influenced by the presence of wetlands and flowing water.

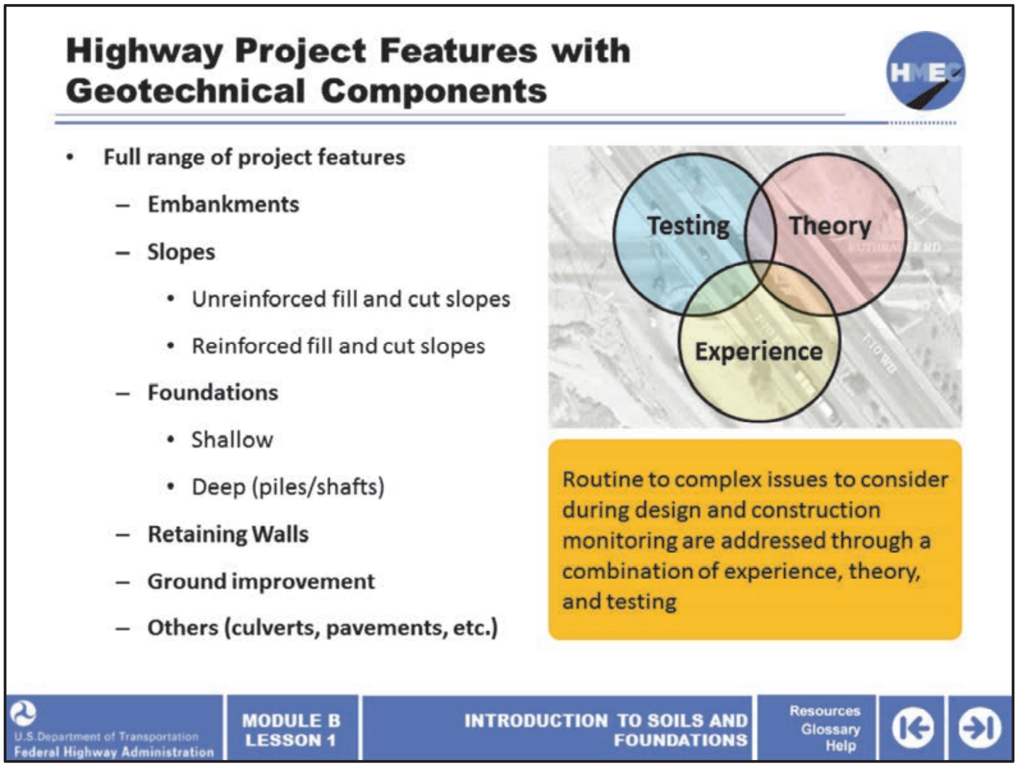


Additional features on transportation projects include retaining walls, reinforced soil slopes, and drainage structures. All of these features have geotechnical components that may require the involvement of geotechnical engineers. Issues to consider for walls and slopes include soil reinforcement type and material degradation, subgrade stability, and stability issues due to vertical and near vertical slopes, construction monitoring, and long-term post construction monitoring. Scour and erosion issues require analysis of drainage path bedding materials in and adjacent to culverts. Large culverts may require slope stability and settlement analysis as well. Large settlement issues can limit the use of certain culvert materials and/or construction methods.

Image description: Photo of a retaining wall.

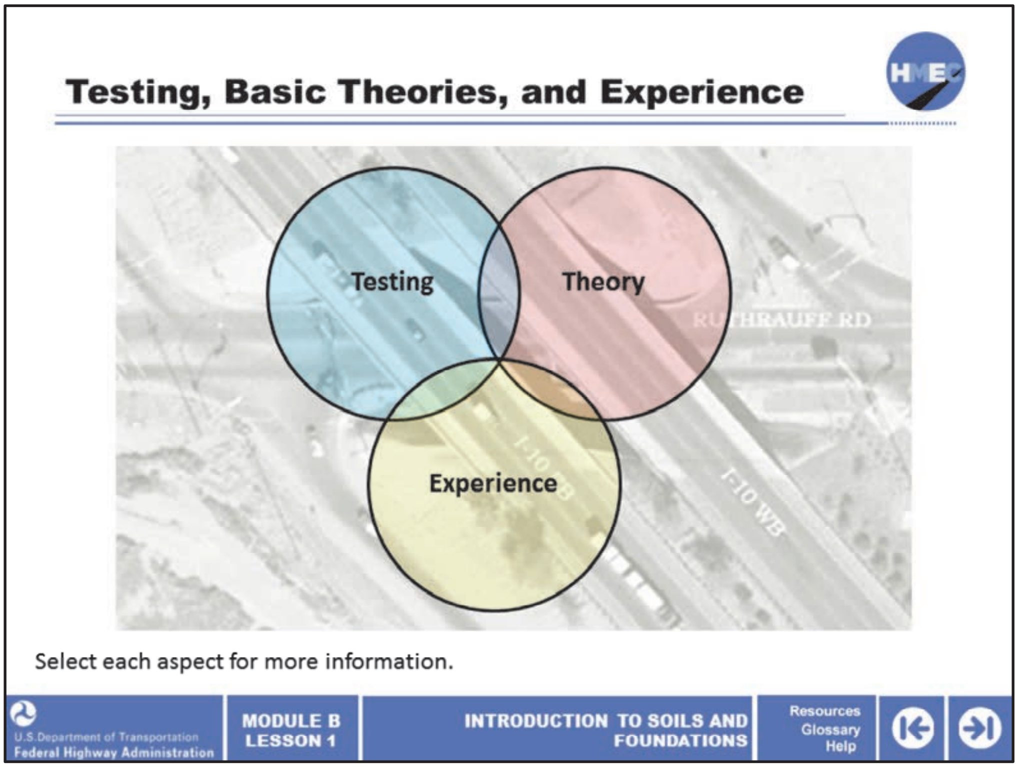
Image description: Graphic of reinforced soil slope.

Image description: Photo of a drainage structure.



Highway project features with geotechnical components cover the full range, including embankments, both reinforced and unreinforced cut and fill slopes, deep and shallow foundations, retaining walls, ground improvements, culverts, and pavements. There are many geotechnical challenges for transportation projects. They may range from routine to complex issues to consider during design and construction monitoring. Those issues need to be addressed through a combination of experience, theory, and testing.

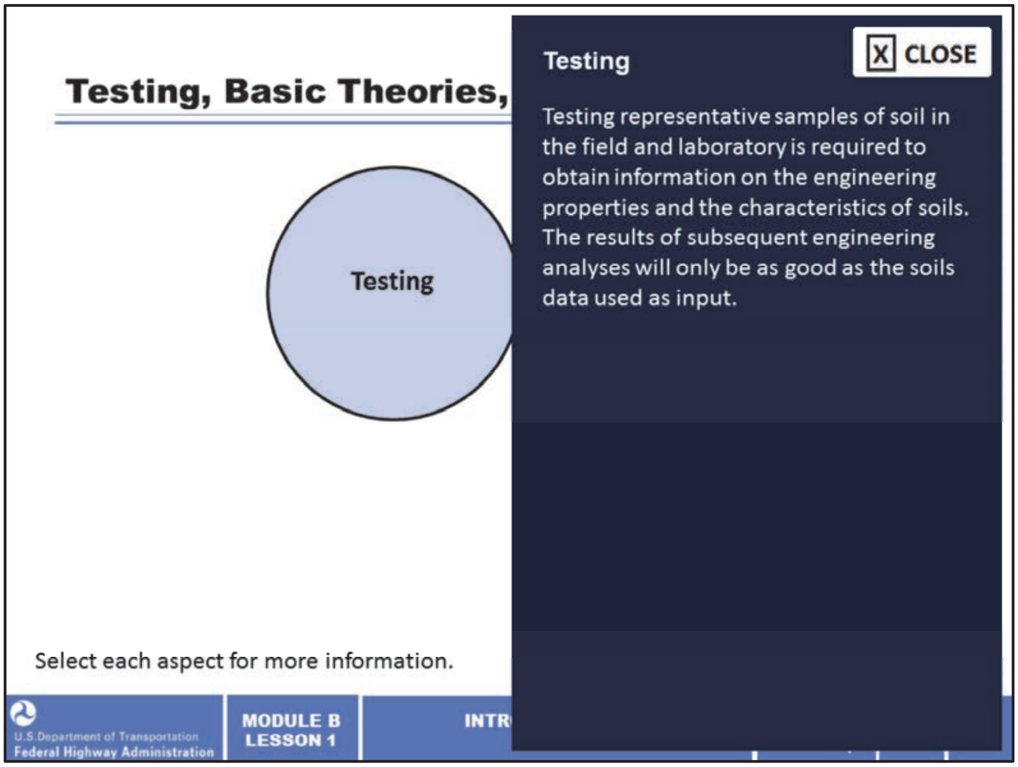
Image description: Photo of an aerial view of typical interstate bridges with three interlocking circles overlaid, with the words “testing”, “theory”, and “experience” in them.



The proper approach to geotechnical problems involves the combined use of testing, basic theories, and experience. Over-reliance on any one of these aspects will not produce a satisfactory design. The sole use of theory (number-crunching) may produce a wonderful design, which cannot be built. Similarly, the sole use of experience (foot-stomping) may produce a design that is at the best, not cost effective, and at the worst, unsafe. Soil conditions at each site must be analyzed by obtaining and testing soil samples, applying basic theory to produce a preliminary result, and then tempering the result with previous experience to produce an optimal design.

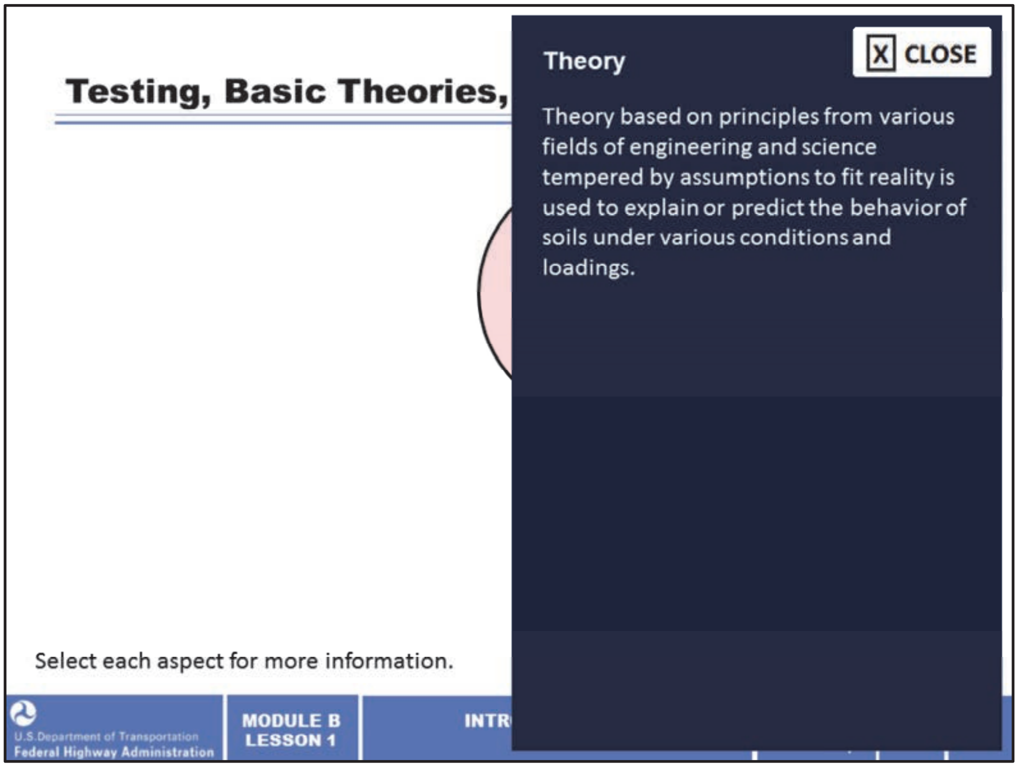
Select each aspect for more information.

Image description: Photo of an aerial view of typical interstate bridges with three interlocking circles overlaid, with the words “testing”, “theory”, and “experience” in them.



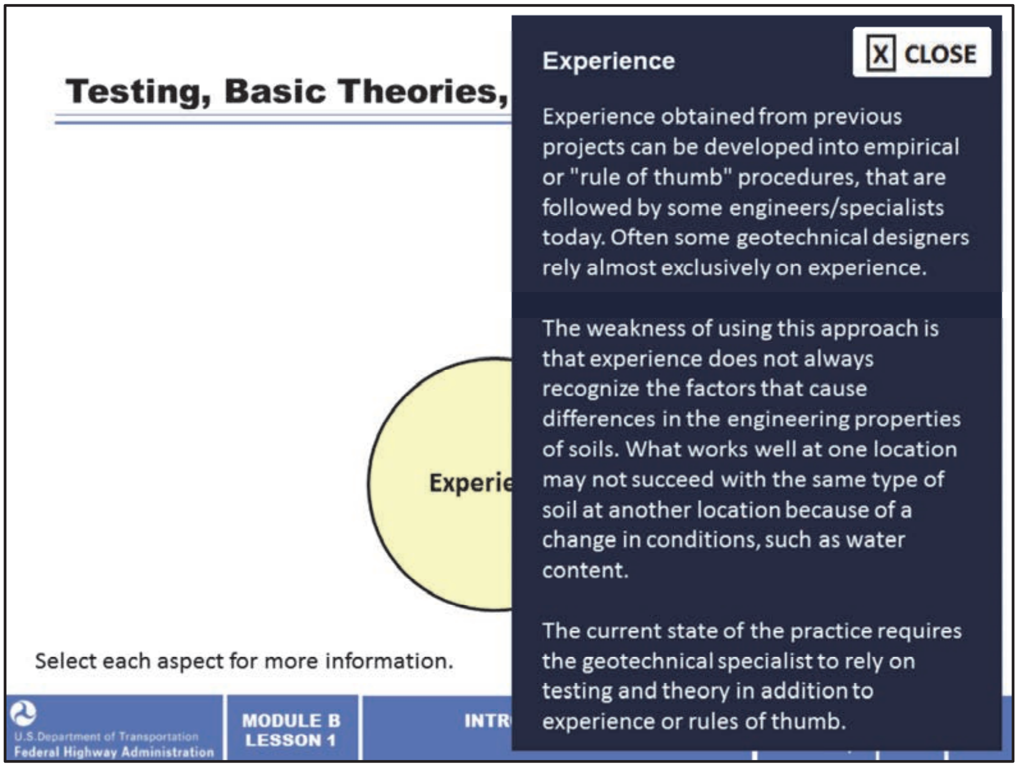
Testing representative samples of soil in the field and laboratory is required to obtain information on the engineering properties and the characteristics of soils. The results of subsequent engineering analyses will only be as good as the soils data used as input.

Image description: A circle with the word “testing” in it.



Theory based on principles from various fields of engineering and science tempered by assumptions to fit reality is used to explain or predict the behavior of soils under various conditions and loadings.

Image description: A circle with the word “theory” in it.

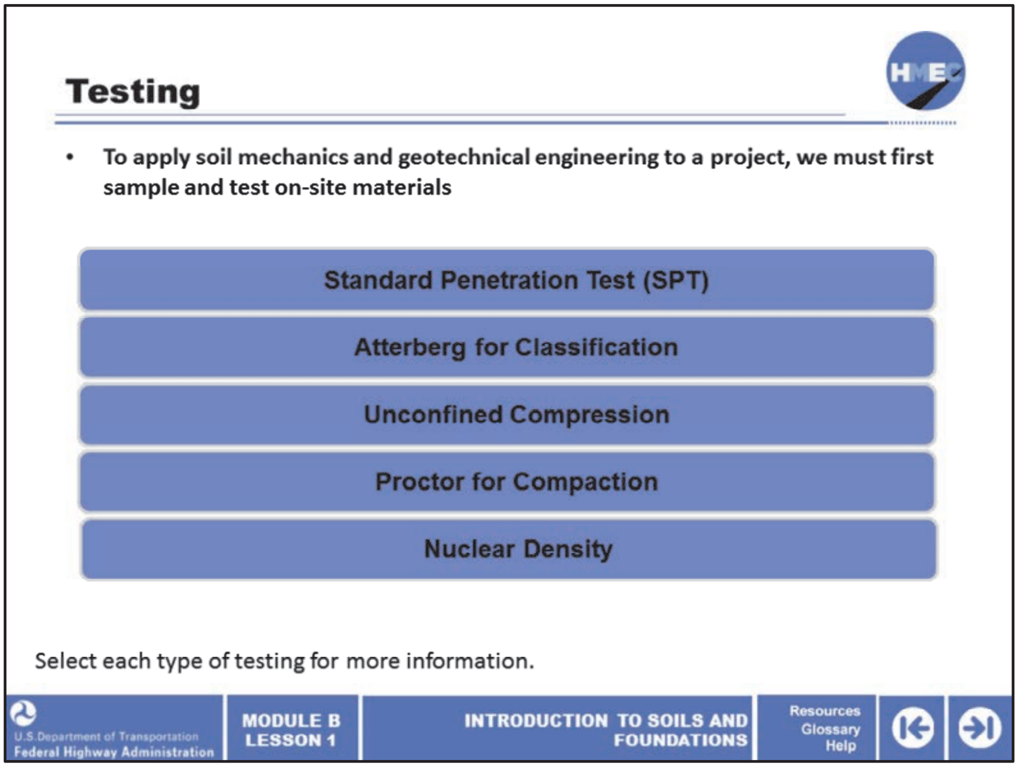


Experience obtained from previous projects can be developed into empirical or "rule of thumb" procedures, that are followed by some engineers/specialists today. Often some geotechnical designers rely almost exclusively on experience.

The weakness of using this approach is that experience does not always recognize the factors that cause differences in the engineering properties of soils. What works well at one location may not succeed with the same type of soil at another location because of a change in conditions, such as water content.

The current state of the practice requires the geotechnical specialist to rely on testing and theory in addition to experience or rules of thumb.

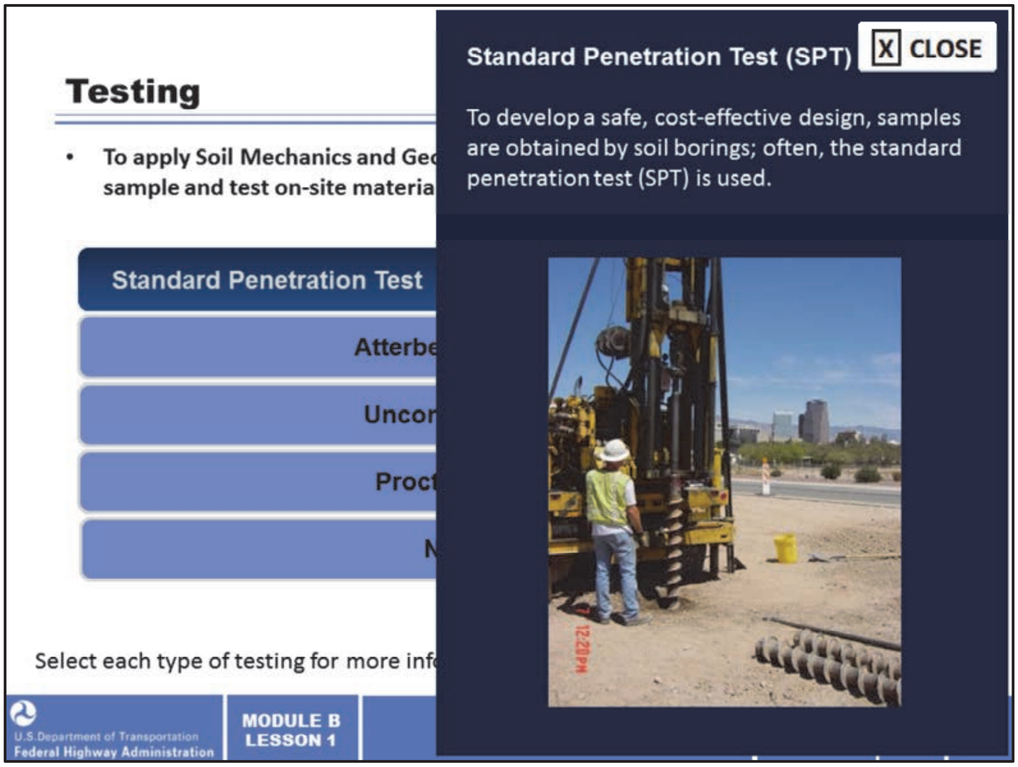
Image description: A circle with the word “experience” in it.



To apply soil mechanics and geotechnical engineering to a project, we must first sample and test on-site materials. Many tests are performed throughout the design and construction of a project.

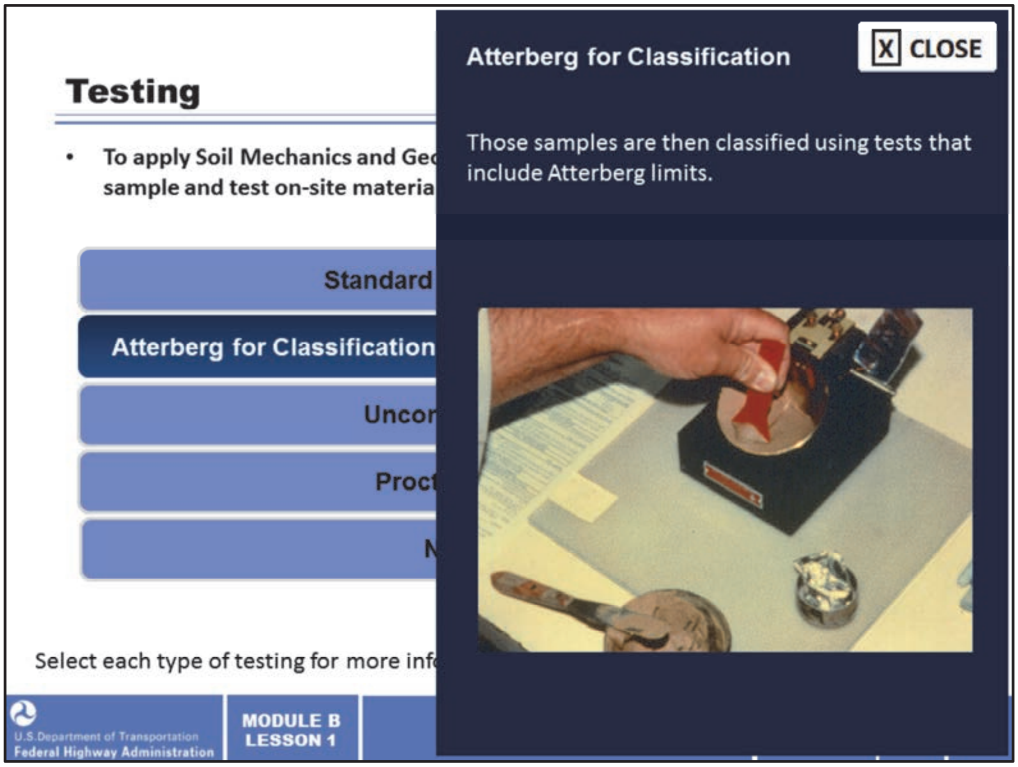
As you can see from this list of a few soil tests, material testing plays a key role throughout the entire design and construction process. However, the testing must be performed properly on representative samples. The adage "garbage in equals garbage out" applies. The application of theory using improper test results is a problem. There is a wide range of other testing that can be performed, which will be discussed in later lessons.

Select each type of testing for more information.



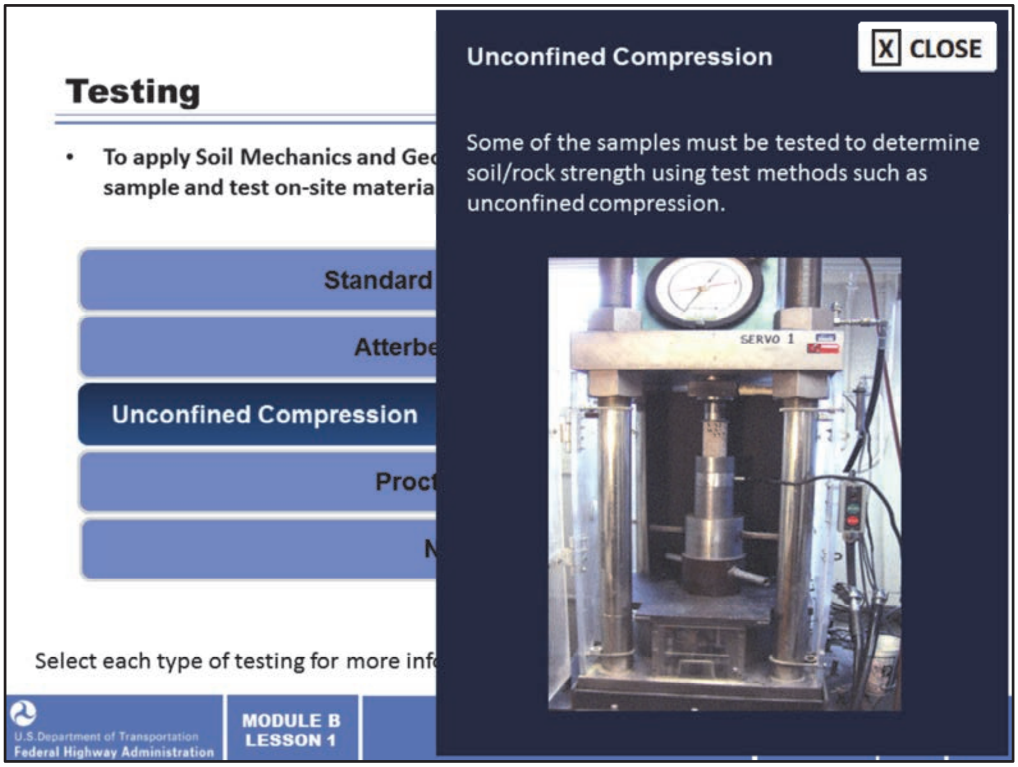
To develop a safe, cost-effective design, samples are obtained by soil borings; often, the standard penetration test (SPT) is used.

Image description: Photo of boring equipment.



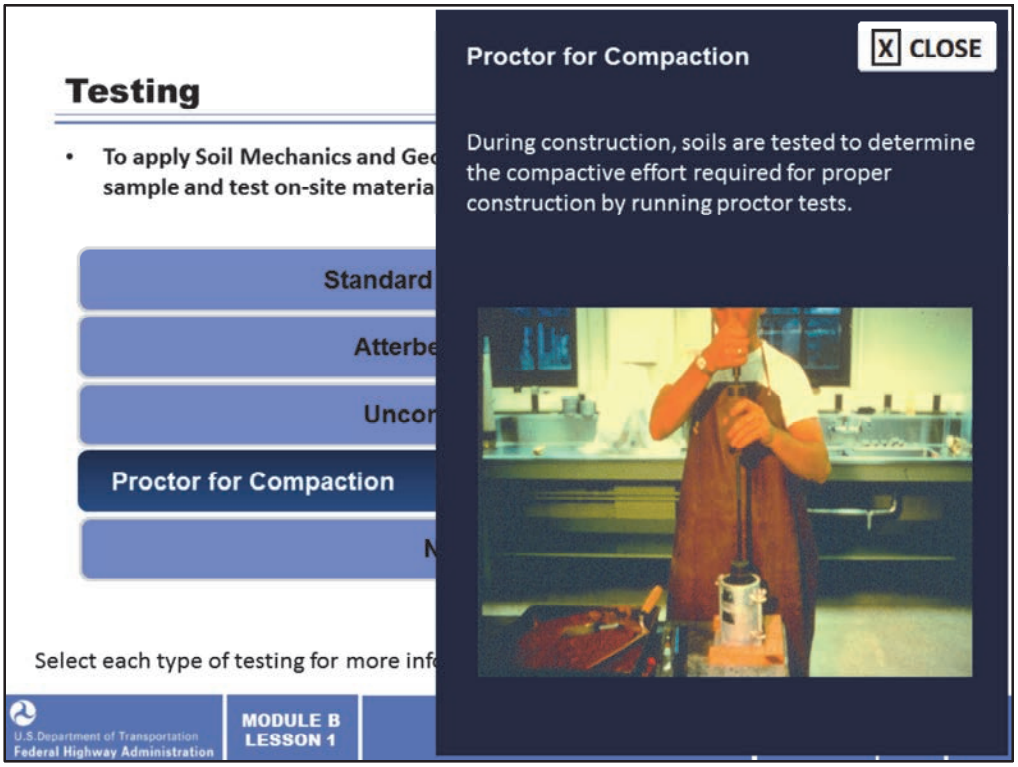
Those samples are then classified using tests that include Atterberg limits.

Image description: Photo of testing equipment.



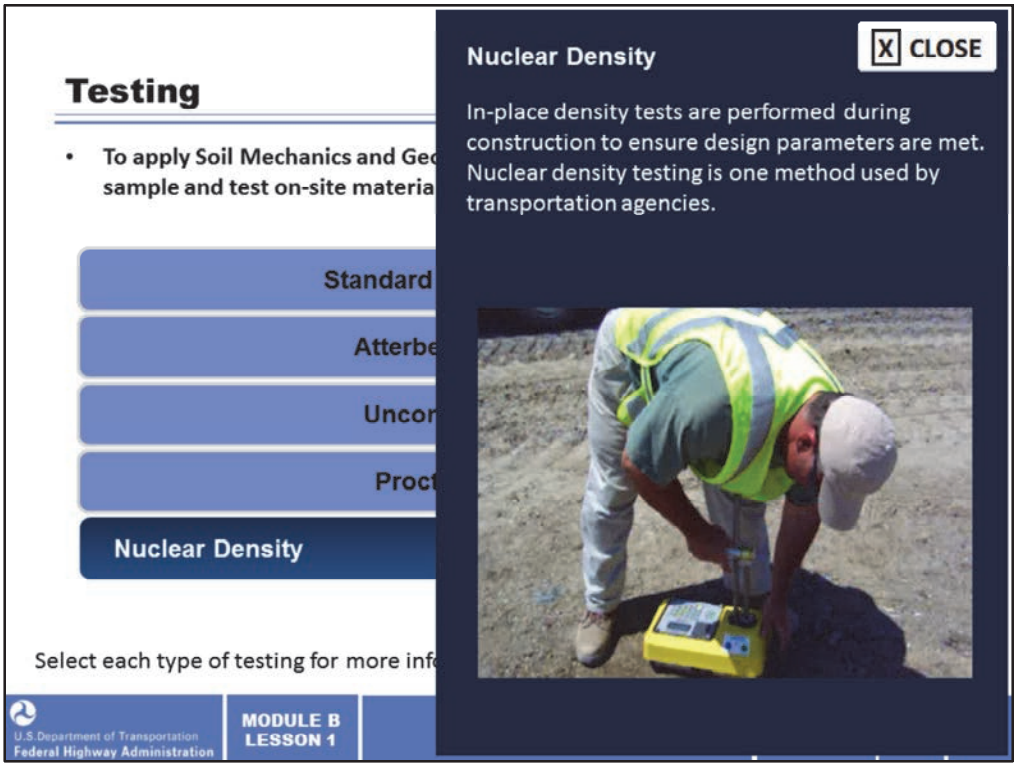
Some of the samples must be tested to determine soil and or rock strength using test methods such as unconfined compression.

Image description: Photo of unconfined compression testing equipment.



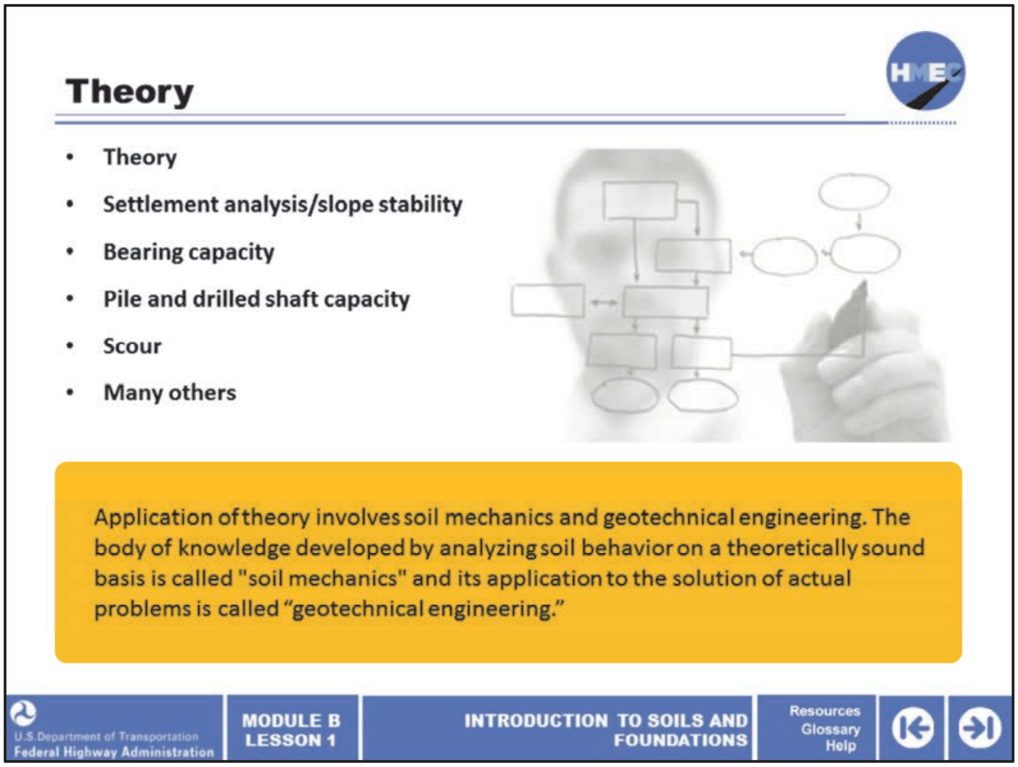
During construction, soils are tested by performing proctor tests so that the effectiveness of compaction effort can be monitored in the field and quality construction achieved.

Image description: Photo of Proctor testing equipment.



In-place density tests are performed during construction to ensure design parameters are met. Nuclear density testing is one method used by transportation agencies.

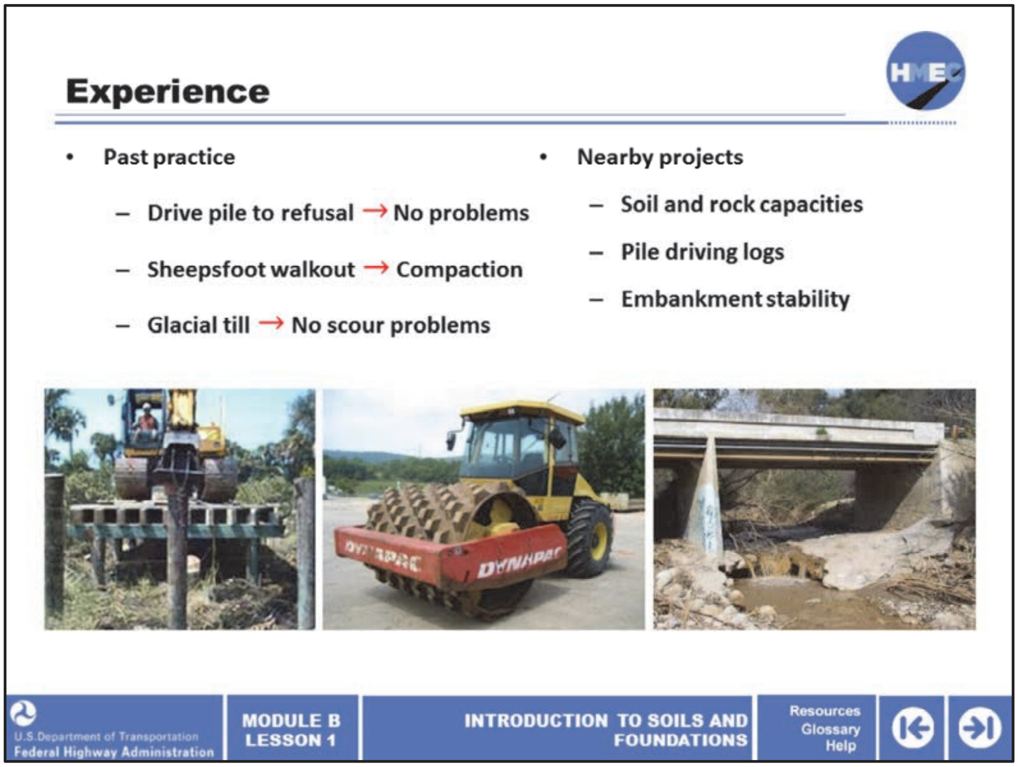
Image description: Photo of a man performing a nuclear density test.



Application of theory involves soil mechanics and geotechnical engineering. The body of knowledge developed by analyzing soil behavior on a theoretically sound basis is called "soil mechanics" and its application to the solution of actual problems is called “geotechnical engineering.”

Once we have properly sampled and tested soil and rock on the project site and in the laboratory, i.e., soil mechanics (or theory), then geotechnical engineering is applied to develop a safe and efficient design. Settlement analysis and slope stability calculations are performed to evaluate embankments and cut and fill slopes. Bearing and skin friction capacity of soil and rocks are determined to evaluate the capacities of spread footings or pile and drilled shaft foundations. Material in and around streams must be evaluated for scour (the erosion of material by moving water) potential to ensure the safety of foundations and roadway fills.

Image description: Photo of a man drawing a flowchart.



Some aspects of design may be based on experience or what has worked before. Experience is used to develop empirical or rule-of-thumb procedures. It can tell us that seepage in a cut slope must be addressed to avoid future problems, that a shale interface may result in a predefined failure plane, or that sheepsfoot roller walkout is a good indication of compaction without moisture-density control.

Experience is a valuable tool, but it must be tempered with testing and theory to ensure a safe but not overly conservative design. An agency may have a practice of driving piling to refusal, since it has always resulted in no problems. However, is that the most cost-effective design?

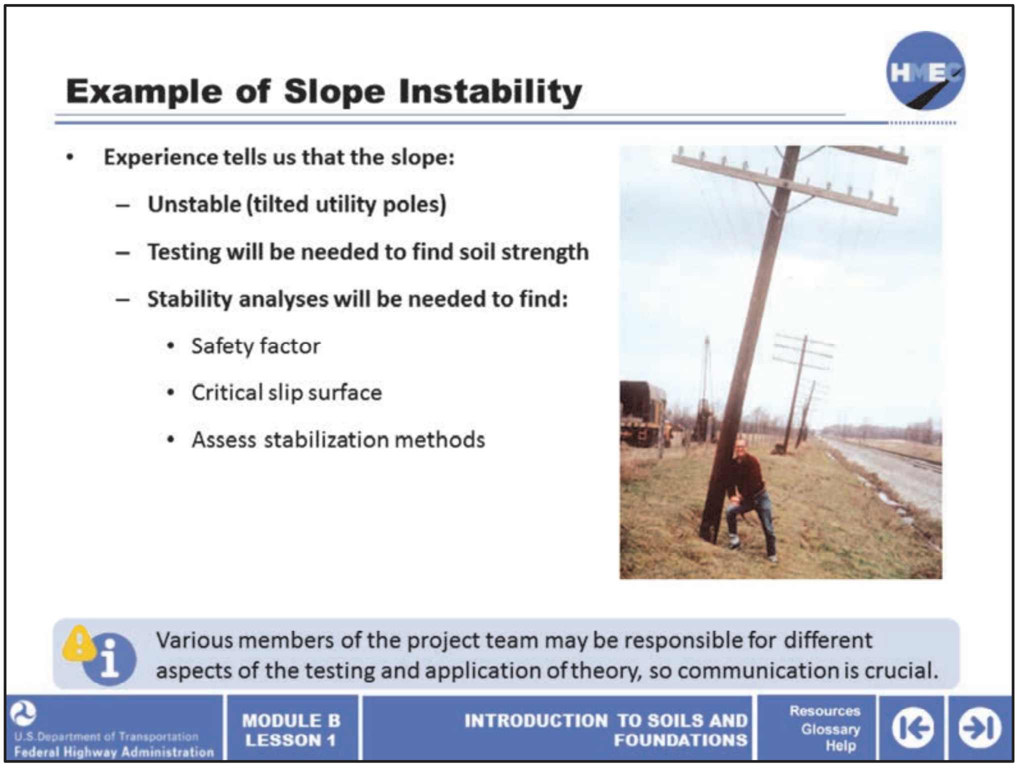
Compacted glacial till is often thought to be resistant to scour; however, scour of glacial fill was instrumental to the failure of the New York State Thruway bridge over Schoharie Creek on April 5, 1987, which resulted in the death of 10 motorists. The experience at Schoharie Creek resulted in the implementation of a nationwide scour evaluation program for all highway bridges. Information from nearby projects may be used to design a new project. However, the variability of soil and rock properties must be considered before data from another site is used.

Are the experiences from nearby projects representative of soil and or rock capacities, pile driving, or embankment stability on this project? Perhaps not, only through a combination of experience, testing, and theory can we be sure.

Image description: Photo of Drive pile equipment.

Image description: Photo of Sheepfoot walkout equipment.

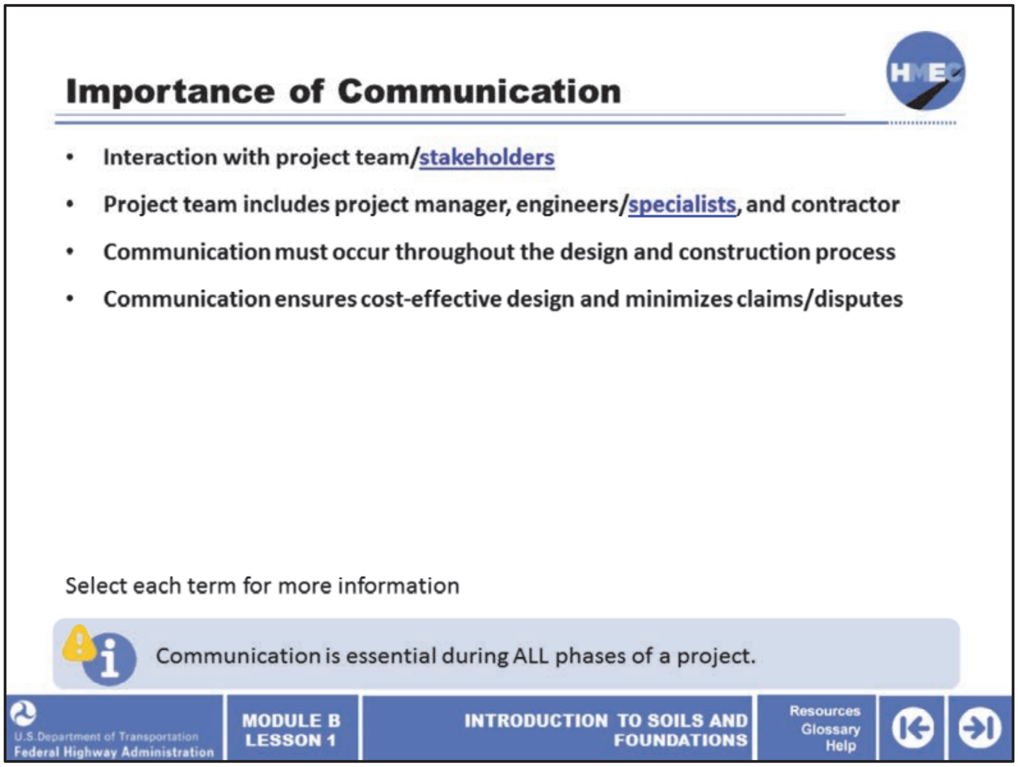
Image description: Photo of a creek running under a bridge.



How would testing, theory, and experience be applied to the solution of this situation? Example of slope instability. Experience tells us that the slope is unstable (tilted utility poles), testing will be needed to find soil strength, and stability analyses will be needed to find the safety factor, critical slip surface, and assess stabilization methods.

Various members of the project team may be responsible for different aspects of the testing and application of theory. Therefore, we must communicate with team members.

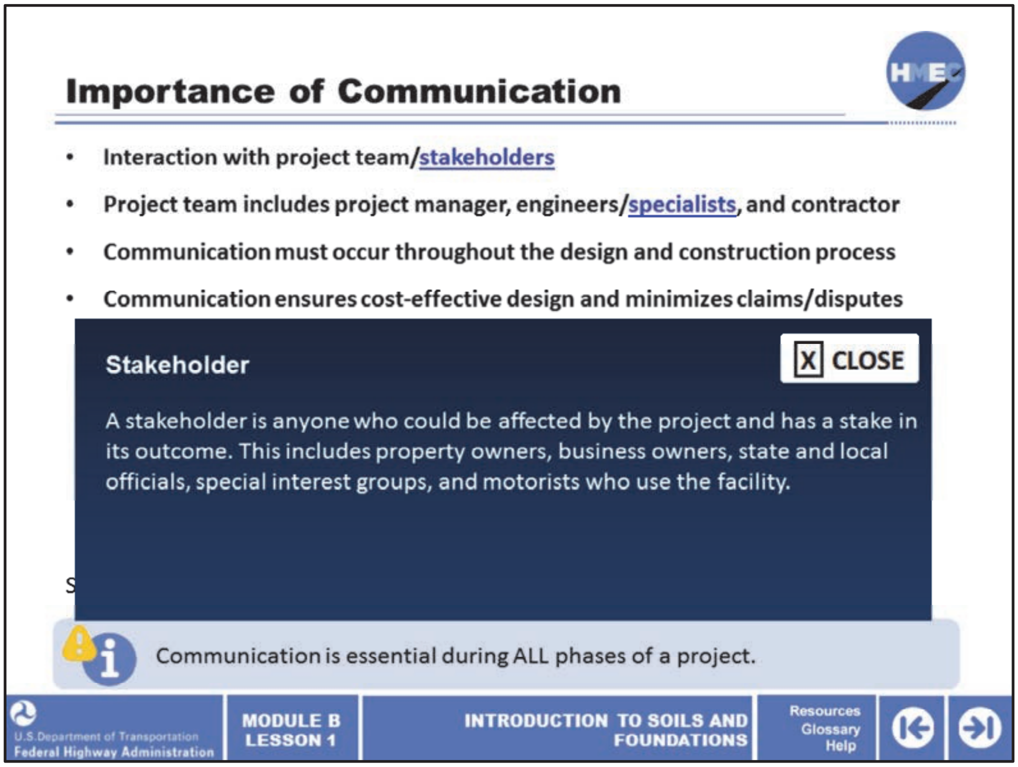
Image description: Photo of unstable (tilted utility poles).



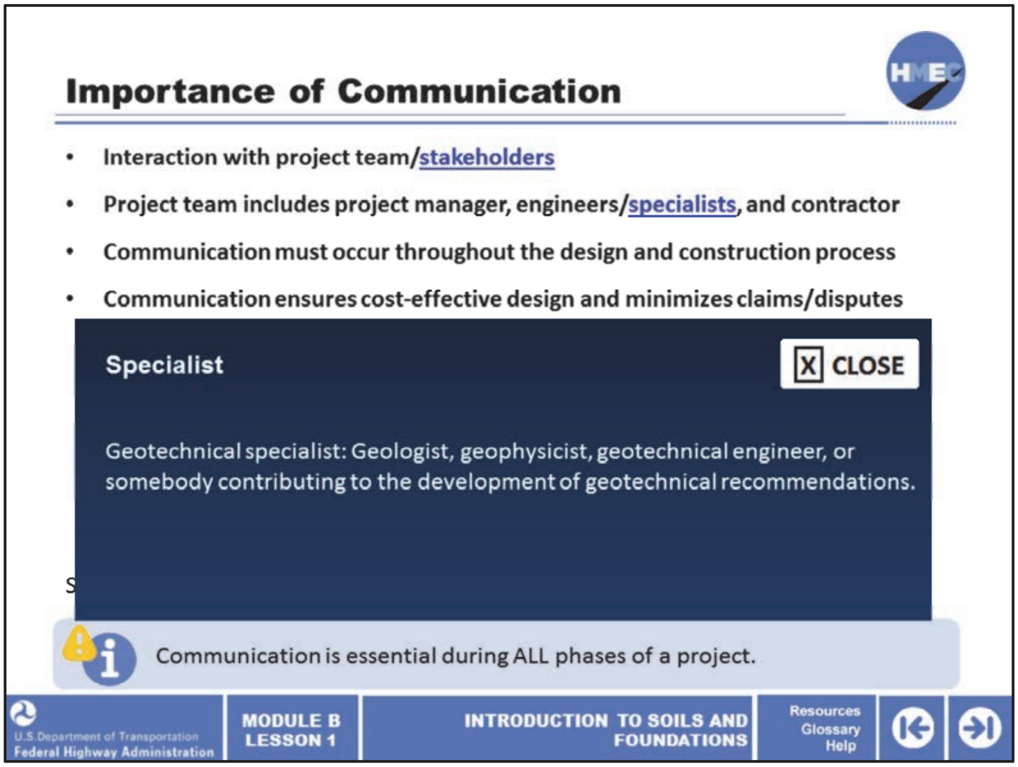
Communication is very important. It is how we interact with the project team and stakeholders. The project team includes the project engineer, engineers/specialists (such as the Material and Geotechnical Engineers) and the contractor. Communication must occur throughout the design and construction process to ensure a good design and that construction is in accordance with the specifications. Communication ensures cost effective design and minimizes claims and disputes. Remember “everyone” communicates with “someone.”

Communication is essential during all phases of the project.

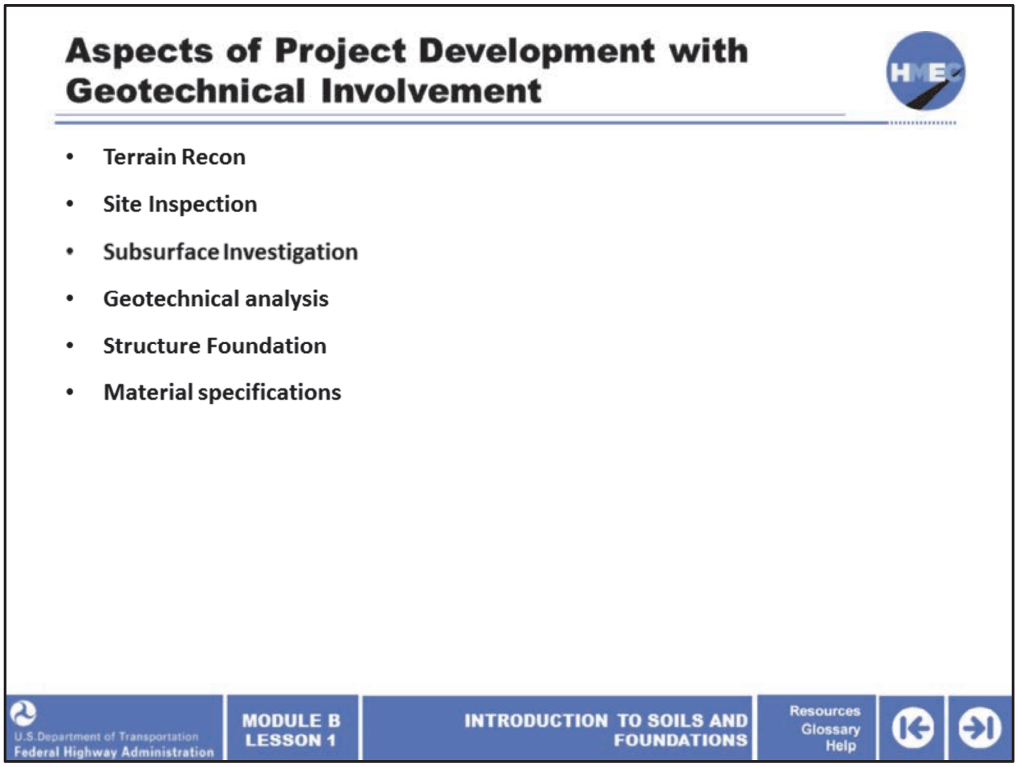
Select each term for more information



A stakeholder is anyone who could be affected by the project and has a stake in its outcome. This includes property owners, business owners, state and local officials, special interest groups, and motorists who use the facility.



Geotechnical specialist: Geologist, geophysicist, geotechnical engineer, or somebody contributing to the development of geotechnical recommendations.



Many aspects of the project require geotechnical involvement throughout all phases of the project. During the planning phase there is geotechnical involvement in the terrain reconnaissance and site inspection. This can identify potential risks and aid final route layout. During the preliminary design phase, there is geotechnical involvement in the subsurface investigation and geotechnical analysis of all earthwork features including embankments, cut slopes, structures, retaining walls, ground improvement, and pavement. During the final design phase, there is geotechnical involvement in selection of the foundation type, pavement, and development of the specifications.

The next several screens will support each of these bullets

Terrain Reconnaissance and Site Inspection

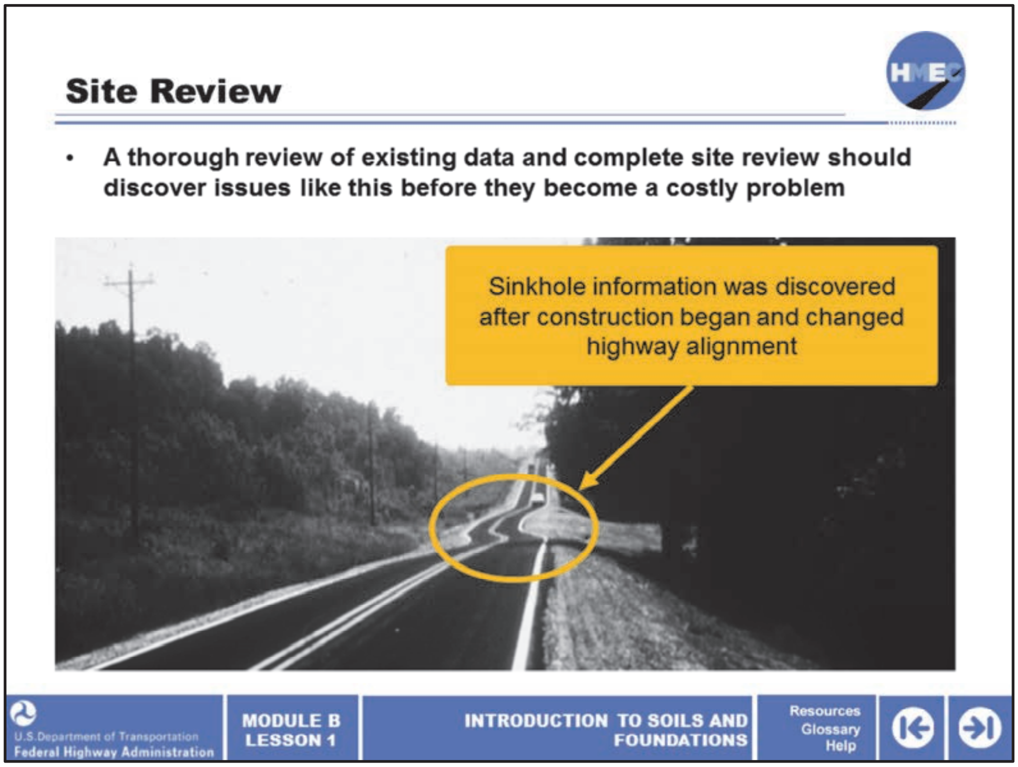
- **Learn from existing project site data**
  - Aerial photographs
  - USGS topographic maps
  - USDA soil maps
  - Groundwater bulletins
  - Well driller logs
  - Logs from adjacent projects
- **Perform site inspection**
- **Prepare "terrain recon" report**

A detailed site inspection is critical and should include inspection of nearby projects for any problems.

A lot can be learned about the project site from existing data such as aerial photographs (especially if there is a series of historical photos), USGS topographic maps, USDA soil maps, groundwater bulletins, well driller logs, boring logs from adjacent projects, etc.

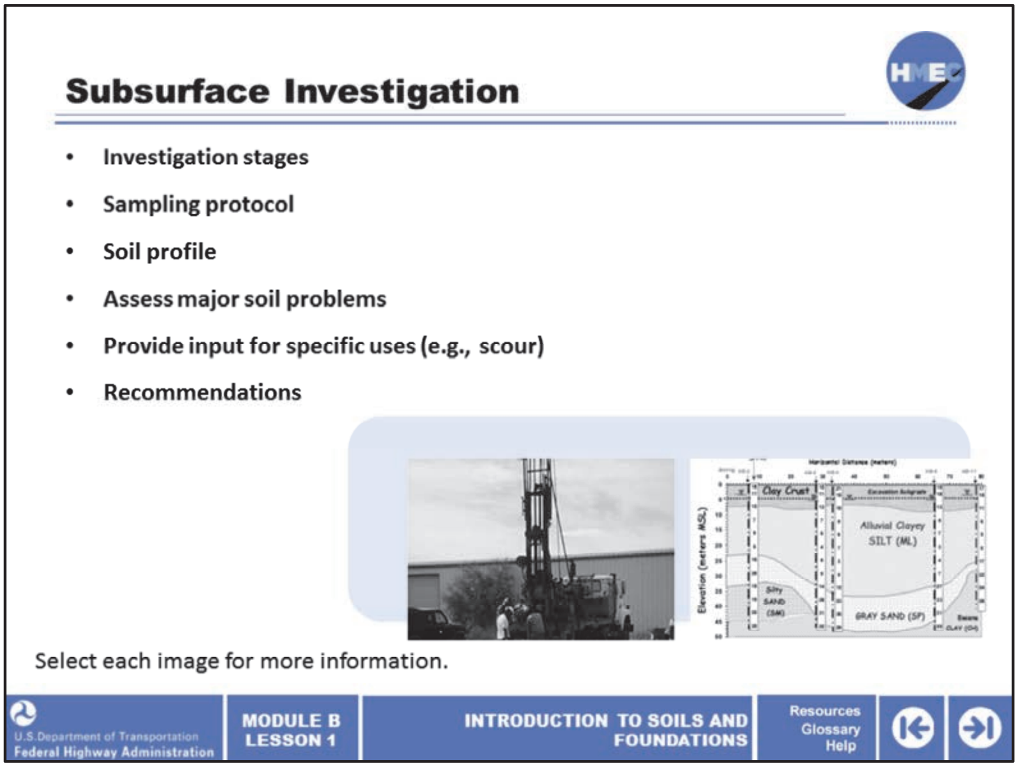
A detailed site inspection is critical and should include review of information from nearby projects and, as applicable, recon and or inspection of nearby projects. Based on the data gathered from the review and the site inspection, a terrain reconnaissance report is prepared for use during design and construction.

Image description: Photo of soil survey books.



This is what can happen if you do not find a sinkhole until after construction begins and have to change alignment. A thorough review of existing data and complete site review should discover issues like this before they become a costly problem.

Image description: Photo of a stretch of road with a circle, highlighting the part of the road where the alignment had to be changed.



Some subsurface investigations are performed in stages. The first preliminary stage involves minimal sampling from limited borings and possibly some geophysical testing to assess variability and help develop a detailed site investigation plan. The second stage will encompass the detailed boring and sampling protocol along the entire project site including problem areas and structure locations.

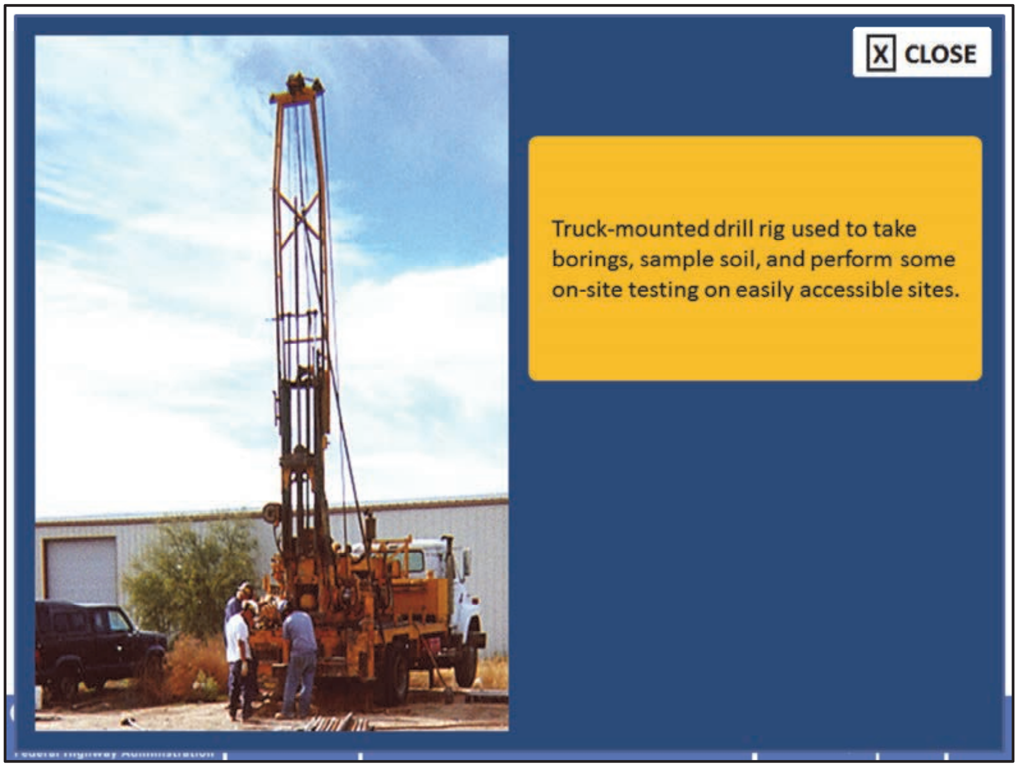
After sampling and testing, a soil profile for the site will be developed to assist the designers and construction personnel with interpreting the site conditions between the boring locations. The geotechnical specialist uses the sampling and testing results to assess soil problems, provide input on specific soil issues (such as scour vulnerability), and making recommendations for design and construction.

As a material engineer, you may be involved in preliminary sampling and testing, development of the detailed sampling and testing program, and making recommendations for design.

Select each image for more information.

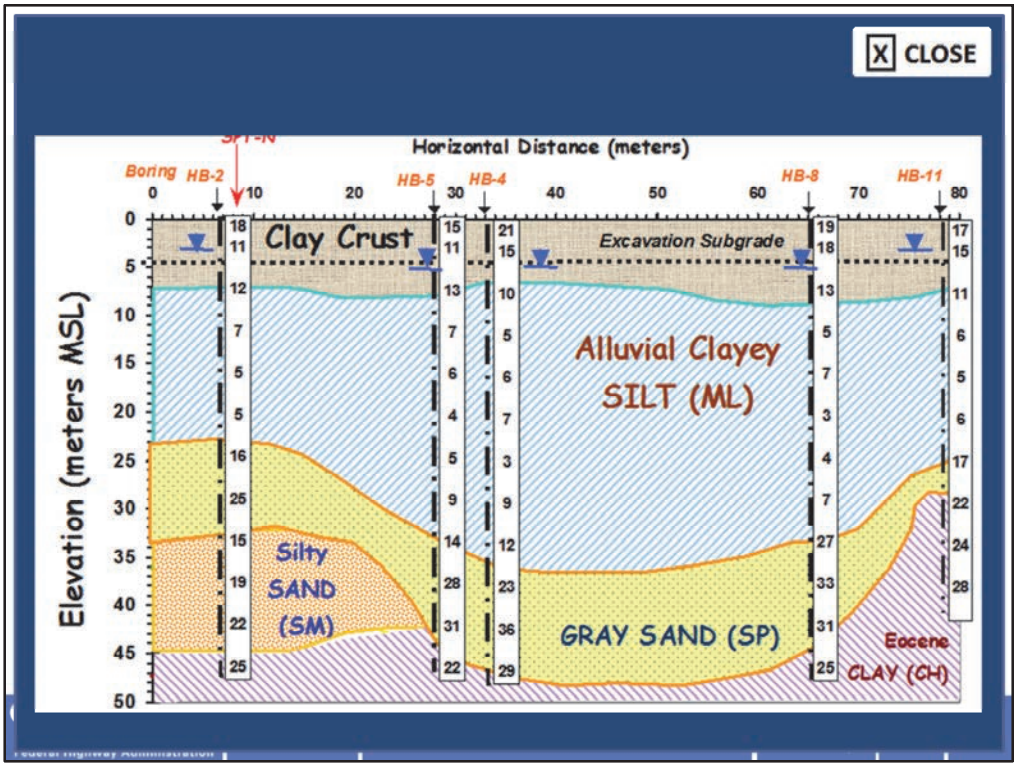
Image description: Photo of truck mounted drill rig.

Image description: Graphic of borings below the ground.



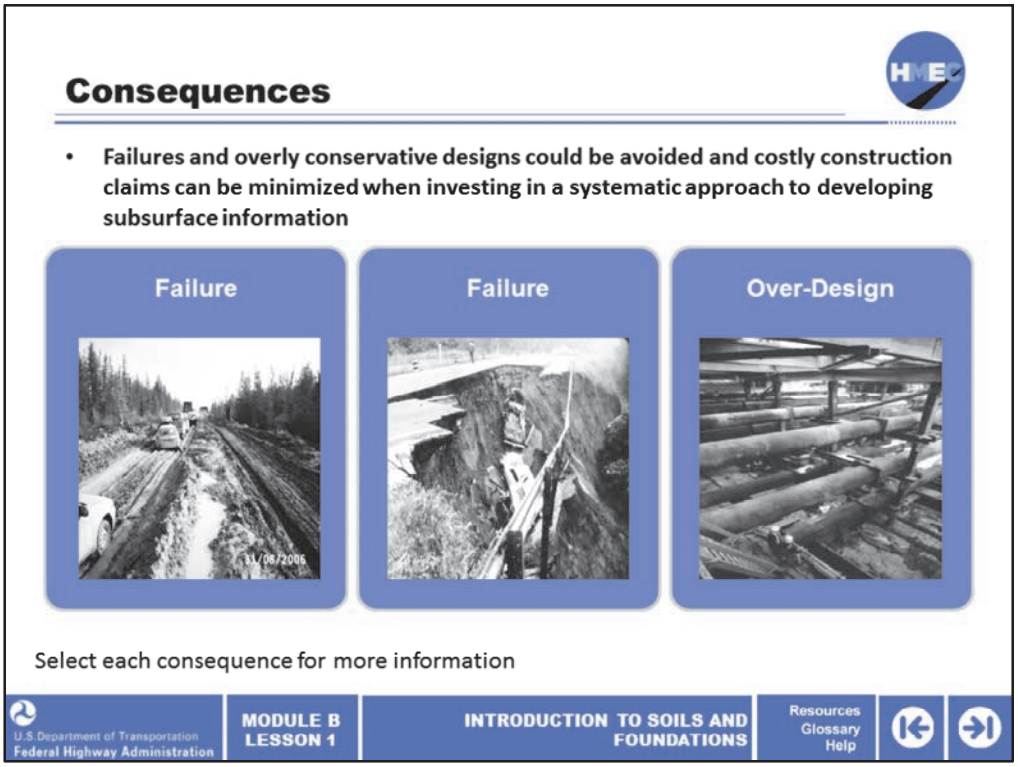
Truck-mounted drill rig used to take borings, sample soil, and perform some on-site testing on easily accessible sites.

Image description: Photo of truck mounted drill rig.



A soil profile is developed based on interpretation between discrete soil borings along the project alignment. This information must be developed by geotechnical specialists. It is used by designers and construction personnel for the design and construction of project features that occur between the boring locations. Geophysic methods can help with the interpretation between borings and to identify anomalies.

Image description: Graphic of borings below the ground.



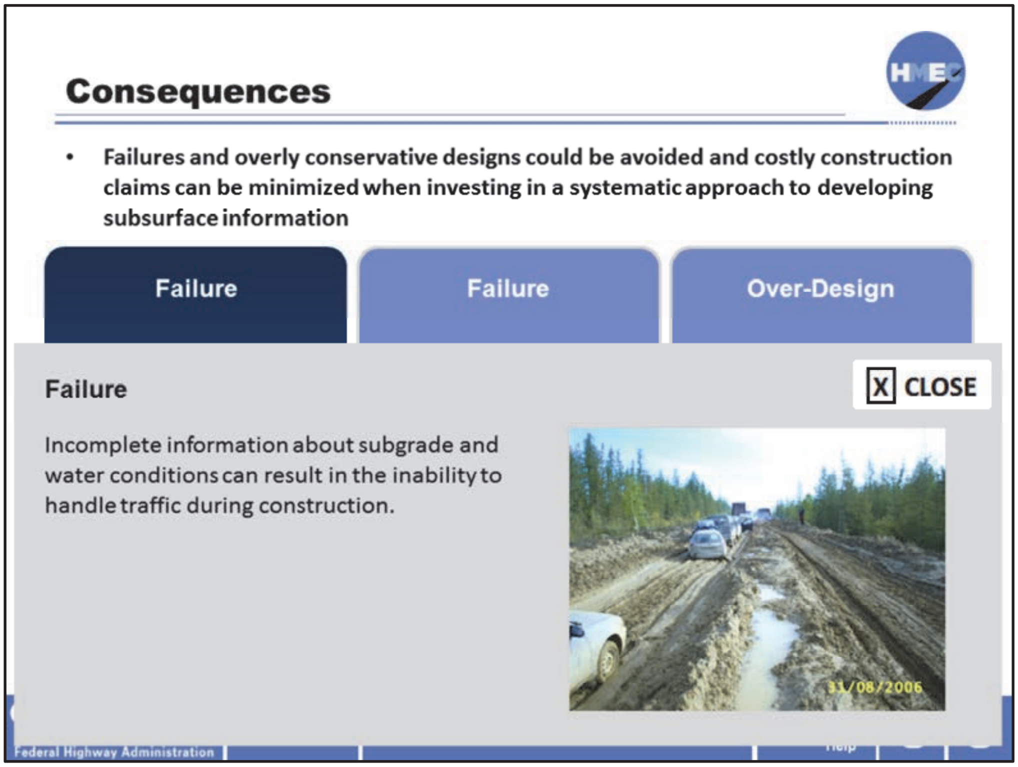
There are consequences to an inadequate subsurface investigation program. By investing in a systematic approach to developing subsurface information, failures and overly conservative designs can be avoided and costly construction claims can be minimized.

Select each consequence for more information.

Image description: Photo of a stretch of road with cars sinking into the pavement.

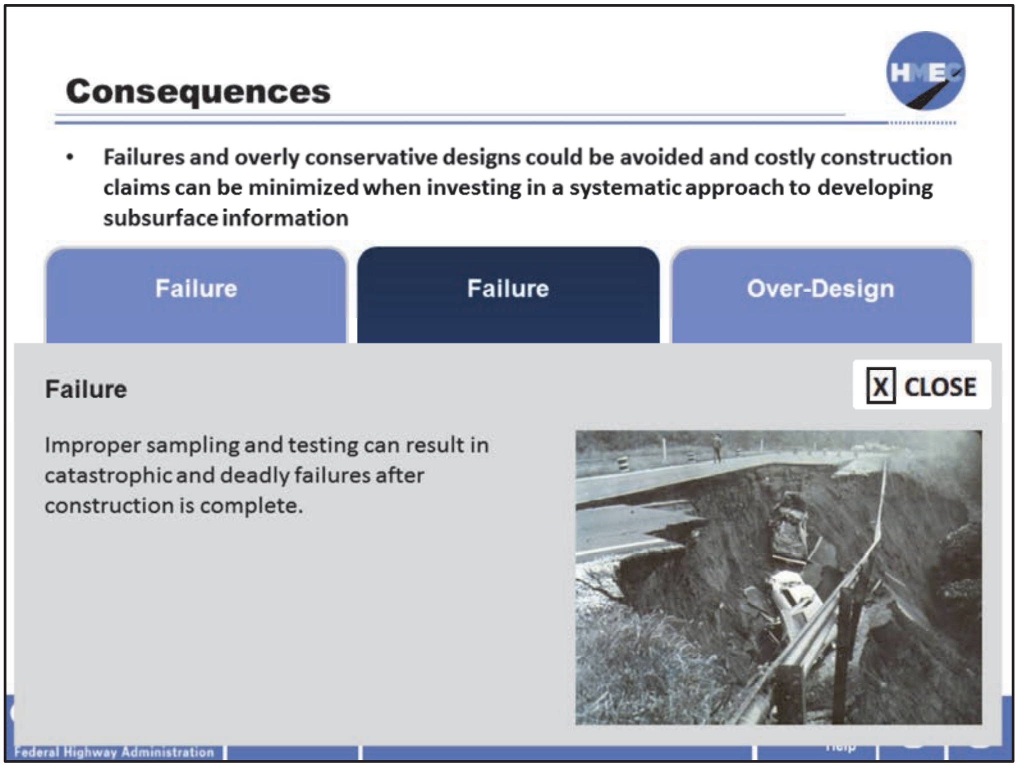
Image description: Photo of cars falling down the embankment of a collapsed road.

Image description: Photo of overly constructed hillside.



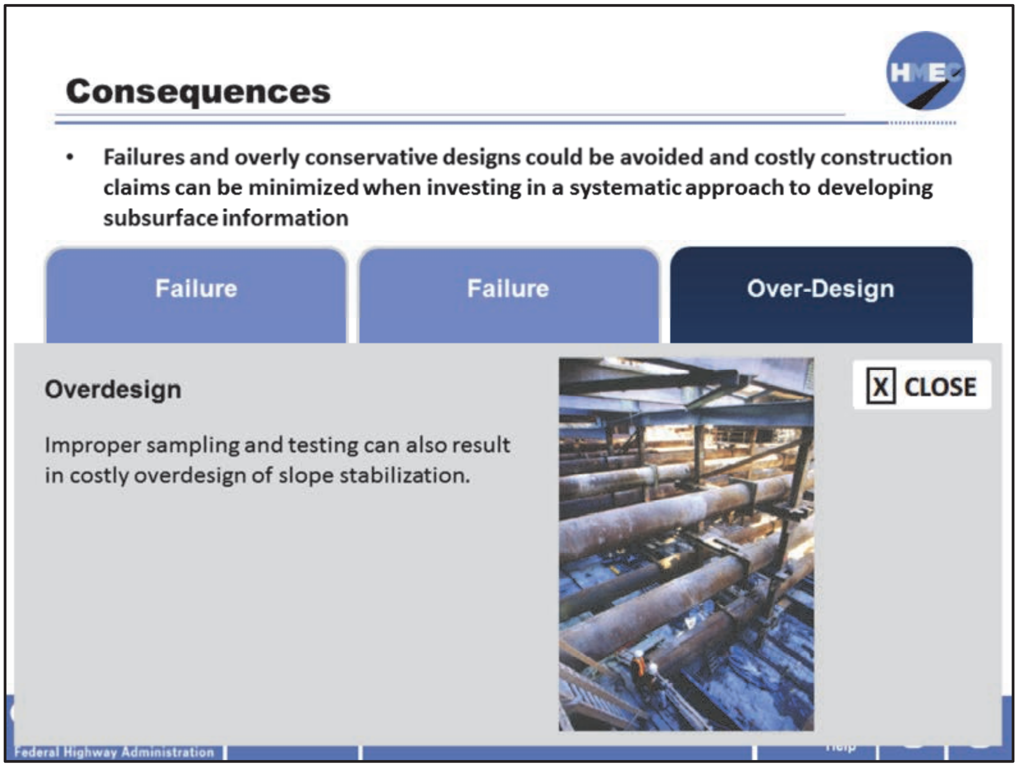
Incomplete information about subgrade and water conditions can result in the inability to handle traffic during construction.

Image description: Photo of a stretch of road with cars sinking into the pavement.



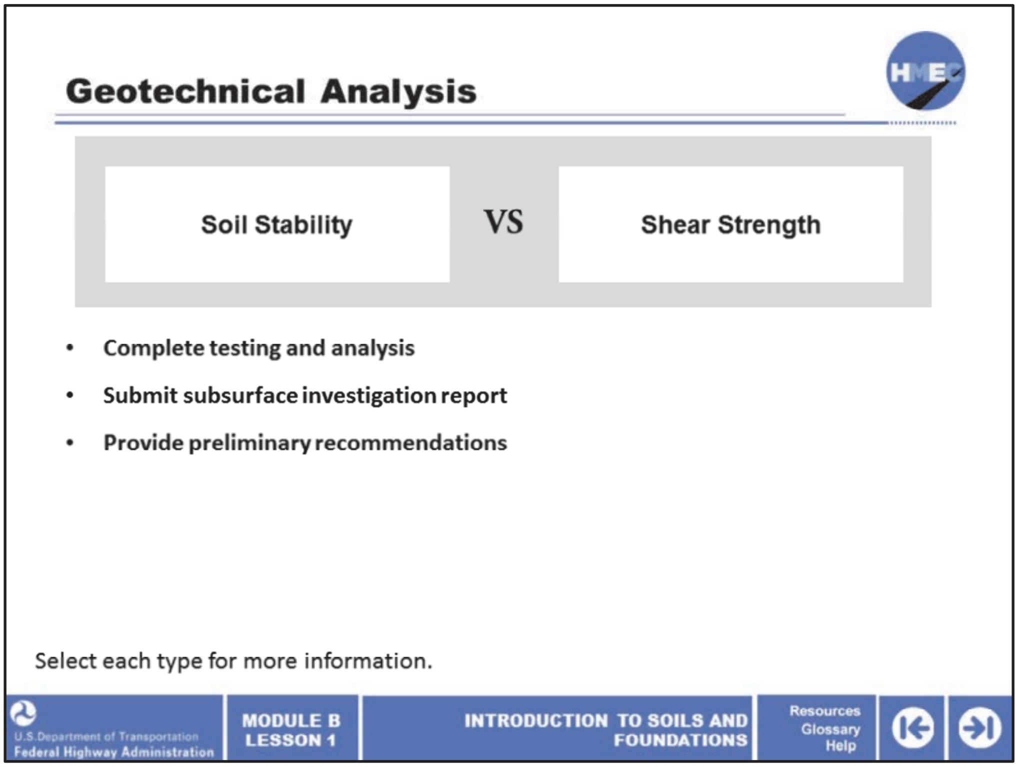
Improper sampling and testing can result in catastrophic and deadly failures after construction is complete.

Image description: Photo of cars falling down the embankment of a collapsed road.



Improper sampling and testing can also result in costly overdesign of slope stabilization, which may result in so much temporary support that it greatly limits working room within the site and drives up construction costs.

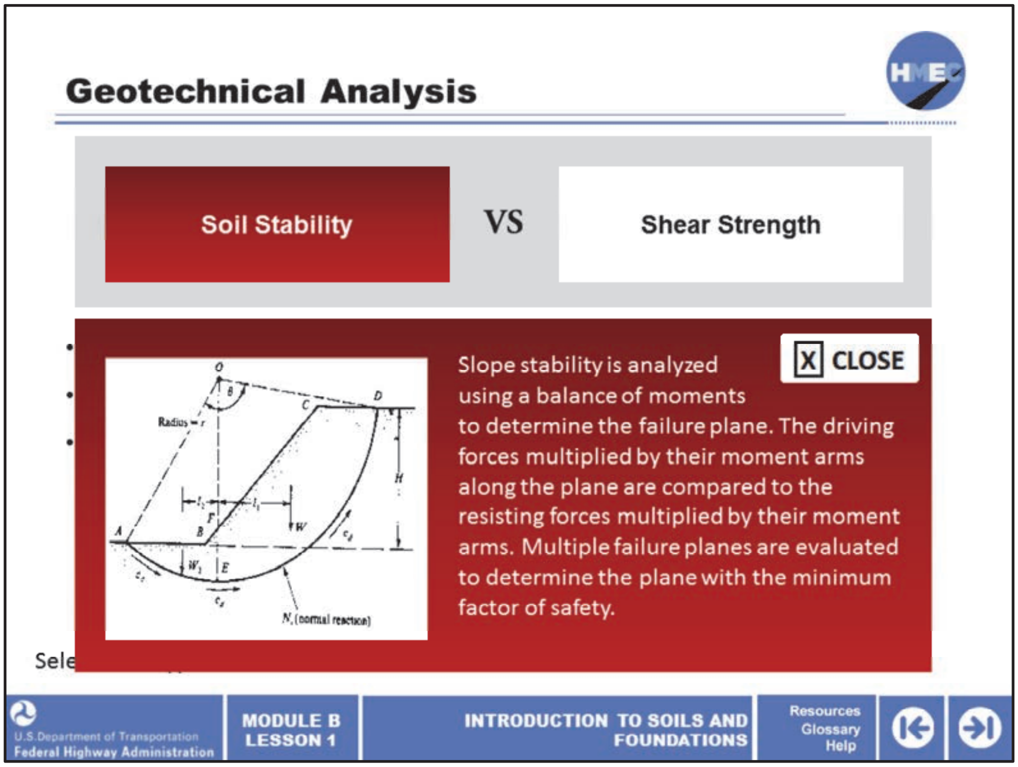
Image description: Photo of overly constructed hillside.



Once the sampling and testing is completed, analysis and design of the geotechnical features can proceed. Analysis may include: settlement and stability of embankments, cut slope stability, evaluation of reinforced slopes, ground improvement needs, drainage of subsurface water conditions, bearing capacities for shallow or deep foundation elements, retaining wall stability, seismic hazards, and subgrade stability for pavements.

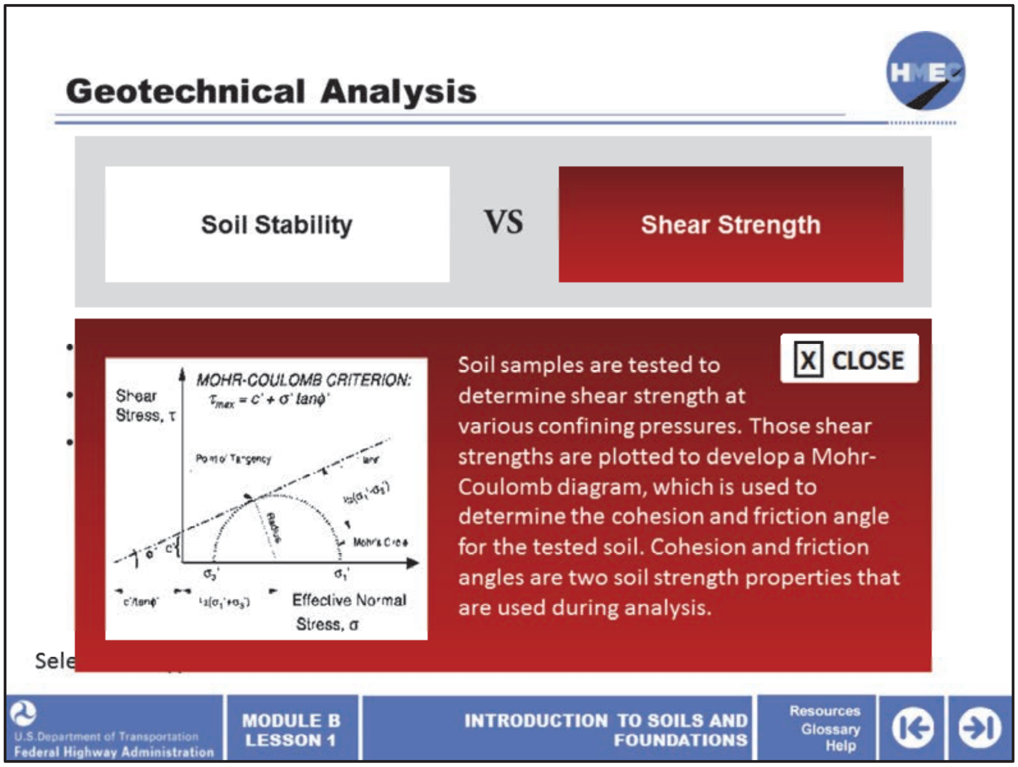
After geotechnical analysis is complete a subsurface investigation report with preliminary recommendations will be written and furnished to the project designers. The preliminary recommendations should not be limited to one design, but should explore alternative designs.

Select each type for more information.



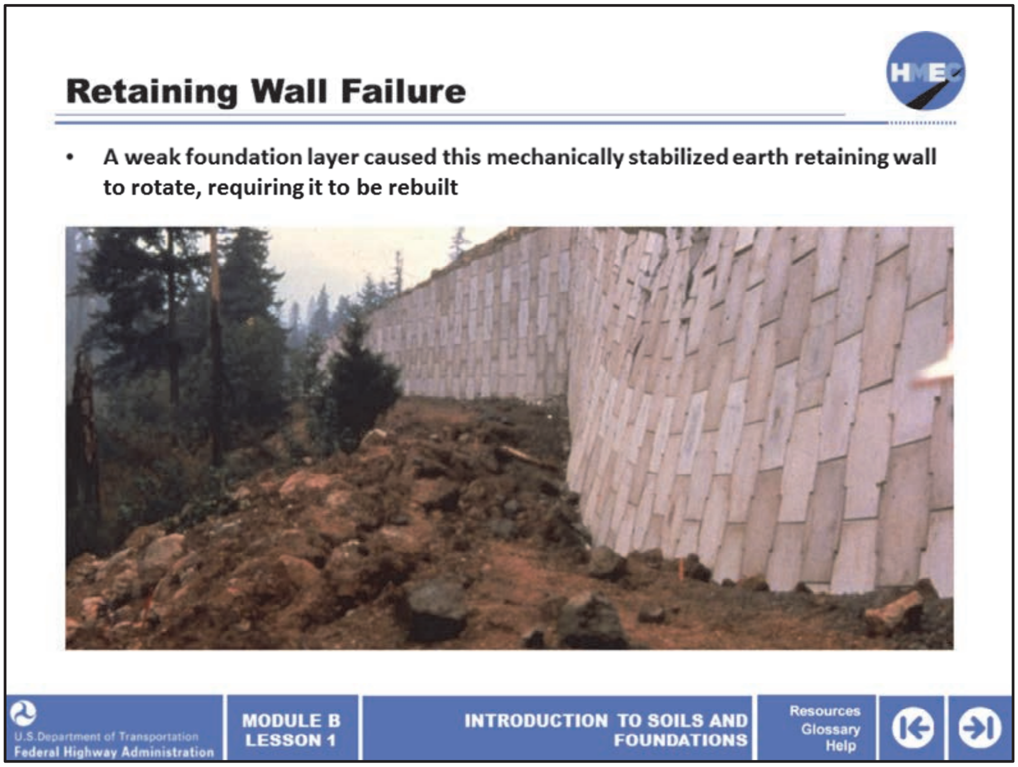
Slope stability is analyzed using a balance of moments to determine the failure plane. The driving forces multiplied by their moment arms along the plane are compared to the resisting forces multiplied by their moment arms. Multiple failure planes are evaluated to determine the plane with the minimum factor of safety.

Image description: Diagram of slope stability analysis.



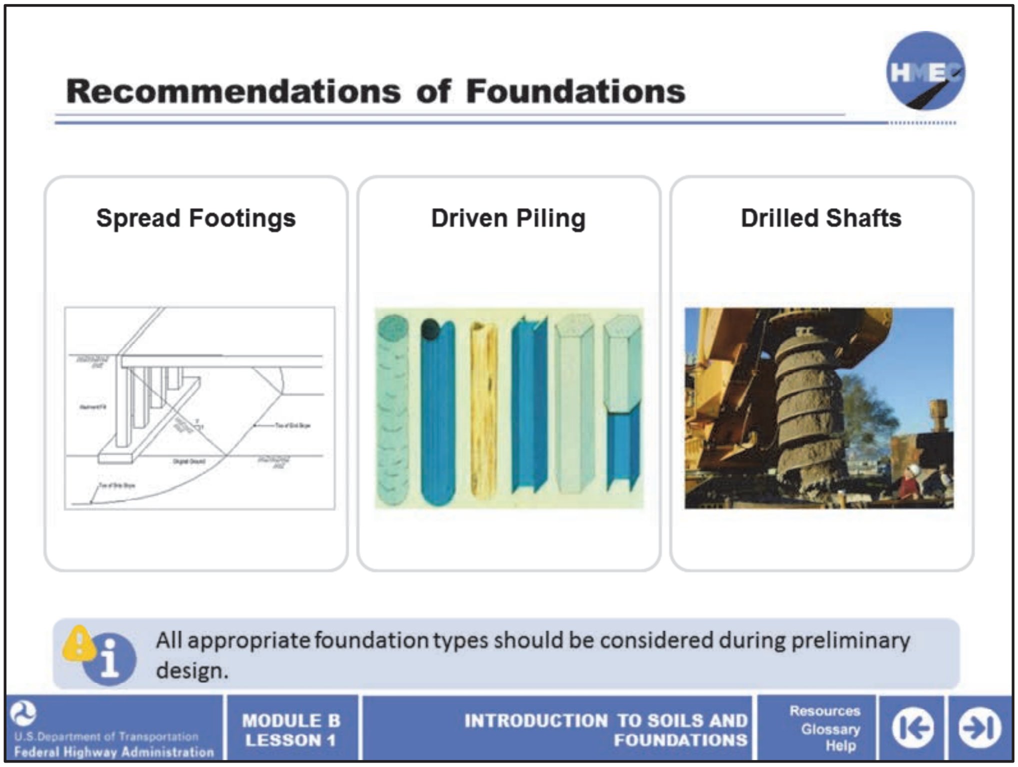
Soil samples are tested to determine shear strength at various confining pressures. Those shear strengths are plotted to develop a Mohr-Coulomb diagram, which is used to determine the cohesion and friction angle for the tested soil. Cohesion and friction angles are two soil strength properties that are used during analysis. They will be discussed in detail during later lessons.

Image description: Mohr-Coulomb diagram.



A weak foundation layer caused this mechanically stabilized earth retaining wall to rotate. Although the wall did not collapse, it had to be stabilized by construction of a rock berm in front of it. Analysis of all possible failure modes within the area of the structure must be completed. The depth, thickness of the layer, and strength of the foundation material must be determined through proper sampling and testing. The results of that sampling and testing must be analyzed using proven methods.

Image description: Photo of retaining wall failure.



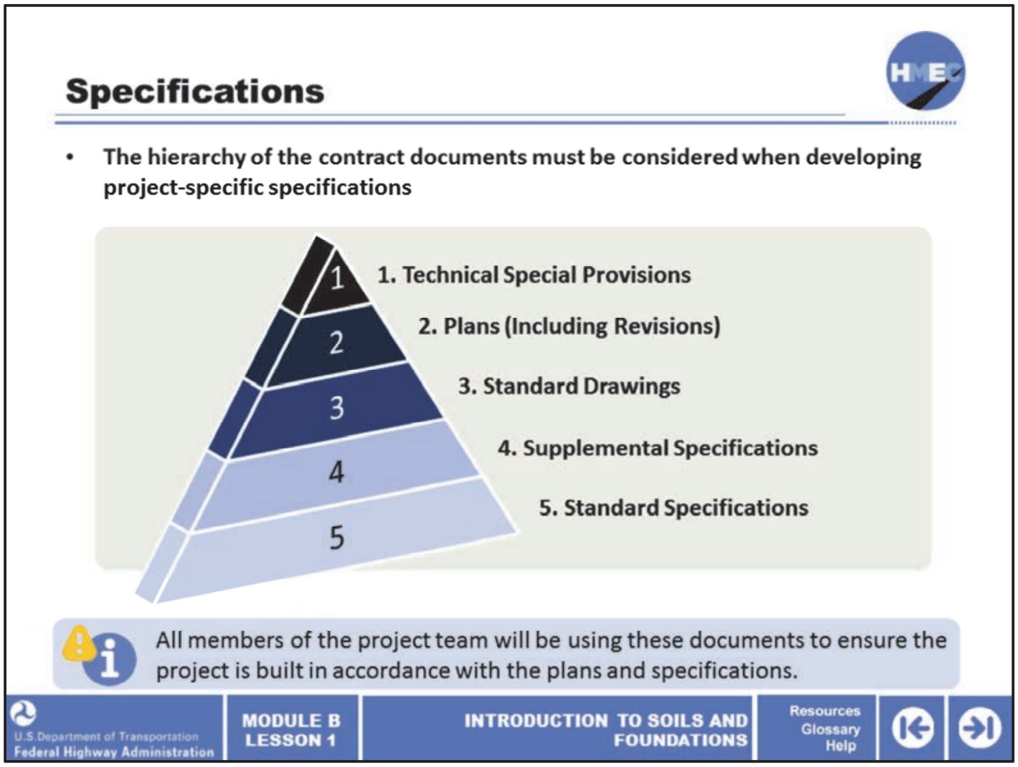
All appropriate foundation types should be considered during preliminary design. The foundation possibilities include both shallow and deep foundations. Shallow foundations are typically spread footings, while deep foundations can be either driven piling or drilled shafts. Piling can be several different materials and shapes.

We will discuss foundation types and selection in detail during Lesson 8.

Image description: Diagram of spread footings.

Image description: Graphic of driven piling.

Image description: Photo of drilled shafts.



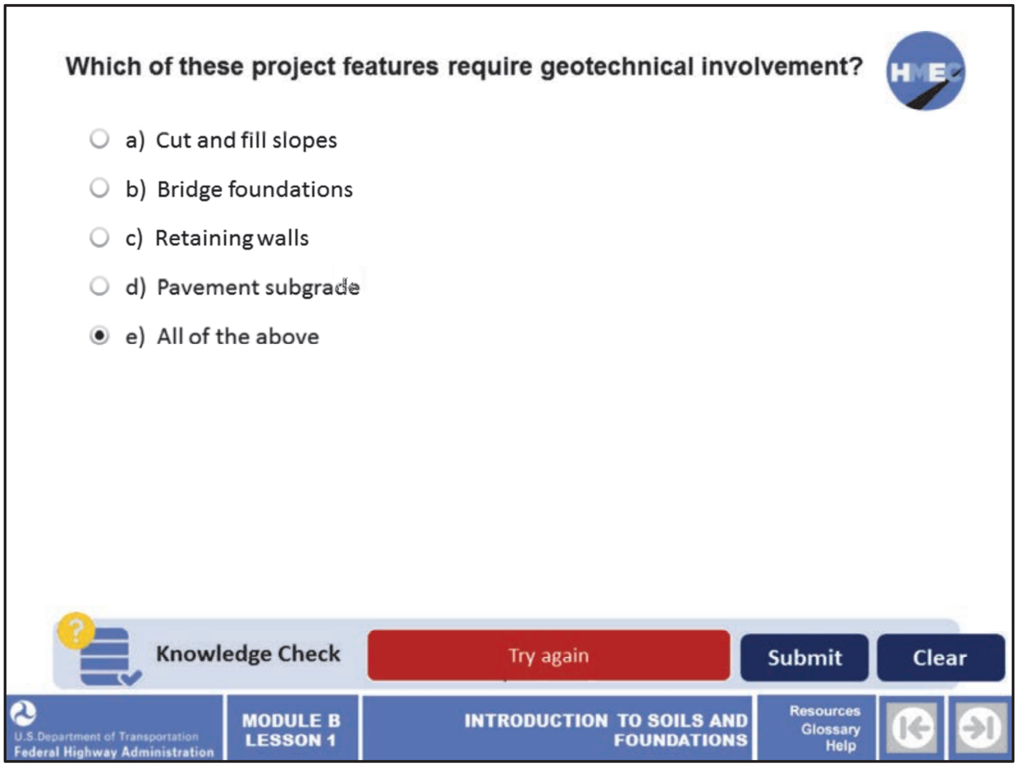
The hierarchy of the contract documents must be considered when developing project-specific specifications. This graphic depicts the association among contract documents with the standard specifications providing the base. Each successive layer modifies or supplements the layer below. The plans and special provisions modify or supplement all other contract documents with project-specific criteria.

All of these documents must support each other and not create ambiguities. As we work to develop material specifications that will direct the design and construction of the project, we must always communicate with the project team members. All members of the project team will be using these documents to ensure the project is built in accordance with the plans and specifications.

Image description: Image of a basic pyramid broken into five segments numbered from 1 to 5 from top to bottom.

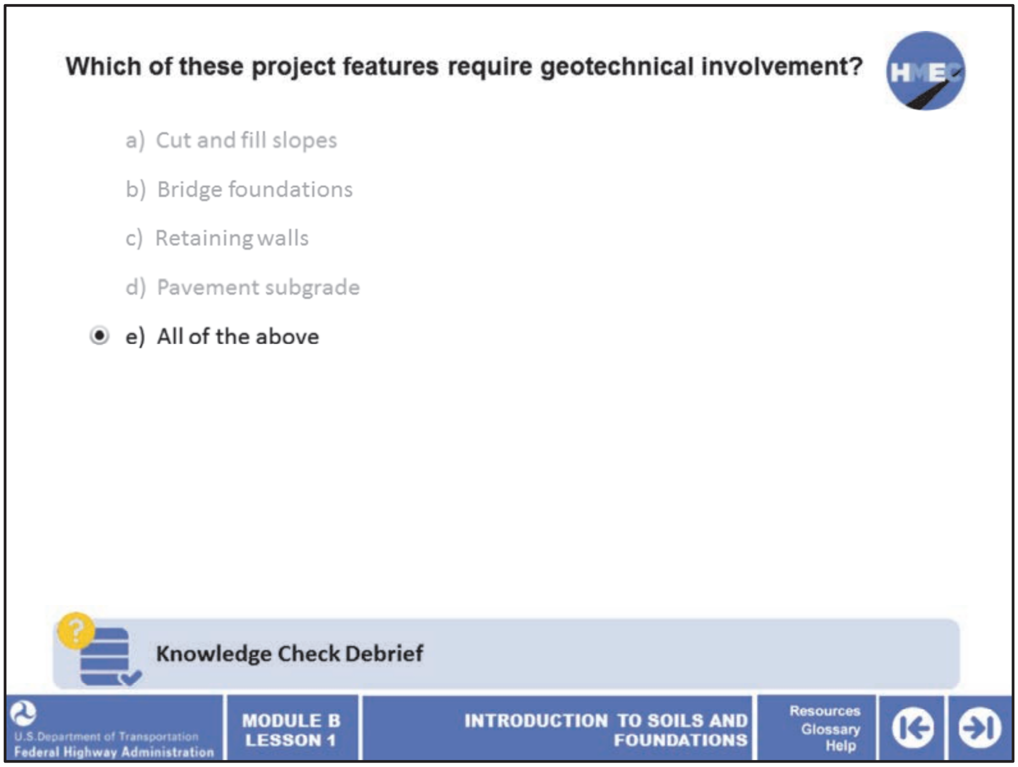
If we work closely and communicate well with the project team including geotechnical specialists, this is an example of the cost-effective, good-looking, long-lasting, smooth-riding project we will achieve.

Image description: Photo of a road curving through natural landscaping.

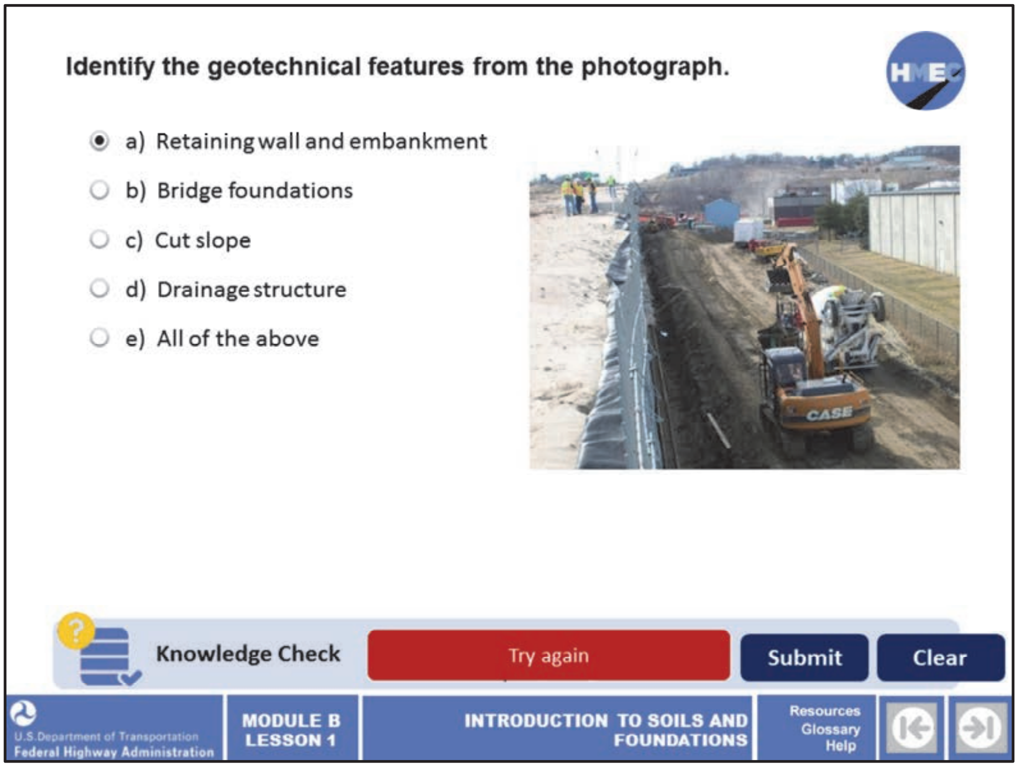


Now let's review what we have learned. Which of these project features require geotechnical involvement?

a) Cut and fill slopes;
b) Bridge foundations;
c) Retaining walls;
d) Pavement subgrade; or
e) All of the above.



The correct answer is e) All of the above. Proper design and construction of all of the features listed require geotechnical review of soil and rock properties and geotechnical analysis of design parameters.



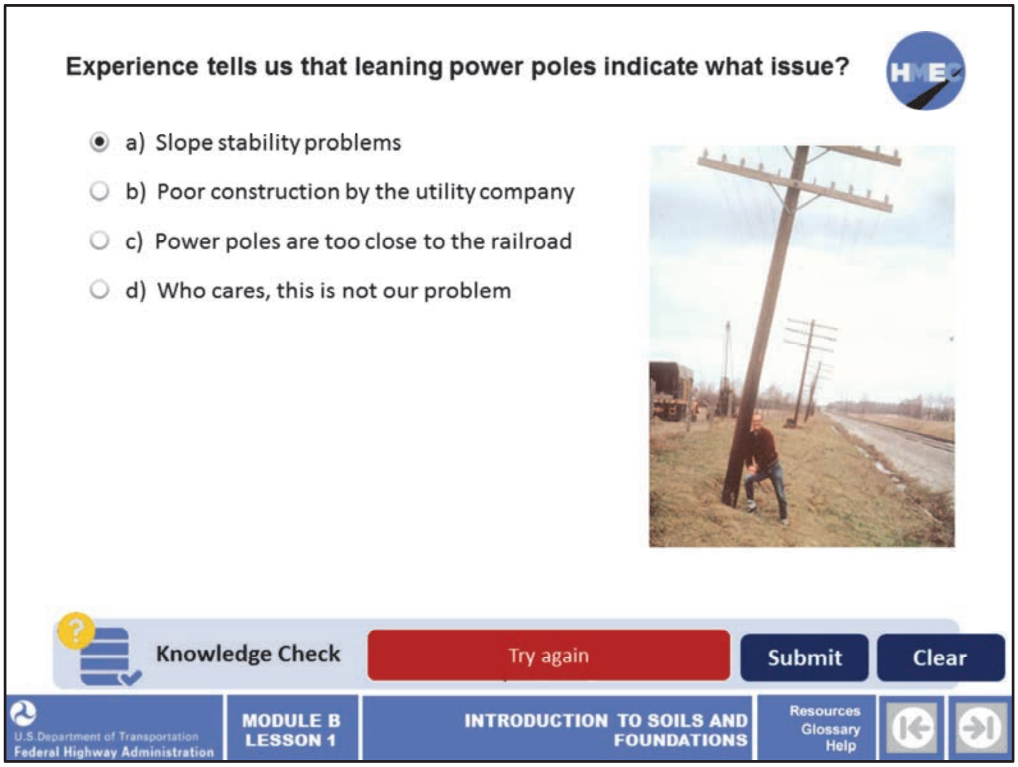
Identify the geotechnical features from the photograph.

a) Retaining wall and embankment;
b) Bridge foundations;
c) Cut slope;
d) Drainage structure; or
e) All of the above.

Image description: Photo of a construction site.

The correct answer is a) Retaining wall and embankment. The photograph is an example of a mechanically stabilized earth retaining wall supporting an embankment. The retaining wall has a temporary wire mesh with fabric facing. A permanent concrete facing is to be placed later after consolidation of the underlying soils and settlement of the wall.

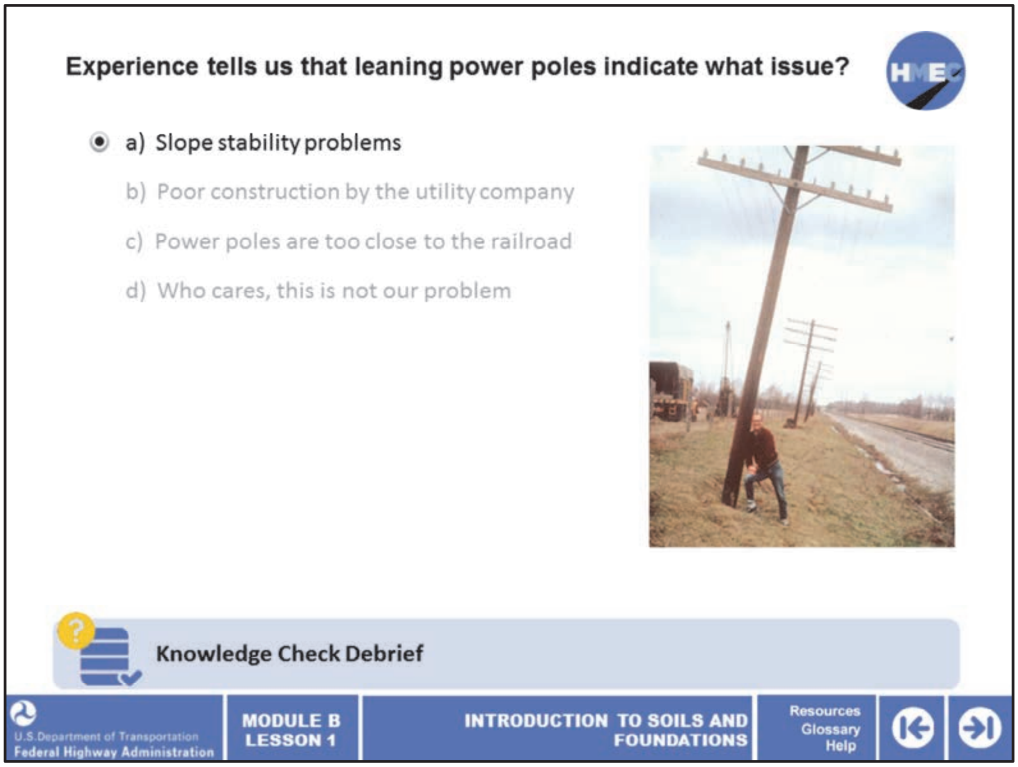
Image description: Photo of a construction site.



Experience tells us that leaning power poles indicate what issue?

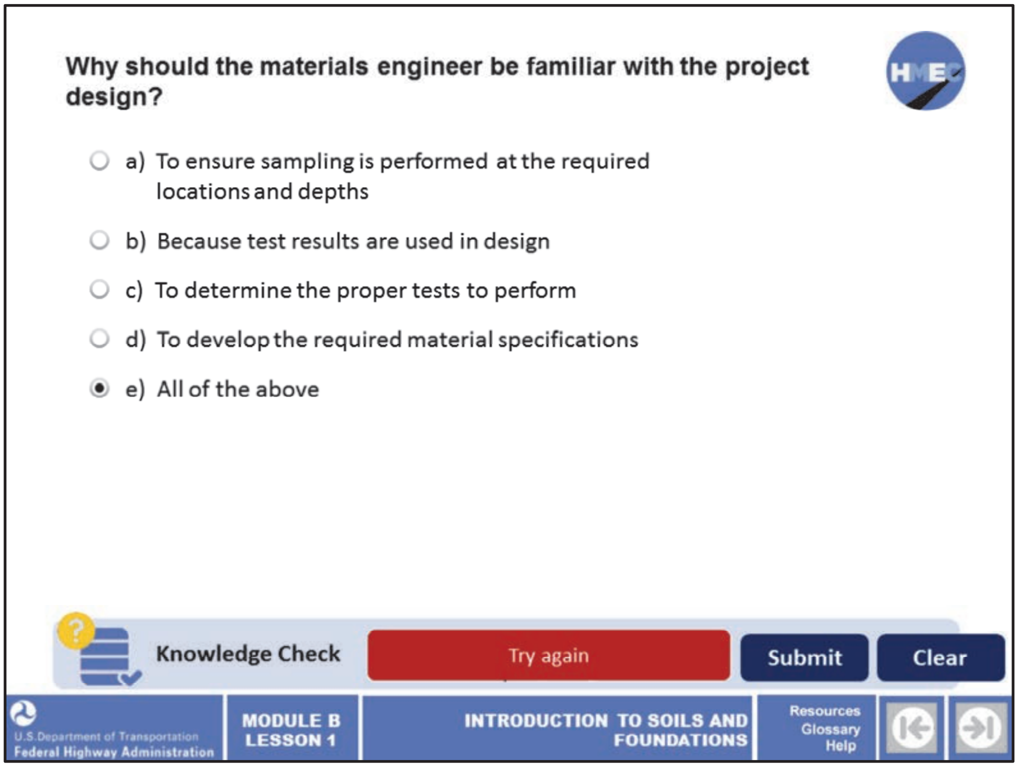
a) Slope stability problems;
b) Poor construction by the utility company;
c) Power poles are too close to the railroad; or
d) Who cares, this is not our problem.

Image description: Photo of unstable (tilted utility poles).



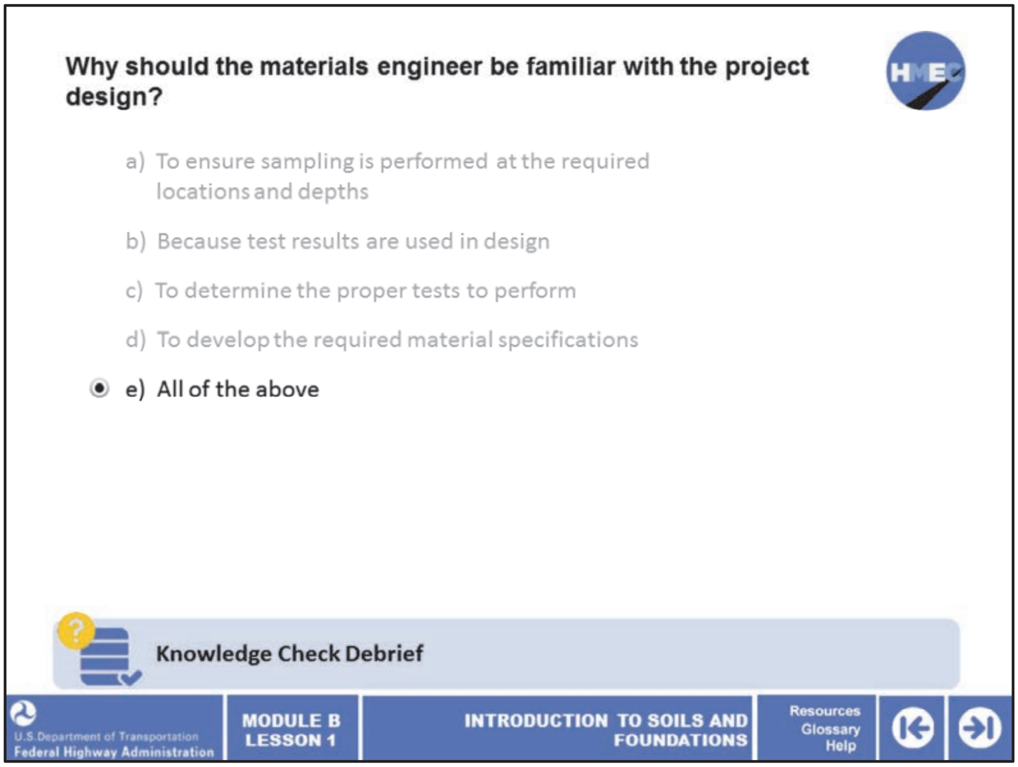
The correct answer is a) Slope stability problems. We must learn to use any and all indications of problems near our project. Leaning power poles, trees, or other structures are a good indication of some slope instability issue. We can use this indicator along with proper testing and analysis (theory) to identify the actual problem and devise a solution.

Image description: Photo of unstable (tilted utility poles).

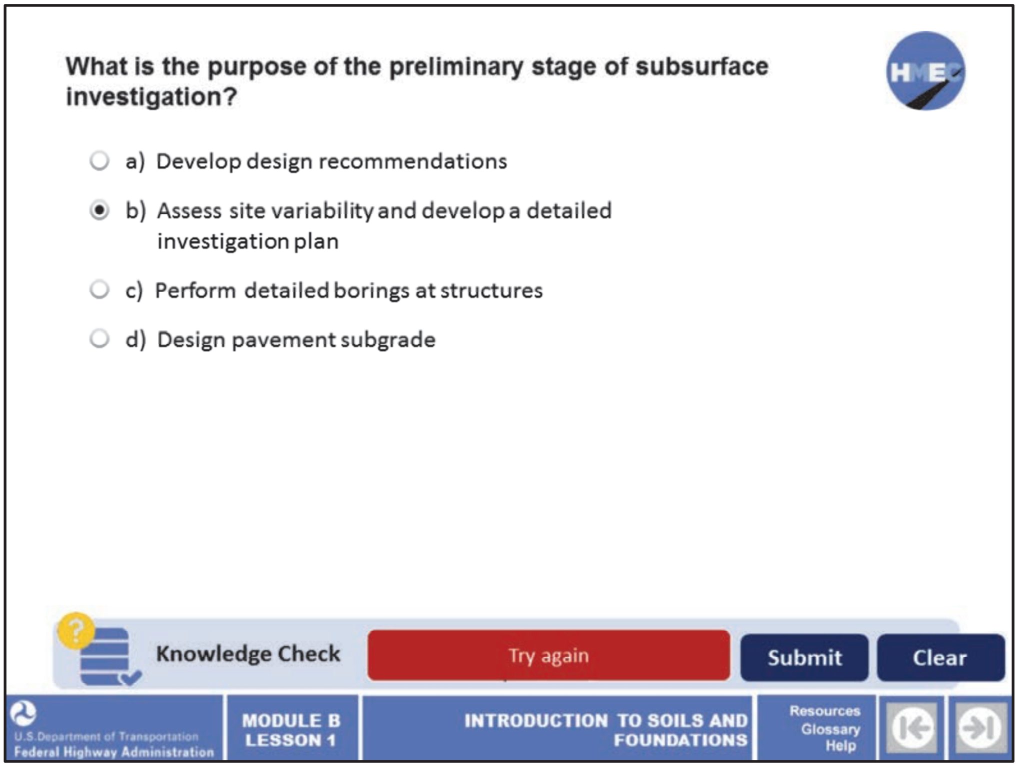


Why should the materials engineer be familiar with the project design?

a) To ensure sampling is performed at the required locations and depths;
b) Because test results are used in design;
c) To determine the proper tests to perform;
d) To develop the required material specifications; or
e) All of the above.

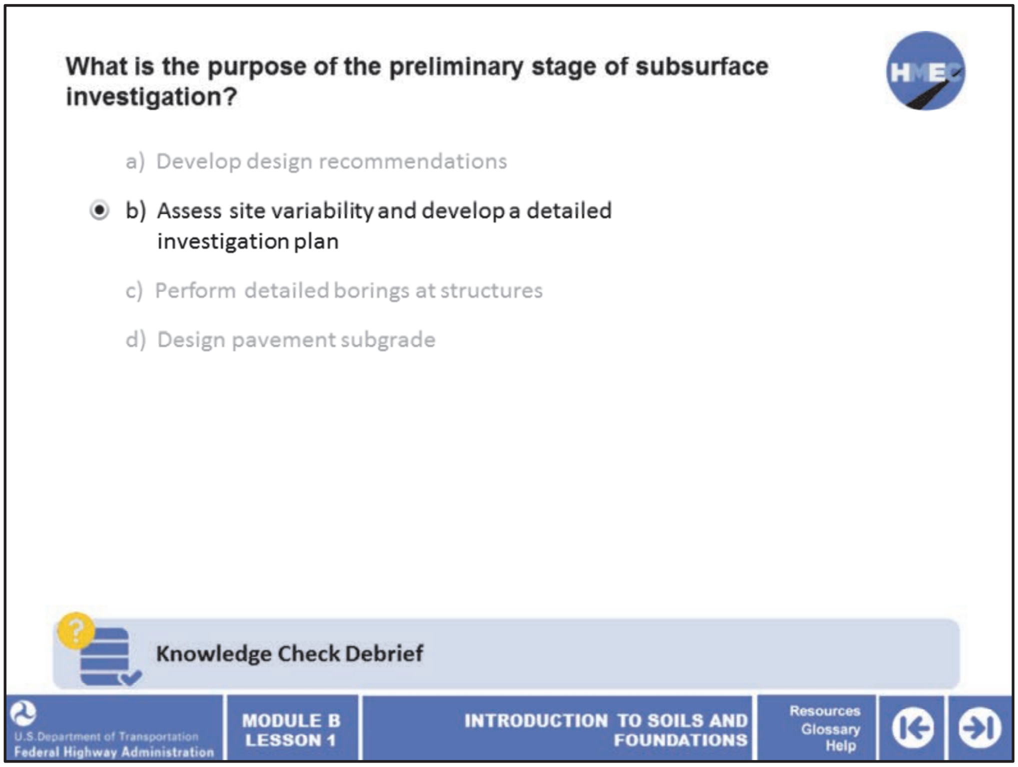


The correct answer is e) All of the above. The materials engineer is a critical member of the project team. They must be familiar with the project design because of their responsibility regarding sampling, testing, and development of material specifications, which are critical to project design and construction.

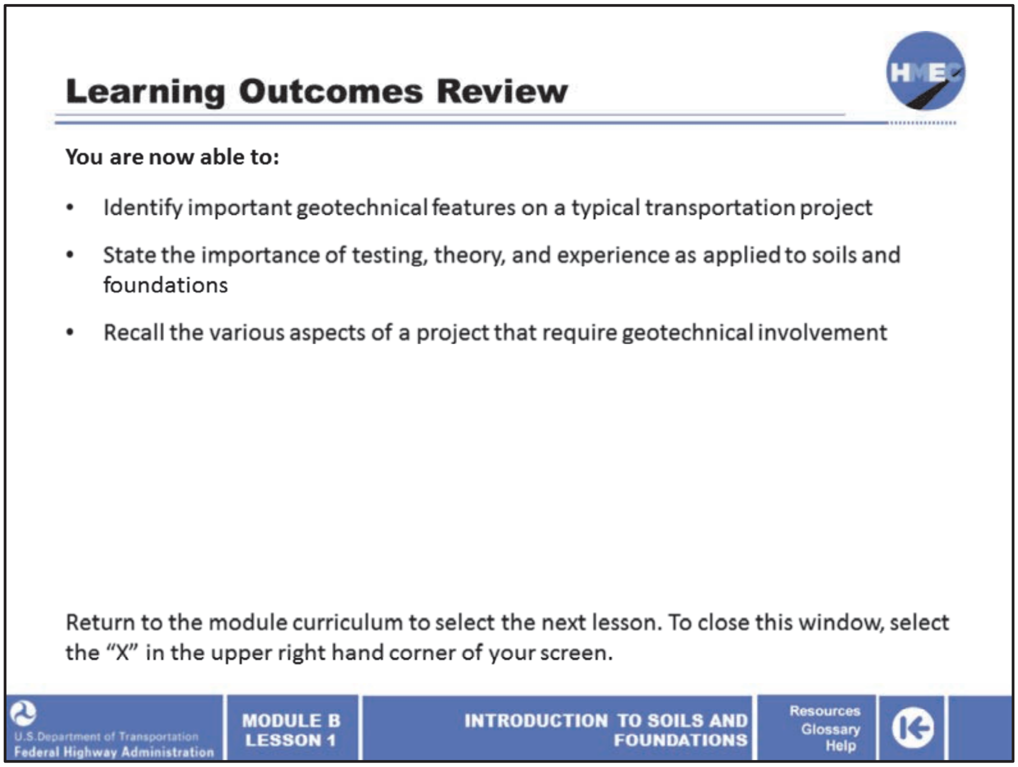


What is the purpose of the preliminary stage of subsurface investigation?

a) Develop design recommendations;
b) Assess site variability and develop a detailed investigation plan;
c) Perform detailed borings at structures; or
d) Design pavement subgrade.



The correct answer is b) Assess site variability and develop a detailed investigation plan. On large complicated projects, a preliminary soil boring program can be a cost-effective method to assess site variability and develop the required borings and sampling for the detailed site investigation.



You have completed Module B, Lesson 1: Introduction. You are now able to:

- Identify important geotechnical features on a typical transportation project;
- State the importance of testing, theory, and experience as applied to soils and foundations; and
- Recall the various aspects of a project that require geotechnical involvement.

Close this lesson, and return to the module curriculum to select the next lesson. To close this window, select the "X" in the upper right-hand corner of your screen.